Schizotypal personality traits and atypical lateralization in motor and language functions

Tomohisa Asai *, Eriko Sugimori, Yoshihiko Tanno

Department of Cognitive and Behavioral Science, Graduate School of Arts and Sciences, University of Tokyo, 3-8-1 Komaba, Meguro-ku, Tokyo 153-8902, Japan

A R T I C L E   I N F O

Article history:
Accepted 26 March 2009
Available online 24 April 2009

Keywords:
Schizotypal personality traits
Laterality
Motor
Language
Schizophrenia

A B S T R A C T

Atypical cerebral lateralization in motor and language functions in regard to schizotypal personality traits in healthy populations, as well as among schizophrenic patients, has attracted attention because these traits may represent a risk factor for schizophrenia. Although the relationship between handedness and schizotypal personality has been widely examined, few studies have adopted an experimental approach. This study consisted of three experiments focusing on motor and language functional lateralization in regard to schizotypal personality in the absence of mental illness: line-drawing, finger tapping, and a semantic go/no-go task. The results suggested that positive schizotypal personality might be related to functional non-lateralization in regard to at least some functions (e.g., spatial motor control and semantic processing in the present study). Subjects with high schizotypal personality traits performed equally with their right and left-hands in the line-drawing task and they reacted equally with their right and left-hands in a semantic go/no-go task involving semantic auditory stimuli presented in both ears. However, those low in schizotypal personality traits showed typical lateralization in response to these tasks. We discuss the implications of these findings for schizotypal atypical lateralization.

© 2009 Elsevier Inc. All rights reserved.

1. Introduction

Atypical cerebral lateralization may represent a risk factor for developing schizophrenia (Crow, 2004). The issue of handedness has interested researchers examining schizophrenia (Claridge & Brooks, 1984; Gruzeliér & Richardson, 1994) and patients with schizophrenia have shown differences in lateralization, as measured by handedness, when compared to controls (Reilly et al., 2001). Such investigations have generally used two populations: patients with schizophrenia and normal participants scoring high on measures of schizotypal personality traits, which are considered a reflection of a genetic predisposition toward schizophrenia (Cybhalová & Claridge, 2005; Lenzenweger, 2006). While studies of handedness in patients with schizophrenia have yielded a range of results (see for review, Dragovic & Hammond, 2005), studies of schizotypal personality traits and handedness in normal participants have yielded more consistent results (Chapman & Chapman, 1987; Claridge, Clark, Davis, & Mason, 1998; Kim, Raine, Triphon, & Green, 1992; Poreh, 1994; Richardson, 1994; Shaw, Claridge, & Clark, 2001). The predominant finding emerging from this research is increased schizotypal personality scores among mixed-handed participants (Annett & Moran, 2006; Somers, Sommer, Boks, & Kahn, 2008) even in non-western cultures (Asai & Tanno, 2009).

This result might implicate a relationship between schizotypal personality and non-lateralized cerebral functioning, at least in regard to motor ability.

Handedness is generally measured by self-report questionnaires (e.g., Annett & Moran, 2006; Asai & Tanno, 2009), which are convenient but which yield data that are less objective and more likely to vary according to the particular questionnaire. Indeed, it has been suggested that cultural differences may interfere with using self-report measures of handedness to elucidate relationships between this factor and other variables (Asai & Tanno, 2009). In this context, experimental methods might also be helpful in examining these issues. Although some experimental methods addressing handedness or motor asymmetry exist, ranging from those measuring finger-tapping speed to those measuring hand-grip force, few studies have used them to examine the relationship between schizotypal personality and motor asymmetry even though some objective techniques have been used to assess motor activity in schizophrenic patients (e.g., Blyler, Maher, Manschreck, & Fenton, 1997; Lohr & Caligiuri, 1997; Tabarés-Seisdedos et al., 2003). Only one previous study has shown non-lateralized motor symmetry in subjects with schizotypal personality traits using experimental methods. That study found that subjects high in schizotypal personality traits were equally likely to draw a straight line with their right and left-hands (Lenzenweger & Maher, 2002).

In our first experiment (Experiment 1), we tried to expand this by study using a PC-based methodology.
The majority of language function is lateralized in the left hemisphere in typical human brains (Geschwind & Levitsky, 1968), although the relationship between handedness and language lateralization is complicated, especially in left-handers (Kimura, 1967). Although the data are not entirely consistent, the majority of relevant studies have reported that normal asymmetry in this regard is absent in people with schizophrenia (see the review by Petry, 1999). Both structural and functional evidence have suggested that schizophrenia is associated with reduced left-hemisphere lateralization of language, and some studies have even reported a reversal of lateralization favoring the right hemisphere (Aydin et al., 2001; Gur & Chin, 1999; Kircher et al., 2002; Kwon et al., 2001; Petty, 1999; Sommer, Ramsay, Kahn, Aleman, & Bouma, 2001; Sumich et al., 2002). For example, individuals with schizophrenia are associated with reduced left-hemisphere lateralization, and some studies have even reported a reversal of lateralization favoring the right hemisphere (Aydin et al., 2001; Gur & Chin, 1999; Kircher et al., 2002; Kwon et al., 2001; Petty, 1999; Sommer, Ramsay, Kahn, Aleman, & Bouma, 2001; Sumich et al., 2002). For example, individuals with schizophrenia showed greater activation in the right temporal cortex in response to speech stimuli (Ngan et al., 2003). One previous study on schizotypal personality found that low scores on right-hemisphere language tasks (e.g., proverbs, logical grammatical sentences, and humor) were significant predictors of high scores on the positive schizotypal personality scale (Nunn & Peters, 2001). Although this might imply an atypical language asymmetry associated with schizotypal personality, nothing is clear about the relationship between schizotypal personality and language lateralization. We examined this relationship in the second experiment (Experiment 2). A failure in the lateralization of language and motor functions is proposed as a critical feature in the predisposition to schizophrenia (Crow, 2000). Thus, we focused on the relationship between these two brain functions and schizotypal personality traits.

2. Experiment 1

2.1. Experiment 1A

Experiment 1A focused on the lateralization of motor function in people with schizotypal personality, especially in regard to spatial motor (or visuomotor) accuracy (line-drawing task), as suggested by a previous study (Lenzenweger & Maher, 2002). The left-hand performed better in response to this task in right-handed participants. This was contrary to expectations, as spatial processing is normally lateralized in the right hemisphere (e.g., Barthelemy & Boulingeau, 2001, 2002), although the relationship between brain laterality and behavior laterality may be more complicated in left-handed people (e.g., Kimura, 1967). Thus, we hypothesized that the left-hands of people low in schizotypal personality traits would perform better than their right-hands and that the right and left-hands of those high in schizotypal personality traits would perform equally well if their motor functions were non-lateralized.

2.1.1. Method

2.1.1.1. Participants. A total of 42 university students (aged 18–22 years, mean = 19.3; 20 men, 22 women) participated in the experiment and completed questionnaires. Respondents were recruited from an introductory psychology class participant pool. Participants responded voluntarily to an e-mail describing the experiment and the questionnaire. None of the subjects had a history of mental illness. We obtained written informed consent from all participants before conducting the experiment.

2.1.1.2. Apparatus. The experiment was conducted in a silent dark room. The visual stimuli were created and the experiments conducted using MATLAB (MathWorks, Natick, MA, USA) and Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). The cursor on the screen (1024 × 1280 pixels) moved in response to movements of a wireless mouse device. The speed of the cursor was synchronized with the movement of the mouse (e.g., when the mouse device was moved 10 cm, the cursor also moved 10 cm on the screen), the cursor originated at the center of the screen in every trial (Fig. 1).

2.1.1.3. Procedure. Participants were asked to move the mouse device in a straight line to one of the four targets and then click the mouse (line-drawing task; Lenzenweger & Maher, 2002). The targets were small squares (2 × 2 pixels) at the corners of the screen. The x-y coordinates of the squares were 250 × 250 pixels.

Three mouse–cursor conditions controlled task difficulty: normal, cursor-disappearing, and cursor-leaving trajectories. Participants did not know which condition was in effect before starting to move the mouse device. Under the normal cursor condition, the cursor moved in synchrony with the mouse. Under the cursor-disappearing condition, the cursor disappeared as soon as the mouse was moved, requiring participants to reach the target without having visual feedback to monitor their arm movements. The cursor appeared again after participants clicked the mouse, revealing the actual errors. Under the leaving-trajectory condition, the cursor left the trajectory independent of the movements of the mouse, and participants could not gauge the actual trajectory of the cursor.

The x-y coordinates were recorded from initial mouse movement to click with a sampling rate of 100 Hz. Subjects participated in two blocks: the right-hand block, in which they moved the mouse device with their right-hand; and the left-hand block, in which they moved the mouse device with their left-hand. The order was counterbalanced among participants. In each block, 48 trials (three cursor conditions × four direction conditions × four repetitions) were conducted in random order. Before beginning the experiment, we briefly trained participants in order to familiarize them with the instruments and experimental requirements.

2.1.1.4. Data analysis. For the spatial motor accuracy value, MATLAB randomly selected the 50 sampled points at each trial and determined the Euclidean distance between the target line and...
the selected sampled points. We calculated the root mean square (RMS) for each trial as the spatial motor accuracy value (see Eq. (Formula 1A)). The RMS considers not only the mean value but also the variance (see Eq. (Formula 1B)). Thus, the RMS value increased if a participant moved the mouse imprecisely. In addition, for the laterality index, we calculated the value following the formula (left-right RMS)/(right + left RMS) using the averaged RMS at each condition and by participant. This value ranges from −1, indicating left-hand superiority, to +1, indicating right-hand superiority in this line-drawing task; greater RMS values indicate poorer performances. We used SPSS 16.0 J for the following statistical analyses:

\[ x_{\text{rms}} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} x_i^2} \quad \text{(Formula 1A)} \]

\[ x_{\text{rms}}^2 = x_i^2 + \sigma_x \quad \text{(Formula 1B)} \]

where \( x \) is the distance between the sampled points and the target line, \( N \) the number of the sampled points (in this case 50), \( x(\text{bar}) \) is the mean of \( x \), and \( \sigma \) is the standard deviation.

### 2.1.1.5. Questionnaire
After the participants finished the experiment, they completed a battery of questionnaires. We assigned a random number to each participant and the data from the questionnaires were crosschecked with experimental data using this randomly assigned number. The battery included the following questionnaires, all of which, except for the AHES, had been translated into Japanese and demonstrated good reliability and validity:

1. **Handedness**: the H.N. Handedness Scale (HNHS; Hatta & Kawakami, 1995; Hatta & Nakatsuka, 1975) is a revised version of the Edinburgh Inventory (Oldfield, 1971) for use with Japanese participants. Revisions were necessary because cultural differences render the original Edinburgh Inventory inappropriate for Japanese participants. The scale is often used in Japan to measure or control for handedness (e.g., Ogawa, Inui, & Sugio, 2006). Participants respond to this scale by indicating whether they use their right, left, or either hand for 10 common actions: handling an eraser; striking a match; brushing their teeth; throwing; and using a pair of scissors, a knife, a screwdriver, and a shaver or lipstick. This scale ranges from −10 to +10; a “right” response is scored as +1, a “left” response is scored as −1 and a response of “either” is scored as zero.

2. **Depression**: the Self-Rating Depression Scale (SDS; Zung, 1965) is a well-known self-report questionnaire comprising of 20 items; responses are based on a 4-point Likert scale measuring depressive tendencies.

3. **Anxiety**: the State-Trait Anxiety Inventory (STAI-T; Spielberger, Gorsuch, & Lushene, 1970) is a well-known self-report questionnaire consisting of 20 items; responses are based on a 4-point Likert scale measuring anxiety traits.

4. **Schizotypal personality traits**: the Oxford-Liverpool Inventory of Feelings and Experiences (O-LIFE; Mason, Claridge, & Jackson, 1995) is a 104-item true–false self-report questionnaire measuring schizotypal personality traits. It consists of four subscales: Unusual Experiences (UnEx), Introvertive Anhedonia (InAn), Cognitive Disorganization (CDi), and Impulsive Non-conformity (ImNo).

5. **Positive schizotypal personality**: the Oxford Schizotypal Personality Scale (STA; Claridge & Broks, 1984; Cyhlarova & Claridge, 2005; Gregory, Claridge, Clark, & Taylor, 2003) is a 37-item true–false self-report questionnaire based on the DSM-III diagnostic criteria for schizotypal personality disorder. It measures schizotypal traits, especially perceptual aberrations that are analogous to positive symptoms, including auditory hallucinations, thought insertions, and delusions of control.

6. **Auditory hallucination proneness**: the Auditory Hallucination Experience Scale (AHES; Onari, 1998; Takeshita, 2003; Tanno, Ishigaki, & Morimoto, 1998), developed in Japan, represents a revised version of the Launay Slade Hallucination Scale for use with healthy populations (LSHS; Launay & Slade, 1981; Morrison, Wells, & Nothard, 2000; Waters, Badcock, & Maybery, 2003). The AHES is a self-report 40-item questionnaire with responses based on a 5-point Likert scale (1–5) measuring the frequency of auditory hallucination-like experiences (e.g., “I heard someone’s voice, but nobody was actually around.”). The scores for this scale range from 40 to 200.

Higher scores for all questionnaires, except for the N.H. Handedness Scale, indicated a stronger tendency. SDS and STAI were used as control measures; that is, we predicted these scales would not be related to lateralization although they might be related to schizotypal personality traits.

### 2.1.2. Results and discussion
We collapsed the four direction conditions because there were no differences among them. We first analyzed the correlation between scores on each questionnaire and the experimental measures (the right-and left-hand RMS) to examine the relationship between schizotypal personality and spatial motor accuracy. However, there were no significant correlations among these factors, indicating that schizotypal personality may not be related to spatial motor performance in this task. This finding was in contrast to the results reported by Lenzenweger and Maher (2002), who suggested that positive schizotypal traits were correlated with poor motor performance in the line-drawing task (see also Fig. 2, which will be used later for comparison between the high and low schizotypal personality groups). This inconsistency may be attributable to differences between the tasks used in each experiment. The task used in our experiment required more spatial processing than that used in the previous study because our participants viewed the PC display and matched their hand movements to the cursor. Thus, our task might measure spatial motor or visuomotor ability rather than motor ability.

Second, we used the laterality index (LI) value for the three experimental conditions. As these values could be extremely non-normally distributed as the handedness scale, we then conducted a normality test, even though ANOVA has robustness for non-normally distributed data to some extent. Kolmogorov–Smirnov’s test revealed that LI in normal and trajectory conditions were distributed normally (D = .073, p > .99; D = .110, and p > .60, respectively), but LI in the disappearing condition might not be distributed normally (D = .138, and p < .05). This means that we need to pay attention to the results of the disappearing condition, although we conducted the following correlation analysis and ANOVA, which require normally distributed data. Then we conducted the correlation analysis with the scores of each questionnaire to examine the schizotypal functional lateralization (Table 1). The results demonstrated a significant positive correlation between each LI value and the AHES (rs > .32, and ps < .05), and partial weak trends with the STA and UnEx (rs > .21, and ps < .10), indicating that positive schizotypal factors might be related to LI as the previous study had suggested (Lenzenweger & Maher, 2002).

To examine how differently people with high and low schizotypal personality scores performed, we selected the participants scoring the highest (top 25%; 11 participants) or the lowest (bottom 25%; 11 participants) on the AHES because this measure demonstrated the strongest correlation with the laterality index (see Table 2 for demographic data). We examined the differences between these two groups using the right- and the left-hand RMS values; we did not use LI values because these values lost some information, including the absolute RMS values. Using RMS values...
and ANOVA, we were able to examine, for example, the differences among the three experimental conditions. We conducted a three-way ANOVA (three cursor conditions / two hand conditions / two groups) and then followed with Ryan’s multiple comparison. The results (Fig. 2) revealed that a first significant order interaction between the groups and the hand condition \[ F(1, 20) = 6.47, \] \( p < .05 \); in addition, main effects of the cursor condition \[ F(2, 40) = 81.2, \] \( p < .001 \), the hand condition \[ F(1, 20) = 7.45, \] \( p < .05 \), and the group \[ F(1, 20) = 6.01, \] \( p < .05 \) were significant, whereas the second-order interaction among the three factors \[ F(2, 40) = 0.47, \] n.s. and the first-order interactions between the hand condition and the cursor condition \[ F(2, 40) = 1.53, \] n.s. and between the group and the cursor condition \[ F(2, 40) = 2.60, \] n.s. were not significant. As to the main effect of the cursor condition, the comparisons between the normal and the disappearing condition and between the trajectory and the disappearing condition were significant (\( p_s < .001 \)). The simple main effects of group in the right-hand condition and of hand condition in the lowest group were significant (\( p_s < .005 \)). In summary, the ANOVA revealed that, although the disappearing condition generally presented the greatest difficulty, the group scoring lowest on schizotypal personality performed better with their left-hands whereas the highest group performed equally with their right and left-hands regardless of the cursor condition.

We confirmed that while people with low positive schizotypal personality scores (AHES score) might show normal motor lateralization, because left-hand/right hemisphere has general superiority in regard to spatial motor accuracy in right-handers (Lenhard & Hoffmann, 2007), people with high positive schizotypal personality scores might not have such lateralization. This finding is congruent with a previous study, which showed the relationship between referential thinking, another aspect of positive schizotypal traits, and non-lateralization in motor performance (Lenzenweger & Maher, 2002). This study was limited insofar as participants were asked to draw the straight line on the paper only once during each condition. We do not know the extent to which writing and motor abilities are directly connected, and the absence of multiple trials reduces the reliability of this method. We used a more general visuomotor experimental paradigm (visually guided reaching paradigm; e.g., Asai, Sugimori, & Tanno, 2008; Ogawa et al., 2006) and replicated and extended the results, demonstrating that positive schizotypal personality scores might be related to func-

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Intercorrelations of questionnaires and laterality index on the three cursor condition.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laterality Index</td>
<td>HNHS</td>
</tr>
<tr>
<td>Normal</td>
<td>(-.03)</td>
</tr>
<tr>
<td>Trajectory</td>
<td>-.08</td>
</tr>
<tr>
<td>Disappearing</td>
<td>.01</td>
</tr>
</tbody>
</table>

Note: \( N = 42 \). Values are Pearson’s correlation coefficients. Correlations were tested for statistical significance using a one-tailed procedure based on a directional a priori hypothesis. HNHS = H.N. Handedness Scale, SDS = Self-rating Depression Scale, STAI = State-Trait Anxiety Inventory, STA = Oxford Schizotypal Personality Scale, AHES = Auditory Hallucination Experience Scale, O-LIFE = Oxford-Liverpool Inventory of Feelings and Experiences; UnEx = Unusual Experiences, InAn = Introvertive Anhedonia, CoDi = Cognitive Disorganization, ImNo = Impulsive Non-conformity.

\* \( p < .05 \).

\** \( p < .01 \).

\^\( p < .10 \).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>The demographical data (mean and standard deviation) between the low and the high AHES groups in Experiment 1.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low AHES</td>
</tr>
<tr>
<td></td>
<td>(3/8)</td>
</tr>
<tr>
<td>N (M/F)</td>
<td>11</td>
</tr>
<tr>
<td>Age</td>
<td>19.4 (7.04.5)</td>
</tr>
<tr>
<td>HNHS [left-hander]</td>
<td>40.2 (45.2)</td>
</tr>
<tr>
<td>SDS</td>
<td>6.5</td>
</tr>
<tr>
<td>STAI</td>
<td>75.1</td>
</tr>
<tr>
<td>STA</td>
<td>30.8</td>
</tr>
<tr>
<td>AHES</td>
<td>1.6</td>
</tr>
<tr>
<td>O-LIFE</td>
<td>9.1</td>
</tr>
<tr>
<td>UnEx</td>
<td>11.4</td>
</tr>
<tr>
<td>InAn</td>
<td>8.7</td>
</tr>
<tr>
<td>CoDi</td>
<td></td>
</tr>
<tr>
<td>ImNo</td>
<td></td>
</tr>
</tbody>
</table>

Significance: \** \( p < .01 \), \* \( p < .05 \), \^\( p < .10 \).

Note: the significances were revealed by \( \chi^2 \) tests for sex ratio and the number of left-handers (HNHS scores \( \leq 4 \)), and MANOVA for Age-ImNo.
tional non-lateralization in spatial motor performance as this phe-
nomena was observed under all three cursor conditions. Further
research should examine which positive schizotypal trait is most
related to atypical lateralization.

As a precautionary measure, we analyzed the handedness scale
but found no significant correlations with other scales or experi-
mental measures. We generally divide participants into groups
according to handedness because most participants scored as
right-handed, precluding the application of correlation analysis
(e.g., Asai & Tanno, 2009). Because our main objective involved
investigating schizotypal functional lateralization with an experi-
mental, rather than self-report, approach to handedness, we do
not refer to the handedness scale since our sample was too small
to be divided into handedness groups (we used the handedness
scale in the following study as a precautionary measure) as in
the previous study (Lenzenweger & Maher, 2002). Nevertheless,
it is important to examine the relationships among schizotypal
personality, handedness, and functional lateralization with a larger
sample size.

2.2. Experiment 1B

Unlike Experiment 1A, 1B focused on the lateralization of motor
function in people with schizotypal personality traits, especially as
regards motor speed and force control (finger-tapping task). It has
been established that the right-hand performs better in response
to the task because of its typical lateralization in the left hemisphere
(Todor, Kyprie, & Price, 1982). Thus, we hypothesized that the
right-hand of those with low schizotypal personality scores would
perform better than the left-hand; conversely, the right and left-
hands of those with high schizotypal personality scores would per-
form equally if motor function were non-lateralized. Alternatively,
we wondered if non-lateralized motor function would be demon-
strated only in regard to certain phenomena (e.g., spatial motor
control, as suggested by Experiment 1A).

2.2.1. Method

2.2.1.1. Participants. A total of 50 university students (aged 18–
21 years, mean = 18.9: 35 men, 15 women) who did not participate
in Experiment 1A were recruited from an introductory psychology
class participant pool. Participants voluntarily responded to an e-
mail describing the experiment and the questionnaire. None of
the subjects had a history of mental illness. We obtained written
informed consent from all participants before conducting the experiment.

2.2.1.2. Apparatus. The experiment was conducted in a silent dimly
lit room using MATLAB (MathWorks, Natick, MA, USA) and Psychophy-
ics Toolbox (Brainard, 1997; Pelli, 1997). The normal button
device was connected to the PC.

2.2.1.3. Procedure. The finger-tapping task involved repetitive tap-
ing with the middle finger. Subjects were asked to tap a button as
quickly as possible for a 15-s period (tapping only with the most
distal part of the finger and keeping their palm on the board). Sev-
eral studies have shown high test–retest reliability in finger-tap-
ing tasks (Peters, 1980; Provins & Cunliffe, 1972) and a lack of a
significant fatigue or training effects on the results (Gill, Reddon,
Stefanyk, & Hans, 1986).

Two conditions were employed: the right-hand condition, in which
participants tapped the button with the middle finger of the
right-hand; and the left-hand condition, in which the subject
tapped the button with the middle finger of the left-hand. The con-
ditions alternated with the first condition counterbalanced among
participants. A total of six trials (three for the right-hand and
three for the left-hand conditions) were conducted, each followed by a rest
period. Before beginning the experiment, we briefly trained partic-
ips in order to familiarize them with the instruments and experimental requirements.

2.2.1.4. Data analysis. For the motor speed and force control value,
MATLAB counted finger tapping. As in Experiment 1A, we also cal-
culated the laterality index (right – left)/(right + left). This value
ranged from −1, indicating left-hand superiority, to +1, indicating
right-hand superiority.

2.2.1.5. Questionnaire. After participants finished the experiment,
they completed a battery of questionnaires including the H.N.
Handedness Scale, the SDS, the STAI-T, the STA, and the AHES.
We excluded the O-LIFE because Experiment 1A suggested that
only positive schizotypal personality traits might be related to
atypical motor asymmetry and O-LIFE, consisting of 104 items,
can be experienced by participants as burdensome.

2.2.2. Results and discussion

We first conducted the correlation analysis between the scores
on each questionnaire and those on the experimental measures
(the right-hand and the left-hand, the total, and the laterality index)
to examine the relationships among schizotypal personality and
motor speed and force control ability (Table 3). Kolmogorov–Smir-
nov’s test revealed that LIs were distributed normally in this task
(D = .115, and p = .40). While positive schizotypal personality
might be related to such motor functions, because the AHES (or
the STA in a weak trend) was negatively correlated to the finger-
tapping scores (rs < −.24, and ps < .05), we found no significant
correlations between any questionnaire and the LI values
(rs < .05, and ps > .05), indicating the absence of a relationship be-
tween schizotypal personality and functional lateralization in re-
gard to motor speed and force-control performance. Indeed, the
possibility that positive schizotypal personality might be corre-
lated with poor motor performance is important because only
one previous study has suggested that such a relationship obtains in
regard to a line-drawing task (Lenzenweger & Maher, 2002).
Tabarés-Seisdedos et al. (2003) showed that schizophrenic patients
tapped less frequently than did normal controls with their right
and left-hands, but the laterality index did not differ between the
two groups. Our results replicated this finding with regard to
schizotypal personality traits.

As a precautionary measure, we conducted a comparison be-
tween the high and low AHES groups (13 participants in each; see
Table 4 for demographic data) as in Experiment 1A (Fig. 3).
We also conducted a two-way ANOVA (two hand conditions ×
two groups). The results revealed that the main effects for the hand
condition [F(1, 24) = 98.8, and p < .001] and group [F(1, 20) = 4.26,
and p < .05] were significant, while the interaction between the
hand condition and the group was not significant [F(1, 24) = 0.92,
n.s.]. In summary, as expected on the basis of the correlation anal-
ysis, the ANOVA showed that there were no significant differences

Table 3

<p>| Questionnaires and laterality index on the finger tapping. |</p>
<table>
<thead>
<tr>
<th>HNHS</th>
<th>SDS</th>
<th>STAI</th>
<th>STA</th>
<th>AHES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-hand</td>
<td>−.17</td>
<td>−.01</td>
<td>.13</td>
<td>−.22</td>
</tr>
<tr>
<td>left-hand</td>
<td>−.19</td>
<td>−.07</td>
<td>.15</td>
<td>−.15</td>
</tr>
<tr>
<td>Total</td>
<td>−.20</td>
<td>−.04</td>
<td>.15</td>
<td>−.21</td>
</tr>
<tr>
<td>Laterality index</td>
<td>−.20</td>
<td>−.04</td>
<td>.15</td>
<td>−.21</td>
</tr>
</tbody>
</table>

Note: N = 50. Values are Pearson’s correlation coefficients. Correlations were tested for statistical significance using a one-tailed procedure based on a directional a priori hypothesis.

*p < .05.

*p < .10.
in regard to laterality even though the low schizotypal personality group performed better than the high schizotypal personality group, regardless of the hand condition, and that, in general, participants performed better with their right-hands.

Unlike Experiment 1A, which focused on the spatial motor ability generally lateralized to the right hemisphere (Barthelemy & Boulinguez, 2001, 2002), this experiment focused on the motor speed and force control abilities, which are lateralized only to the left hemisphere in general (Todor et al., 1982). These features are both related to motor functioning but differently lateralized. Experiments 1A and 1B suggested that schizotypal personality traits might be related to non-lateralization, at least in spatial motor ability if not in terms of general motor functioning. Scores on the handedness scale might also be related to motor functions, but the category of functions involved remains unclear. For example, according to the H.N. Handedness Scale (Hatta & Kawakami, 1995; Hatta & Nakatsuka, 1975), “handling an eraser” or “striking match” seemed to be more related to force control, while “throwing” or “using scissors” seemed to be related to spatial features. It is important to discriminate between lateral and non-lateral functions rather than between total hemisphere non-lateralization or reversal. For this reason, we focused on language lateralization in Experiment 2.

3. Experiment 2

While Experiment 1 focused on the motor function, Experiment 2 focused on the lateralization of the language function in schizotypal personality. Motor and language functions are essential to understanding human beings in general and schizophrenia in particular (Crow, 2000). We used a semantic go/no-go paradigm to investigate schizotypal language lateralization, applying the previous studies (Ngan et al., 2003; Welsh & Elliott, 2001; Welsh, Elliott, & Simon, 2003). Classical dichotic listening, wherein two different speech sounds are presented at the same time, one in each ear (e.g., Bryden, 1988), might be an approach to this topic (Broks, Claridge, Matheson, & Hargreaves, 1984; Hugdahl et al., 2008; Rawlings & Borge, 1987). Due to the preponderance of the contralateral auditory pathways (Rosenzweig, 1951), acoustic input from the right ear to the left auditory cortex predominates when the stimuli are verbal in nature (Bryden, 1988). Welsh et al. newly developed an audio-motor (or verbal reaching) paradigm to adapt dichotic listening in order to avoid potential attention bias (Welsh & Elliott, 2001; Welsh et al., 2003). This paradigm might also be useful to infer the neural pathway from the ear (cochlea) to the hand through the language area in the brain. It is well-known that the left hemisphere processes auditory semantic or speech information (Capo-
zzoki, 1999; Gernsbacher & Kaschak, 2003) and we therefore hypothesized, according to the schema suggested by the previous study (Welsh & Elliott, 2001; Figs. 4 and 7), that because the right-hand is closely connected to the left hemisphere, people with low schizotypal personality scores, would perform better with their right than with their left-hands, and that the right and left-hands of those with high schizotypal personality scores would perform equally if their language function were non-lateralized.

3.1. Method

3.1.1. Participants
A total of 46 university students (aged 18–21 years, mean = 19; 33 men, 13 women), who did not participate in Experiment 1, were recruited from an introductory psychology class participant pool. Participants voluntarily responded to an e-mail describing the experiment and the questionnaire. None of the participants had a history of mental illness. We obtained written informed consent from all participants before conducting the experiment.

3.1.2. Apparatus
The experiment was conducted in a soundproof room. The experiments were conducted using MATLAB (MathWorks, Natick, MA, USA) and Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). The normal button device and the headphone (SONY, MDR-Z600) were connected to the PC. The auditory stimuli consisted of two kinds of speech sound: the normal (meaningful) and the anagrammatized (meaningless) spoken words. We used

![Fig. 5. Oxford Schizotypal Personality Scale (STA) group vs. Reaction Time (RT) in semantic judgment.](image1)

![Fig. 6. (A) Oxford Schizotypal Personality Scale (STA) group vs. hit ratio. (B) STA group vs. correct rejection ratio.](image2)
Three ear conditions (right, left, or both ears) were randomized for each participant. A total of 60 trials were conducted, with rest breaks scheduled every 20 trials. Before beginning the experiment, we briefly trained participants in order to familiarize them with the instruments and experimental requirements.

3.1.3. Procedure
Subjects were asked to press a button as quickly as possible with the index finger of the indicated hand only when they heard the meaningful words (go/no-go paradigm). They could press the button only 2000 ms after the end of the auditory stimuli. The original words from which the anagrammatized words were taken were identical to the normal words. One man and one woman recorded spoken sounds according to the standard procedure for 30 meaningful and 30 meaningless words. The sound volumes were normalized and durations were converted to 600 ms. White noise covered the onset of the auditory stimuli. First, white noise was transmitted to participants through both ears via headphones for 1500–3500 ms (random at each trial) at 65 dB. Subsequently, the auditory stimulus, with a total sound pressure of 70 dB, was played over the white noise for 600 ms. The auditory stimuli were presented to the right, left, or both ears of participants.

3.1.4. Data analysis
Three indices were used in this experiment: the hit ratio (pressing the correct button when the meaningful words were presented), the correct rejection ratio (correctly ignoring the stimulus when the meaningless words were presented) and the reaction time (the duration between the end of the auditory stimulus and the button press in the hit trials). As in Experiment 1, we calculated the laterality index (left – right-hand)/(left + right-hand) only for reaction time because hit and correct rejection ratios assumed discrete values within each participant (that is, they took only certain values: 0%, 20%, 40%, ..., 100%), thus preventing calculation of the accurate laterality index values. This LI values ranged from –1, indicating left-hand superiority, to +1, indicating right-hand superiority; a longer reaction time indicates poorer performance.

3.1.5. Questionnaire
After the participants finished the experiment, they completed a battery of questionnaires that included the HNHS, the SDS, the STAI-T, the STA, and the AHES, as in Experiment 1B.

3.2. Results and discussion
We first conducted the correlation analysis between the questionnaire scores and the reaction times under the six conditions (the right and the left-hand x the right, left, and both ears). However, we found no significant correlations among those factors (rs < .10, and ps > .05), indicating that high schizotypal personality might not be related to the rapidity of button pressing or language processing in this task. Second, we used the laterality index (LI) value under the three conditions (the right, left, and both ears). Kolmogorov–Smirnov’s test revealed that LIs in all three conditions were distributed normally (Ds < .100, and ps > .70). Then we conducted the correlation analysis with the scores on each questionnaire to examine the relationship between schizotypal personality and functional lateralization (Table 5). The results confirmed significant correlations (or significant trends) between each LI value and the AHES and the STA (rs > .21, and ps < .10).

We focused on the STA data to compare the high and low groups (12 participants in each; see Table 6 for demographic data) because this scale was most strongly correlated with the experimental laterality index values regarding this task (Fig. 5). The two-way ANOVA for the both-ears condition (two hand conditions x two groups) revealed significant trends for the interaction [F(1, 22) = 3.51, and p < .10], while the main effects of the group [F(1, 22) = 1.35, n.s.] and the hand [F(1, 22) = 0.67, n.s.] were not
significant. In addition, the simple main effects of group within the left-hand condition and of the hand condition within the low STA group represented significant trends (ps < .10). The low group performed faster with the right-hand, similar to the general right-handed population because semantic processing is lateralized to the left hemisphere (Ngan et al., 2003) which also controls the right-hand in most right-handers (Velay & Benoit-Dubrocard, 1999). In contrast, the high group performed equally well with the right and left-hands, indicating that semantic processing in this group may be non-lateralized.

For the right- and left-hand conditions, the three-way ANOVA (two ear conditions \times two hand conditions [contralateral or ipsilateral] \times two groups) revealed that the main effects of hand condition \([F(1, 22) = 19.2, p < .001]\) and the first-order interaction between the group and hand condition \([F(1, 22) = 4.76, p < .05]\) for the right- and left-hand conditions were significant, while the main effects of the group \([F(1, 22) = 1.65, n.s.]\) and the ear \([F(1, 22) = 1.35, n.s.]\), and the second \([F(1, 22) = 0.01, n.s.]\) and the first-order interactions between the group and the ear \([F(1, 22) = 0.02, n.s.]\) and between the ear and the hand \([F(1, 22) = 0.32, n.s.]\) were not significant. Furthermore, the simplest main effects of group in the ipsilateral hand condition \((p < .05)\) and hand condition (contra- or ipsilateral) within the high STA group \((p < .001)\) were significant. Regardless of the ear condition (right or left), while the low STA group performed equally with their right and left-hands, the high STA group performed better with their ipsilateral hands, which might represent the benefit to the neural transfer under the ipsilateral condition (see Velay & Benoit-Dubrocard, 1999) for the visual-motor ipsilateral effect. In other words, the high STA group demonstrated the ipsilateral effect involving the ear and the hand. Next, we focused on the hit and correct rejection ratios (Fig. 6). While we were unable to analyze the correct–rejection data because of the ceiling effect, we conducted ANOVAs on the hit ratio. The two-way ANOVA revealed that the main effect of the hand condition was significant \([F(1, 22) = 9.48, p < .01]\) for the both-hands condition, while the main effect of the group \([F(1, 22) = 0.00, n.s.]\) and the interaction \([F(1, 22) = 0.38, n.s.]\) were not significant. For the right- and left-hand conditions, the three-way ANOVA revealed that the main effect of the hand condition (contra or ipsilateral) was significant \([F(1, 22) = 6.54, p < .05]\), while the main effects of the group \([F(1, 22) = 0.07, n.s.]\) and the ear \([F(1, 22) = 0.78, n.s.]\), and the second \([F(1, 22) = 0.43, n.s.]\) and the first-order interactions between the group and the hand \([F(1, 22) = 0.02, n.s.,]\) between the group and the ear \([F(1, 22) = 0.00, n.s.]\), and between the hand and the ear \([F(1, 22) = 0.98, n.s.]\) were not significant. That is, there was no meaningful difference in the schizotypal lateralization in regard to hit or correct rejection ratios although we also confirmed right-hand superiority under the both-ears condition and the general ipsilateral effect on the hit ratio.

These results suggest that positive schizotypal personality might be related to the non-lateralization of semantic processing. First, participants with high schizotypal personality scores reacted to semantic auditory stimuli with their right and left-hands equally under the both-ears condition. Furthermore, they tended to show a stronger ipsilateral effect. One possible way to reconcile these findings involves the notion that these participants could process semantic stimuli in both right and left hemispheres. If so, they could react equally well with their right and left-hands under the both-ears condition and could show the ipsilateral effect even under the left-ear condition (see Fig. 7). Some older studies using the dichotic listening task found that schizotypal participants exhibit a weakened asymmetry for presented verbal stimuli (Broks et al., 1984; Rawlings & Borge, 1987), as do patients with schizophrenic (e.g., Hugdahl et al., 2008), which suggests a higher prevalence of bilateral language representation. Of course, this conclusion is not clear, because each ear sends most information to the contralateral hemisphere and minimal information to the ipsilateral hemisphere (Sidtis, 1982); this differs from the processes underlying vision, in which each visual field sends all information to the contralateral hemisphere (Velay & Benoit-Dubrocard, 1999). Nevertheless, the present study represents the suggestion of the importance of the relationship between schizotypal personality and non-lateralization in regard to language function using a newly developed task that differs from classical dichotic listening and that enabled us to infer the neural pathway from the ear (cochlea) to the hand through the language area in the brain.

More specifically, we addressed the question of what component of speech processing might be lateralized in the general population and not in schizophrenia and in schizotypal personalities. Brain imaging studies have suggested that the larger size of the left than the right planum temporal area (in the upper posterior temporal lobe) might be the best evidence for structural and functional lateralization of speech processing (see Hugdahl, 2000 for a review). In schizophrenia, however, the expected leftward asymmetry in the planum temporal area is reduced (Green, Hugdahl, Mitchell, 1994). The planum temporal area might process phonological information rather than acoustic contents, including sound frequency and amplitude (Hugdahl et al., 1999). In the present task, we differentiated between speech stimuli with and those without semantic information, anagrammatizing the source letters. Given that the difference in processing might be related to the phonology rather than acoustic contents of language, the present finding is in line with previous studies that indicated schizophrenic atypical lateralization not in a tonal but in a phonetic dichotic task (Bruder et al., 1999).

### General discussion

We conducted three experiments to examine schizotypal atypical lateralization in motor (spatial or speed) and language functions because a failure in the lateralization of language and motor functions has been proposed as a critical feature in the pre-
disposition to schizophrenia (Crow, 2000), in addition to a classical language-spatial dichotomy (e.g., Hugdahl, 2000; Kimura, 1996). Experiment 1 (A and B) showed that spatial motor control (line-drawing task) may be non-lateralized while motor speed or force control (finger-tapping task) may be lateralized among highly positive schizotypal participants. In general, the former is lateralized to the right hemisphere/lefthand while the latter is lateralized to the left hemisphere/right-hand (Barthelemy & Boulinguez, 2001, 2002; Todor et al., 1982). Experiment 2 showed that highly positive schizotypal participants may not show lateralization in response to the semantic auditory–motor response (language semantic go/no-go task), in which semantic processing is generally lateralized to the left hemisphere (Capozzoli, 1999; Gernsbacher & Kaschak, 2003). These results suggest that positive schizotypal personality might be related to functional non-lateralization, at least in regard to some functions, including spatial motor control and speech semantic processing in the present study.

In general, these results are consistent with those of previous studies. Nicholls et al. showed a significant correlation between the laterality index in a finger-tapping task and positive schizotypal personality (Nicholls, Orr, & Lindell, 2005). Schizophrenic patients performed more poorly in finger-tapping tasks but demonstrated a normal lateral index (Tabarés-Seisdedos et al., 2003). On the other hand, highly positive schizotypal personality might be correlated with the laterality index in the line-drawing task insofar as schizotypal subjects might not show lateralization (Lenzenwegner & Maher, 2002). However, lateralization may not emerge among schizophrenic patients in response to a line-drawing task (Byler et al., 1997), perhaps due to a focus on motor dysfunctions as atypical lateralization might be related to positive symptomatology, as the present study suggests. However, a functional magnetic resonance imaging study indicated that although healthy subjects showed increased activation in the right frontal, temporal, and cingulate regions, schizophrenic patients showed greater activation compared with control subjects in the left frontal, temporal, and parietal regions, and in right frontal regions, during the spatial working memory task; that is, schizophrenic spatial processing involved increased activation in the left hemisphere as well as the right (Lee et al., 2008). Furthermore, dichotic listening tasks revealed that schizotypal participants exhibit a weakened asymmetry for presented verbal stimuli (Broks et al., 1984; Rawlings & Borge, 1987), as do schizophrenic patients (e.g., Hugdahl et al., 2008), which suggests higher prevalence of bilateral language representation. Ngan et al. (2003) and Spironelli, Angrilli, and Stegagno (2008) used neuroimaging or ERP to show that schizophrenic patients have a failure of linguistic lateralization. Behavioral studies except for dichotic listening tasks have produced no evidence in this regard because it seems difficult to examine such a topic without neuroscientific methods. We could open a new methodological door by administering verbal–motor (go/no-go paradigm) measures, applying the previous studies (Welsh & Elliott, 2001; Welsh et al., 2003), which could be useful to infer non-invasively the neural pathway from the ear to the hand through the language area in the brain.

How do we understand atypical lateralization given that schizophrenia or schizotypal personality might not be functionally lateralized? Perhaps the two hemispheres work independently, at least with regard to some functions. For example, linguistic functions are typically located in the left hemisphere for right-handed people, but those functions might be located in both hemispheres in schizophrenic or highly schizotypal people. Many studies have suggested that patients with schizophrenia have abnormal interhemispheric connections (e.g., Lohr et al., 2006). The results of Experiment 2 support this suggestion. Those with highly positive schizotypal personality scores had stronger ipsilateral effects even when they heard the auditory stimuli in their left ear (that is, most information was sent to their right hemisphere), while those with low schizotypal personality scores performed equally well with their right and left hands regardless of the ear receiving the auditory stimuli (in other words, regardless of the ipsilateral or contralateral condition), indicating that the two hemispheres were in close communication. Since the ipsilateral effect was observed in regard to reaction time, indicating neural transfer, and not in regard to hit ratio, we inferred that subjects could understand linguistic stimuli equally but process them more slowly under the contralateral condition; this may be a consequence of some dysfunction in inter-hemispheric transfer (Fig. 7). To examine interhemispheric transfer, a multimodal task, including visuomotor (Velay & Benoit-Dubrocard, 1999) or tactuomotor tasks (van Mier & Petersen, 2006) would be useful, in addition to the audiomotor task we administered.

How does the atypical laterality, which we examined in the present study, cause abnormal schizotypal or schizophrenic experiences, including auditory hallucinations? A challenging speculation suggests that auditory hallucinations could be caused by speech processing in the right hemisphere in schizophrenics (cf. the bicameral mind; see Olin, 1999 for a review of this relationship; Bentaleh, Beaufregard, Liddle, & Stip, 2002). As commented in other papers (e.g., Sommer, Aleman, & Kahn, 2003), this has not been verified. However, it could be considerable because it assumes a causal model from schizophrenic genes, through abnormal laterality, through misattribution of self-produced speech, to schizophrenic symptomatology. That is, genes related to schizophrenia (e.g., Klar, 1999) might cause atypical brain laterality (e.g., Harrison, 2004). Atypical brain laterality might, in turn, cause misattribution of self-produced speech, if, for example, the right hemisphere receives unexpected speech information that is interpreted as another person’s speech rather than self speech (for a review of research on the neural mechanism for self–other attribution, see Frith, 2005). The possibility that this is the mechanism underlying auditory hallucinations (e.g., Ford & Mathalon, 2005) is worthy of future research.

We analyzed results regarding the relationship between schizotypal personality and functional lateralization in two ways: linear correlation analysis and comparisons between the high and low score groups using ANOVA. The correlation analysis, which is easily interpreted in terms of individual differences, might be suitable for questionnaire-based studies or simple experiments, while well-designed multiple factor experiments (for example, 2 × 2 design) require ANOVA. Because each of these methods has strengths and limitations, we used both kinds of analysis to identify the relationships between schizotypal personality and functional lateralization. The difference between the two statistical approaches may reflect another construct based on a continuum: a quasi- or fully dimensional model of schizotypal personality (Claridge & Davis, 2003). According to the former perspective, only those with high scores on measures of schizotypal personality exhibit schizotypal traits; this approach might allow us to compare groups (high vs. low or average; e.g., Asai & Tanno, 2007, 2008; Smyrnis et al., 2007). According to the latter perspective, all people exhibit schizotypal personality traits to some extent, and those with strong schizotypal traits might develop schizophrenia; this perspective could enable us to conduct a correlation or regression analysis (e.g., Asai et al., 2008; Lenzenwegner & Maher, 2002). Our results did not directly address the issue of whether schizotypal personality should be understood in terms of a continuum or a dimensional model, perhaps because of the relatively small sample size especially in group comparison. However, because the correlation analysis and the group comparison revealed consistent results, it was possible to extrapolate our results. Basically, our two approaches (correlation analysis and the comparison between the high and the low groups with ANOVA) match each other, thereby
supporting a fully dimensional model of schizotypal personality as located on a continuum bounded by schizophrenia. Although we prefer a multidirectional study involving three different tasks for different samples (which would ensure sample independence), addressing this more directly would require a large sample to study continuity, even in regard to one task (e.g., Smyrnos et al., 2007).

In the present study, we did not focus on the handedness scale, although we assessed handedness as a precautionary measure. As we discussed in our Results and Discussion in Experiment 1A, it is not easy for the present study to examine the potential effects of handedness, although we confirmed that the handedness scores of participants in the high and the low schizotypal group did not differ in the experiments (see Tables 2, 4 and 6). Although handedness might be related to the cognitive functions that we measured in the experiments, including spatial performance and language processing (e.g., Crow, Crow, Done, & Leask, 1998; Peters, Reimers, & Manning, 2006), handedness scales or hand preference might be restricted to some motor or non-categorized functions. Some motor functions are related to the right hemisphere, whereas others are related to the left, as we examined in Experiments 1A and 1B. Handedness scales do not take into account this theoretical issue. We should distinguish clearly between hand preference or dominance, which can be measured by questionnaires, and hand skill or performance, which can be measured by experimental procedures, because the two conflict in some cases (for example, most right-handed people tend to manipulate mouse devices with the right-hand in everyday life, although the left-hand might outperform the right in spatial motor tasks using a mouse device; e.g., Lenhard & Hofmann, 2007), although they also can be highly correlated (e.g., Peters, 1998). The focus of this experiment was the relationship between hand dominance and schizotypal personality, and the participants’ hand preferences were not relevant to our study, as previous studies (e.g., Lenzenweger & Maher, 2002). However, the relationships between hand preference and hand dominance or among hand preference, dominance, and schizotypal personality constitute additional important issues that should be examined in the future.

In conclusion, we conducted three experiments to examine atypical lateralization in motor and language functions among schizotypal participants because a failure in these functions has been proposed as a critical feature in the predisposition to schizophrenia. The results suggest that positive schizotypal personality traits (especially proneness to auditory hallucinations) may be related to functional non-lateralization in spatial motor control and speech processing, as suggested by previous studies that included both schizophrenic patients and participants with schizotypal personality traits. This finding may help us understand schizophrenic symptomatology, especially with regard to the positive factors.

References