A psychometric approach to the relationship between hand–foot preference and auditory hallucinations in the general population: Atypical cerebral lateralization may cause an abnormal sense of agency

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1. Introduction

Many people with schizophrenia describe a sense of passivity to their experiences, in that their actions, thoughts, or emotions are experienced as created for them by some external agent rather than by their own will. These positive symptoms of schizophrenia are included among Schneider’s first-rank symptoms for the diagnosis of schizophrenia (Schneider, 1959; Mellors, 1970). In most cases, the actions carried out when people feel that they are being controlled by alien forces are not discrepant with their intentions (Frith et al., 2000a, 2000b). In other words, people with schizophrenia have an abnormal sense of agency, that is, of the feeling of causing our own actions (Gallagher, 2000). Phenomena such as delusions of control, auditory hallucinations, and thought insertion may all be caused by an abnormal sense of agency (Frith et al., 2000a; Gallagher, 2004; Lindner et al., 2005). For example, one’s own speech could seem to be auditory hallucinations (McGuigan, 1966; McGuire et al., 1993), indicating that these people might produce speech but not think that they actually spoke. As a result, they may hear their own voices as the voices of others.

The abnormal sense of agency in schizophrenia has been shown empirically. Some studies reported that when required to make judgments about the origin of hand actions, movements, or speech based upon biased feedback, people with schizophrenia were more likely than normal controls to misattribute their own actions (Daprati et al., 1997; Franck et al., 2001; Johns and McGuire, 1999; Johns et al., 2001). This is also true for the case of schizotypal personality traits in the healthy general population. Asai and Tanno (2007, 2008) empirically ascertained that people high in schizotypy also tend to have an abnormal sense of agency in their actions, including speech, both on explicit and implicit measures (Asai et al., submitted for publication), indicating the continuum of the abnormal sense of agency between schizophrenia and schizotypal traits.

It was recently suggested that psychopathological models of schizophrenia that include the sense of agency may also apply to schizotypal personality traits (schizotypy). Cyhlarova and Claridge (2005) indicated that schizotypal people, identified by questionnaires or semi-structured interviews, might have a predisposition to schizophrenia. Although schizotypal people can have schizophrenic-like experiences, many can live normal lives. The traits of schizophrenia are generally considered to span a continuum though controversy remains regarding whether this continuum is quasi-dimensional, applying only to those people with schizophrenia and schizotypy who have schizophrenic genes, or fully dimensional, applying to all people (Claridge and Davis, 2003). Correlations between cognitive dysfunctions and schizotypal scores in the general population (e.g., Lenzenweger and Maher, 2002) and the relationship between a general personality theory.
and schizotypy (Asai et al., 2011a) support the fully dimensional model of schizotypy, although some previous studies support the quasi-dimensional model (e.g., Smyrnis et al., 2007). Individual differences in schizotypal personality disorder have been explored to examine the nature and structure of the symptoms. Research on schizotypal personality disorder in the general population may offer a particular opportunity to study the biological and cognitive markers of vulnerability to schizophrenia without the confounding effects of long-term hospitalization, medication, and severe psychotic symptoms (Raine and Lencz, 1995). Relatives of schizophrenic patients scored significantly higher on measures of schizotypal personality, suggesting the existence of an at least partially genetic range within the spectrum of schizophrenic disorders along which schizotypal traits can be expressed (Kremen et al., 1998; Plated and Gallup, 2002; Lenzenweger, 2006).

The hypothesis of the schizophrenic abnormal sense of agency has been developed relatively recently. On the other hand, atypical cerebral lateralization may represent a risk factor for developing schizophrenia (Crow, 2004). Patients with schizophrenia have shown differences in lateralization as measured by handedness (Reilly et al., 2001), and scores for schizotypal personality traits are higher among mixed-handed participants drawn from the general population (Annett and Moran, 2006; Somers et al., 2009), even in non-Western cultures (Asai and Tanno, 2009). These results may imply that schizophrenia or schizotypal personality and non-lateralized cerebral functioning are related, at least with regard to motor ability. Furthermore, non-lateralization in not only motor but also language functioning among those with schizophrenia has been suggested by empirical research (e.g., Byler et al., 1997; Lohr and Caligiuri, 1997; Lenzenweger and Malher, 2002; Ngan et al., 2003; Tabarés-Seisdedos et al., 2003; Hugdahl et al., 2008; Asai et al., 2009a), implying that the essential disconnection between the two hemispheres may render them equivalent, at least with respect to certain motor and language functions (Asai et al., 2009a). As a result, patients with schizophrenia may have second language areas in their right hemisphere (cf. “bicameral mind”; for review see, Cavanna et al., 2007; Olin, 1999; Sher, 2000). Many studies have shown that right homologues of language-related areas were activated during auditory verbal hallucinations (e.g., Sommer et al., 2008).

Sommer et al. (2003) proposed a challenging but important hypothesis, namely, the sense of agency and laterality hypothesis, in their attempt to connect these two theories of schizophrenia. According to this hypothesis, atypical hemispheric lateralization in people with schizophrenia may cause an abnormal sense of agency. In the present study, we tried to examine this hypothesis in the general population using a questionnaire-based approach. As mentioned above, many previous studies have suggested that schizotypal personality scores were increased among mixed-handed participants drawn from general populations (e.g., Asai and Tanno, 2009). The relationship of these scores to footedness, however, has not been examined sufficiently, although footedness may not be as susceptible to social influence as is handedness (for example, the hand used for writing used to be corrected frequently in both Western and non-Western cultures; for review, see Levy, 1974). Foot preference may provide a more accurate indication of functional lateralization (Elias and Bryden, 1998). The present study focused on both hand and foot preferences and then examined their relationship to proneness to auditory hallucinations and the sense of agency. A questionnaire distributed to large samples may constitute one important means of examining this issue.

2. Methods

2.1. Participants

Data were collected from undergraduate psychology students in Japan during three consecutive years. The 836 students (f = 251, m = 585) who participated in the study were drawn from a variety of disciplines, although the majority came from the school of Arts and Sciences. The age at which subjects completed the study ranged from 18 to 29 years, with an average age of 19.1 years.

2.2. Questionnaire

They completed a battery of questionnaires. We assigned a random number to each participant. The battery included the following questionnaires, all of which, except for the HNH, AHES-17 and SOAS, have been translated into Japanese and demonstrate good reliability and validity.

2.2.1. Auditory hallucination proneness

The Auditory Hallucination Experience Scale 17 (AHES-17, Asai et al., 2011b) is a brief version of the Auditory Hallucination Experience Scale (AHES, Sugimori et al., 2009), which has been developed in Japan because a scale for directly measuring auditory hallucination-like experiences was needed. The Launay-Slade Hallucination Scale (LSSH, Launay and Slade, 1981) and its revised version (LSSH-R; Waters et al., 2003) measure hallucination-like experiences, including auditory hallucinations, but do not focus on auditory hallucinations separately. The AHES-17 is a self-report 17-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 17 to 85. Test–retest reliability (r = 0.78, p < 0.0001) and internal reliability (α = 0.84) were adequate, and the investigation of criterion-related validity showed that the AHES-17 was highly correlated with scales measuring positive schizotypy, including auditory hallucination proneness (Asai et al., in press).

2.2.2. Hallucination proneness

The Launay-Slade Hallucination Scale (LSSH, Launay and Slade, 1981) measure hallucination-like experiences, including auditory hallucinations. The LSSH is a self-report 12-item questionnaire with responses based on a 5-point Likert scale (1–5) measuring the frequency of hallucination-like experiences.

2.2.3. Schizotypal personality traits

The Schizotypal Personality Questionnaire Brief (SPQB; Raine and Benishay, 1995) is a shortened version of the Schizotypal Personality Questionnaire (SPQ; Raine, 1991). SPQB is a 22-item true–false self-report questionnaire measuring schizotypal personality traits. It consists of three subscales: Cognitive–Perceptual (Pos: positive schizotypy), Interpersonal (Neg: negative schizotypy), and Disorganization (Dis: disorganized schizotypy).

2.2.4. Sense of agency

The Sense of Agency Scale (SOAS; Asai et al., 2009a,b) is a newly developed prototype measure for assessing the sense of agency. It includes 22 items that are related to an abnormal sense of agency in the general population according to previous experimental studies. The scale consists of three subscales: misattribution of the agent (Mental Self: e.g., “I sometimes turn around feeling as if someone called my name in a crowd.”), uncontrollability of one’s own body (Physical Self: e.g., “I sometimes feel I cannot move my body as I want.”), and self-assertiveness in social situations (Social Self: e.g., “I sometimes feel my behavior has some effect on society.”). Responses are based on a 4-point Likert scale. It was reported that test–retest reliability (r = 0.673, p < 0.0001) and internal reliability (α = 0.77) were adequate (Asai et al., 2009b).

2.2.5. Handedness

The H.N. Handedness Scale (HNHS; Hatta and Nakatsu, 1975; Hatta and Kawakami, 1995) 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 and Inui, 2007). 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;thumb tacking; hammering; 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.

2.2.6. Footedness

Chapman foot preference inventory (CFP; Chapman et al., 1987) requires participants to respond by indicating whether they use their right, left, or either foot for 11 common actions: step on a spade; put on first stocking: stand on one’s foot; be uppermost when crossing legs; kick a ball; hop; stamp on an object; step forward; put on first shoe; step up on a stool; pick up object with this. Scale ranges from 11 to 33; “a right” response is scored as +1, a “left” response is scored as −3 and a response of “either” is scored as +2. Except for handedness and footedness, higher scores for all questionnaires indicate a stronger tendency on the relevant dimension.

2.3. Statistical analysis

The hand and foot questionnaires included criteria for categorizing preference (right, mixed, and left). Because these criteria may not be conclusive, previous studies have categorized handedness or footedness groups according to their own criteria (e.g., Gregory et al., 2003). The present study, however, categorized the participants statistically (cluster
The means and SDs for each questionnaire are shown in Table 1. The data indicate that the majority of subjects preferred to use their right hand or foot. Consistent with a previous study (Hatta and Kawakami, 1995) females showed a stronger rightward bias than did males in terms of handedness. Consistent with the findings of Nicholls et al. (2005), however, males showed a stronger rightward bias in terms of footedness. Because the literature contains few studies about the relationship between footedness and sex differences, further research should examine whether this finding is specific to Japanese individuals. In addition, females obtained higher scores on the Auditory Hallucination Experience Scale (AHES) and the Sense of Agency Scale (SOAS). Because the present sample included twice as many males as females, the sex differences discovered in our study may not be conclusive (even if statistically controlled). In addition, our aim does not concern gender differences. We did not divide the sample into gender groups but used the entire sample and did not address these in the following analysis, although the nature of gender differences in laterality continues to be an important issue.

To examine the internal consistency (reliability) for each questionnaire score, we calculated Cronbach’s α. The desirable value of α is greater than 0.80 (or 0.70 in practice, since questionnaires that treat broader phenomena might have lower α). The α of AHES, LSHS, SPQB, SOAS, HNHS, and CFPI are 0.85, 0.84, 0.78, 0.75, 0.94, and 0.93, respectively. Though SPQB and SOAS, which have some subcategories, might have lower values, we concluded that all of the questionnaires have sufficient reliability.

### 3.2. Correlation among questionnaires

Table 2 shows the Pearson’s correlation matrix among the questionnaires used, revealing that most relationships were significant since our sample size was relatively large. Especially among these, the robust relationships in terms of effect size (r) between SOAS total and AHES or LSHS (stronger than that with SPQB), between AHES and Pos in SPQB (stronger than that with Neg or Dis), and between AHES and Men in SOAS (stronger than that with Pys or Soc) would suggest good external validity for each questionnaire used (especially, AHES and SOAS, which we have developed).

As to the relationships with handedness and footedness questionnaires, some schizotypal and sense of agency factors might be linearly but weakly related to footedness, while handedness was related only to AHES. The relationship between the lateral index, including handedness and footedness, and schizotypal traits, however, might not be linear. Schizotypal personality scores might increase among mixed-handed

### Table 2

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<td>AHES</td>
<td>0.69**</td>
<td>0.41**</td>
<td>0.41**</td>
<td>0.23**</td>
<td>0.35**</td>
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<td>LSHS</td>
<td>-</td>
<td>0.42**</td>
<td>0.44**</td>
<td>0.23**</td>
<td>0.35**</td>
<td>0.55**</td>
<td>0.52**</td>
<td>0.43**</td>
<td>0.15**</td>
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<td>SPQB</td>
<td>-</td>
<td>0.79**</td>
<td>0.82**</td>
<td>0.79**</td>
<td>0.40**</td>
<td>0.39**</td>
<td>0.41**</td>
<td>-0.06</td>
<td>-0.02</td>
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<td>Pos</td>
<td>-</td>
<td>0.40**</td>
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<td>0.36**</td>
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<td>0.26**</td>
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<td>-</td>
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<td>0.19**</td>
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<td>0.32**</td>
<td>-0.21**</td>
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<td>Dis</td>
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<td>0.42**</td>
<td>0.37**</td>
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<td>SOAS Total</td>
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<td>0.39**</td>
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<tr>
<td>Mental Self</td>
<td>-</td>
<td>0.55**</td>
<td>0.08**</td>
<td>0.02</td>
<td>-0.04</td>
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<tr>
<td>Pysical Self</td>
<td>-</td>
<td>0.00</td>
<td>0.02</td>
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<tr>
<td>Social Self</td>
<td>-</td>
<td>-0.05</td>
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<tr>
<td>Handedness</td>
<td>-</td>
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Note: N=836.  
*p<0.05.  
**p<0.01.
people (e.g., Annett and Moran, 2006) or among non-right handed people (e.g., Gregory et al., 2003). On the other hand, though the relationship with footedness has been examined less fully than the relationship with handedness, Kelley and Coursey (1992) reported a sinistral shift for foot preference in individuals with high schizotypy. Therefore, we need to divide the participants into handedness or footedness subgroups without arbitrary methods since the varied criteria among the studies might lead to controversy.

### 3.3. Handedness

To categorize the participants into the three handedness groups that formed our three clusters (right, mixed, and left), we used a cluster analysis with Ward’s method to the handedness scores (z scores), setting the number of clusters as three. As a result, scores for the left-handed group (LH, \(n = 50, 6.0\%\)) ranged from \(-10\) to \(-1\), whereas the traditional values range from \(-10\) to \(-5\) (Hatta and Kawakami, 1995). Scores for the mixed-handed group (MH, \(n = 127, 15.2\%\)) ranged from 2 to 7, whereas the traditional values range from 4 to 7. Scores for the right-handed group (RH, \(n = 659, 78.8\%\)) ranged from 8 to 10, identical to the traditional values. The analysis of criteria by cluster showed a wider range for the left-handed group using our criteria than using the traditional standards (see Fig. 1). Gregory et al. (2003) used Annett’s scale and reported that RH was 57%, LF was 1%, and MH was 42.1% in a Japanese sample, while the distribution was 61%, 5%, and 33% respectively in a UK sample. In our previous study in Japanese (Asai and Tanno, 2009), we reported a distribution of 48%, 2%, and 50%, respectively, when Annett’s scale was used and 79%, 4%, and 17%, respectively, in a UK sample. In our previous study in Japanese (Hatta and Kawakami, 1995), we reported a distribution of 48%, 2%, and 50%, respectively, when HNHS (Japanese revised version of the Edinburgh Inventory; used in the present study) was used.

Next, we examined the differences in schizotypy scores among these handedness groups (criteria by cluster analysis). The MANOVA revealed the whole model was significant (Wilks Lambda Approximate \(F = 3.11, df = 16, 1636\), \(p < 0.05\), multivariate \(\eta^2 = 0.033, 1-\beta = 0.92\)), and a significant main effect of handedness for the Launay–Slade Hallucination Scale (LSHS) \(F = 2.97, df = 2, 827, p < 0.05\) and the positive symptoms (cognitive–perceptual) in the Schizotypal Personality Questionnaire Brief (Pos in SPQB) \(F = 3.57, df = 2, 827, p < 0.05\). Ryan’s post-hoc multiple comparison revealed simple main effects between RH and LH and between RH and MH in terms of both LSHS and Pos (\(ps < 0.05\)), indicating that the LH or MH groups may have more prevalent schizotypal personality traits (Fig. 2), especially those positive in nature; this finding is consistent with those of previous studies (e.g., Gregory et al., 2003; Annett and Moran, 2006; Somers et al., 2009).

### 3.4. Footedness

As with handedness, we categorized the participants into the three footedness groups that formed the three clusters (right, mixed, and left) and used a cluster analysis with Ward’s method to the footedness scores (z scores), setting the number of clusters as three. As a result, scores for the left-footed group (LF, \(n = 130, 15.6\%\)) ranged from 24 to 33, whereas the traditional values range from 28 to 33 (Chapman et al., 1987). Scores for the mixed-footed group (MF, \(n = 331, 39.6\%\)) ranged from 16 to 23, whereas the traditional values range from 17 to 27. Scores for the right-footed group (RF, \(n = 375, 44.9\%\)) ranged from 11 to 15, whereas the traditional values range from 11 to 16. The analysis of criteria by cluster showed a wider range for the left-footed group using our criteria than using the traditional criteria, as was the case in the handedness analysis (see Fig. 1). Next, we examined the differences in schizotypy scores among these footedness groups (criteria by cluster analysis). The MANOVA revealed the whole model was significant (Wilks Lambda Approximate \(F = 5.28, df = 2, 827, p < 0.05\); total \(F = 6.55, df = 2, 827, p < 0.05\) in SPQB; and mental self (Men) \(F = 5.32, df = 2, 827, p < 0.05\) and social self (Soc) \(F = 6.68, df = 2, 827, p < 0.05\) in the SOAS. Ryan’s post-hoc multiple comparison revealed simple main effects between LF and MF and between LF and RF for AYES, total SPQB, Pos, and Men (Fig. 3) \(ps < 0.05\), indicating that the LF group may have more prevalent positive schizotypal personality traits. In addition, the MF group showed higher Soc and lower Neg scores than did the LF and RF groups.

### 3.5. Combination of Handedness and Footedness

Next, we examined the combination of handedness and footedness. As noted above, we categorized the participants into three groups for handedness and footedness. This enabled the use of a 3×3 matrix to represent hand–foot-preference combinations. However, the scatter plot for hand–foot preferences, which closely resembled that of a previous study (Chapman et al., 1987), indicated the possibility that the LH–MF, MH–LF, and MH–RF groups may contain no members (Fig. 1). We therefore performed the cluster analysis with Ward’s method to hand and footedness scores (z scores), setting the number of clusters as six (we confirmed that the results described below would not change if we set the number at 7). As a result, six clusters corresponding to the LH–RF (cluster 1, \(n = 11, 1.3\%\)), MH–MF (cluster 2, \(n = 62, 7.4\%\), RH–RF (cluster 3, \(n = 296, 35.4\%\)), RH–MF (cluster 4, \(n = 340, 40.7\%\),

![Fig. 1. Scatter plot between the handedness and footedness. Categorical criteria or clusters were determined by the cluster analysis.](image)

![Fig. 2. Handedness clusters and questionnaire scores. Note. LH = left-handedness, MH = mixed-handedness, RH = right-handedness.](image)
Schizotypal traits

To examine the relationship between the sense of agency and schizotypal personality traits, we constructed a path model for cluster 6, in which we assumed a priori directional path from the sense of agency to the schizotypal traits since the abnormal sense of agency might cause the schizotypal experiences (e.g., Asai et al., 2008). Fig. 5 shows the best model for the sense of agency and schizotypal traits in cluster 6 (n = 97, χ² = 16.8, df = 16, p = 0.40, GFI = 0.96, AGFI = 0.91, NFI = 0.93, CFI = 1.00, RMSEA = 0.023, AIC = 56.80), indicating that the components of the sense of agency might explain the schizotypal traits respectively. Especially as expected, Mental Self (i.e., misattribution of the agent) would predict the auditory hallucination (AHES) and then general hallucination (LSHS) and finally positive symptom (Pos). Physical Self (i.e., uncontrollability of one’s own body) would predict negative (Neg) and disorganized (Dis) symptoms, which include fewer and disorganized physical activities. Social Self (i.e., self-assertiveness in social situations) would predict positive symptoms (Pos), except for hallucination, which might be, for example, delusional ideation (e.g., delusions of persecution, reference, and grandeur). As to the schizotypal hierarchic structure, we have already suggested this in terms of the continuum of schizotypy (Asai et al., 2011). When the same model was applied to the total sample (since some clusters didn’t have a large enough sample to use path analysis), the fitness scores did not reach satisfactory levels (n = 836, χ² = 239.0, df = 16, p = 0.00, GFI = 0.94, AGFI = 0.86, NFI = 0.89, CFI = 0.89, RMSEA = 0.130, AIC = 278.0). The analysis of the best model for the total sample (N = 836, χ² = 15.3, df = 8, p = 0.054, GFI = 1.00, AGFI = 0.98, NFI = 0.99, CFI = 1.00, AGFI = 0.98, NFI = 0.93, CFI = 0.99, AGFI = 0.98, NFI = 0.93, CFI = 0.99).
RMSEA = 0.033, AIC = 71.3) showed that the AIC scores indicated that this model was not as appropriate for all respondents as it was for cluster 6. These results indicate that the sense of agency may be more closely connected to schizotypal traits in cluster 6 than in other laterality clusters, though the path analysis doesn’t ensure the directional causality and so this depends on an a priori hypothesis. Among those path relationships, the misattribution of agency and proneness to auditory hallucinations were connected most strongly (see Fig. 5).

4. Discussion

4.1. Potential connection between sense of agency and laterality

The present study examined the relationship between atypical cerebral lateralization patterns represented in hand and foot preferences and schizotypal personality traits, especially proneness to auditory hallucination as related to the sense of agency. Atypical hemispheric lateralization in patients with schizophrenia and people with schizotypal traits have emerged repeatedly from studies using various methods including brain imaging, behavioral experiments, and questionnaires. Although atypical cerebral lateralization may represent a risk factor for developing schizophrenia (Crow, 2004), the abnormal sense of agency among those with schizophrenia has recently attracted researchers in various fields because it may explain such passive schizophrenic phenomena as auditory hallucinations on both neural and behavioral levels (for a review, see Frith, 2005).

Sommer et al. (2003) hypothesized that atypical hemispheric lateralization may cause the misattribution of agency (i.e., auditory hallucinations). The finding of decreased cerebral asymmetry in schizophrenia has been replicated with several techniques. In addition, functional imaging studies have reported decreased lateralization of language-related activation in patients with schizophrenia compared with healthy controls (Sommer et al., 2001). It could be hypothesized that inner speech, originating from right cerebral homologues of the language areas, is perceived as an auditory hallucination in these cases. The right hemisphere may include instances of “prediction violation.” Self-produced language activity normally leads to inhibition of language perception areas (McGuire et al., 1996) because self-produced sensations can be predicted accurately and filtered appropriately (e.g., Blakemore et al., 1998). When this inhibitory mechanism fails, verbal thoughts may not be recognized as originating from the self and may erroneously be attributed to an external source. Indeed, inhibition of language perception may be more prone to failure when language activity is derived from an unusual site (i.e., from contralateral homologue areas in the right hemisphere). Patients with auditory hallucinations may have second language areas in their right hemisphere but be unable to predict this irregular language processing or to attenuate related feedback. As a result of this prediction violation, these individuals would experience the self-produced (inner) voices as emanating from others.

4.2. Hand and foot preferences, and schizotypal traits

This is a challenging hypothesis, which we addressed with a questionnaire-based approach. The left- or mixed-handedness group, defined in terms of statistical clusters, may show more prevalent positive schizotypal traits, as previous studies have indicated (e.g., Gregory et al., 2003; Annett and Moran, 2006; Somers et al., 2009). Whereas some studies have found that schizotypal personality scores increased among mixed-handed compared with right- and left-handed participants drawn from the general population (Annett and Moran, 2006; Asai and Tanno, 2009; Somers et al., 2009), other studies have shown that schizotypal personality scores increased among left-handed or non-right handed participants (e.g., Gregory et al., 2003). This finding may derive from the general scarcity of left-handed participants (approximately 5–6% at most) and the disproportionate impact of these few left-handed participants even when large samples were used. Huge samples are needed to resolve this problem.

On the other hand, the left-footed group may obtain higher scores on positive schizotypal traits. The relationship between schizotypal traits and footedness has not been examined fully. Indeed, Kelley and Coursey (1992) reported a sinistril shift for foot preference in individuals with high scores on a combined battery of 11 schizotypy measures, but Nicholls et al. (2005) examined the relationship between schizotypal traits (magical ideation, MI) and footedness and reported no relationship. In terms of atypical footedness and schizophrenia, Schiffman et al. (2005) showed that the rate of left- or mixed-footedness, but not handedness, discriminated between those who did and did not develop schizophrenia spectrum disorders. Although neither the previous nor the present study can conclude whether the reduced (e.g., Cannon et al., 1995) or reversed (e.g., Dragovic et al., 2005) lateralization in hand or foot preferences is related to schizophrenia, the present study does suggest a relationship between positive schizotypal traits and atypical preferences for hands and feet even in non-Western cultures (see also, Asai and Tanno, 2009).

It is also important to focus on the combination of hand-foot preferences because lack of consistency in the various markers of lateral preference has been a useful indicator of weak cerebral lateralization (Porac, 1997). Indeed, individuals inconsistent across modalities in their lateral preferences, including with respect to hands, eyes, ears, and feet, obtained higher MI scores (Nicholls et al., 2005). The present study focused on hand and foot preferences because the questionnaires measuring these phenomena contained approximately 10 items, and we expected more widely distributed individual differences; some of the lateralization questionnaires contain only three or four items (e.g., Porac and Cohen, 1981), which may be too few from a psychometric perspective. Alternatively, more detailed analyses could be conducted. The present study, which categorized these individual differences in laterality preferences on a statistical basis, found that people with the combination of right-handedness and left-footedness may be characterized by more schizotypal traits and not merely by inconsistency in hand and foot preferences. Collinson et al. (2004) suggested that crossed hand-foot preference was not significantly higher in a group of schizophrenic patients. Future studies should examine specific crossed combinations. In addition to hand or foot preferences, schizotypal personality has also been linked to atypical patterns of cerebral dominance. In support of this, Leonhard and Brugger (1998) found that individuals with low MI scores showed the expected right visual field advantage for lexical decisions, whereas individuals with high MI scores showed no visual field asymmetry. A link between schizotypy and atypical pseudoneglect (Kalayciglu et al., 2000), unilateral olfactory perception (Mohr et al., 2001), and dichotic listening (Weinstein and Graves, 2002) has also been reported. These aberrant patterns of cerebral dominance may not simply be a consequence of the disorder, but may play important roles in the manifestation and development of schizotypal personality and schizophrenia itself (Crow, 1997; Gur, 1999).

4.3. Crossed cerebral lateralization might cause an abnormal sense of agency

In addition to the relationship between schizotypal traits and lateral preferences, the present study examined the sense of agency and atypical lateralization in terms of the hypothesis proposed by Sommer et al. (2003). We found that right-handed and left-footed individuals may have a more pronounced proneness to auditory hallucinations and a greater tendency to misattribute agency with regard to the items measured by the questionnaires. To confirm this relationship, we constructed path models and examined fitness scores. The best fitness score (that is, the AIC) was achieved by the model leading from the sense of agency to schizotypal traits, including the path from misattributing agency to proneness to auditory hallucinations, indicating that the abnormal sense of agency in this crossed-lateralization group may cause...
schizotypal personality traits. Though the reason for this crossed lateral preference remains unclear, we should consider at least two things. First, why are people with LH-RF very rare (1.3%) compared to people with RH-LF (11.6%)? Second, why might people with RH-LF have higher schizotypy scores than people with LH-RF or MH-MF? One possibility is early switching in handedness, though we did not ask about laterality correction in subjects' early age. Given the fact that handedness may be more subject to parental or social influence, RH-LF might be the result of early switching in handedness (i.e., left handedness → right handedness, but left footedness → left footedness) if so, the number of people with RH-LF might be much larger than the number of people with LH-RF. Furthermore, if crossed laterality or non-laterality might simply cause schizotypal traits, one could not explain that only people with RH-LF have enhanced schizotypy. The key point we assume is the correction after birth (i.e., crossed- or non-laterality as the results of the correction) rather than crossed laterality or non-laterality at birth. Indeed, in Asian cultures, particularly Japanese, left hand preference is relatively infrequent, presumably because of social pressures that forbid using this hand for certain activities, including writing (Shimizu and Endo, 1983). Guo (1984) reported concerning a huge sample of Chinese, who also have a tradition of left-handedness correction, that 0.3% of the Chinese are left-handed but 9% are mixed handed, indicating that although correction occurs, originally left-handed people would not become completely right-handed, but mixed-handed instead. Hoosain (1991) reported that 3.2% of the Hong Kong sample use their right hand for writing but use their left hand for other hand activities, indicating correction of the writing hand. Though this might be speculative, the present study suggests that correcting laterality, especially handedness, exerts a negative influence (e.g., Arlitt, 1946), or alternatively, that inordinately malleable laterality might be the vulnerability. Hemispheric non-lateralization may cause language processing in the right hemisphere, which could cause auditory verbal hallucinations (Sommer et al., 2003). Hemispheric disconnection may cause this non-lateralization, as previous studies have assumed (e.g. Asai et al., 2009a,b). In addition, crossed lateral preference may also cause non-lateralization (Porac, 1997) followed by an abnormal sense of agency and finally auditory hallucinations. Alternatively, hemispheric functional disconnection may also be caused by non-lateralization resulting from crossed lateral preference. Indeed, Gregory et al. (2003) reported that Japanese participants whose handedness had been changed early in their development obtained higher scores for positive schizotypal traits than did those whose handedness had not been changed, and Shimizu et al. (1985) also reported greater frequency of early hand-switching among Japanese schizophrenics. Thus, although this connection remains speculative, this causal model (early hand-switching might cause crossed- or non-lateralization leading to hemispheric functional disconnection, and finally, to language processing in the right hemisphere) that moves from the functioning of the developing brain to clinical phenomena seems important and may contribute to a more encompassing hypothesis about schizophrenia. The present study represents the first to show the relationship among atypical lateralization (weak lateralization), a sense of agency, and schizotypal traits using a questionnaire-based approach. Further studies should address this relationship from the perspective of causality and employ other methods including behavioral experiments and brain imaging.

Appendix A. Supplementary data
Supplementary data to this article can be found online at doi:10.1016/j.psychres.2011.02.014.

References
Asai, T., Sugimori, E., Tanno, Y., submitted for publication. Exploring the implicit measure for the sense of agency: auditory hallucination like-experiences as the results both from the explicit self-other attribution and implicit regulation in speech.


