Self is “other”, other is “self”: poor self-other discriminability explains schizotypal twisted agency judgment

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ABSTRACT

Anomalous agency has been reported clinically and empirically for people with schizophrenia. This finding is expected to contribute to understanding positive symptomatology in schizophrenia in terms of a general neurocomputational model of motor control, because anomalous agency has also been reported in schizotypal traits in the general population. However, superficially opposite conclusions have been suggested: over-attributed or under-attributed agency in patients. In this work, healthy participants (N=104) were presented continuous morphed self-other visual feedback of their reaching movements and rated the agency they felt for it. The slope of the regression line in stimuli-response coordination as a function of self-other discriminability was estimated for each participant. The estimated slopes were significantly associated with positive schizotypal symptomatology. Higher schizotypal participants exhibited a lower slope, indicating poorer discriminability between their own and others’ movements. Furthermore, the estimated regression lines in the high and low groups are predicted to cross at the approximately center point in the coordinates, which should produce both over- and under-attribution errors for the high group compared with low group. The pattern of schizotypal attribution error depends on the S/N (signal-to-noise) ratio of the given stimuli within our sensorimotor system where the self-originated stimulus is the signal to be detected. The current study, for the first time, suggests both over- and under-attribution within participants scoring high on schizotypy.

1. Introduction

The sense of agency refers to the subjective experience of controlling one’s own action (Gallagher, 2000; Haggard and Chambon, 2012). In this decade, this sense has drawn attention from researchers in philosophy, psychology, neuroscience, psychiatry, and other fields because it could be a window to knowing how we are aware of ourselves and might help in understanding some mental illnesses like schizophrenia (Haggard and Chambon, 2012). Indeed, various measurements in many empirical studies have suggested that people with schizophrenia or even with schizotypal personality traits have “anomalous” agency (Asai and Tanno, 2012; Daprati et al., 1997; David et al., 2008a, 2008b; Fourneret et al., 2002; Franck et al., 2001; Haggard et al., 2003). However, there is a serious inconsistency among studies regarding how anomalous their agency is. The first meta-analytic study, which focused on the relationship between schizophrenia and agency, concluded that such patients have “reduced self-recognition” (Waters et al., 2012), indicating their agency is weaker (under-attribution). On the other hand, another meta-analytic study concluded that patients have an “exaggerated sense of self” (Hur et al., 2014), indicating their agency is stronger (over-attribution). This inconsistency has often been questioned but is still unresolved (van der Weiden et al., 2015; Werner et al., 2014). The current study aimed to explain these superficially contradictory results in terms of the psychophysics of agency (Repp and Knoblich, 2007).

1.1. Mechanism for agency

It has been proposed that we have a mechanism for discriminating between self- and other-originated sensory information (Miall and Wolpert, 1996). The forward model (Wolpert and Miall, 1996) can predict the sensory outcome of a motor command to be matched with the actual sensory outcome (i.e., feedback). Since this forward modeling should be able to predict self-originated sensory outcomes, little mismatch (i.e., prediction error) between predicted and actual outcomes means that that sensory information is highly likely to have come from the self. On the other hand, unless our own motor representation is confounded with others’ though a mirror system (e.g., motor resonance, e.g., Klimesh et al., 2003), other-originated sensory outcomes are not associated with that prediction, so a large
mismatch should be detected. As a result, the feeling of no-large-error is the sense of agency (Asai, 2015; Knoblich and Sebanz, 2005). Empirically, as the inserted bias gets larger in action feedback, participants detect mismatch more easily and feel less agency for that feedback (Asai and Tanno, 2008, 2012). On the contrary, when fake feedback, congruent with the prediction, is presented, participants feel illusory agency for it (Asai, 2015; Nielsen, 1963). When this motor prediction process is uninformative or less reliable, cognitive inferences of agency might also be influential (Moore et al., 2009; Synofzik et al., 2008; van der Weiden et al., 2015), as summarized as Wegner’s principle: exclusivity, priority, and consistency (Wegner, 2003). When the outcome has no other sources except for the action, when the action precedes the outcome, and/or when the action follows a reasonable outcome, we judge cognitive self-agency over that outcome. Though the interplay between motor and cognitive processes for agency is also of great interest (Khalighinejad and Haggard, 2016), the current study focused more on the motor prediction process for agency (see also Fig. 5), where the newly-developed task manipulates prediction errors continuously.

1.2. Schizophrenia as a disorder of agency

Clinical and empirical observations have also suggested that schizophrenia, especially its positive symptomatology, is related to anomalous agency, though the two-tailed abnormalities have been reported as mentioned above (Haggard et al., 2003; van der Weiden et al., 2015). One end is the delusion of reference or megalomania, where patients have a strong belief that external events have a particular significance to them. Even when patients receive self-irrelevant sensory information, they might attribute it to themselves (Daprati et al., 1997; Haggard et al., 2003; Hauser et al., 2011a, 2011b; Hur et al., 2014). The other end is the delusion of influence or passivity symptom (the alien motor control, auditory verbal hallucination, or thought insertion), where patients have a strong belief that their body and mind are controlled by others. Even when patients receive their own action feedback, they might not recognize it as their own (Johns and McGuire, 1999; Waters et al., 2012; Werner et al., 2014). These clinical symptoms are all categorized as positive symptoms in schizophrenia. Their contradictory attribution patterns (illusory self-attribution as well as illusory other-attribution) are still big issues to resolve (van der Weiden et al., 2015).

The essential reason for the two-tailed abnormalities in people with schizophrenia might be their unoptimized motor prediction (i.e., forward modeling) (Asai et al., 2008; Izawa et al., 2015; Synofzik et al., 2010). In theory, if the predicted sensory outcome is imprecise, a false error would be detected even for a self-originated feedback (MISS response for self-attribute). At the same time, a false matching (no-error) would be judged even for an other-originated sensory outcome (false alarm (FA) response). Of course, a “self” response for self-stimuli (HIT) and “other” response for other-stimuli (Correct Rejection (CR) are correct (e.g., David et al., 2008a), see also Fig. 1, right panel). Patients with schizophrenia often fail to detect that prediction error (Fourneret et al., 2002; Franck et al., 2001; Knoblich et al., 2004); hence, they feel illusional agency for other-attributed outcomes (biased feedback or other-originated outcomes, Daprati et al., 1997). They also often detect false error for their own non-biased feedback as well (Werner et al., 2014); hence, they feel less agency for self-attributed outcome (Johns et al., 2001).

1.3. Psychophysics of agency

These findings are all interpretable in terms of the psychophysics of agency (Repp and Knoblich, 2007)(Fig. 1). When we assume a continuum axis between self- and other-originated sensory information (x-axis), high discriminability among them in participants’ response (y-axis) is expressed as a steep slope (gray line in Fig. 1); the ideal standardized slope is 1.00, where a participant hits all self-originated stimuli and correctly rejects all others-originated stimuli), which might be realized by precise motor prediction. If the self-other discriminability is poorer, for example, for schizophrenia, the slope gets lower (black line in Fig. 1). Poor performance would yield a horizontal slope close to 0.00 (equivalent to a participant’s randomly choosing an answer). As a result, when more self-like or self-sided sensory information (a higher S/N ratio, where the self-originated stimulus is the signal to be detected) is given (i.e., rightward in Fig. 1), patients might often make a MISS response for self-attribute, compared to healthy people. When more other-like or other-sided sensory information (S/N ratio is lower) is given (i.e., leftward in Fig. 1), patients might make a FA response for other-attribute. The point here is that patients’ patterns in attribution error (MISS (under-attribute) or FA (over-attribute)) depends on the stimuli given, but these two-tailed errors do not contradict each other in a psychophysical illustration. Both should occur if the self-other discriminability is low.

1.4. The current study

The current study examined the above-mentioned hypothesis, where schizophrenia symptomatology (especially positive symptomatology) is thought to be related to a lower slope as a function of poorer self-other discrimination. For that purpose, it involved some methodological planning. First, a new paradigm—motion morphing between self and other movements—was developed. Though some previous studies manipulated self or other stimuli categorically (e.g., Daprati et al., 1997) (or manipulated the degree of bias in self stimuli, e.g., Franck et al., 2001; Kang et al., 2015), the motion morphing technique enables us to manipulate them continuously, such as self 0% (=other 100%) to self 100% feedback (see Method for details). This has a good fit with psychophysical methodology, where we can estimate a psychometric function (i.e., slope). Given the fact that people with schizophrenia or schizotypy exhibit opposing attribution errors depending on the self-other conditions, as mentioned above, just averaging over all conditions might lead to the false conclusion that they do not show any attribution errors.

Second, the current study recruited a relatively large sample of healthy participants (N=104) and examined individual differences in terms of schizotypal personality traits. This was because psychophysics requires many time-consuming conditions and trials, which may not always be easy for all clinical patients (screening is necessary, which might bias the results). Schizotypy study is now regarded as a good pilot or an analogous study for patients since we can generally see similar results for people with schizophrenia and schizotypy (van Os and Kapur, 2009). Investigating the schizotypal personality in the general population provides the opportunity to examine 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). The continuum perspective between healthy people and patients might also go well with psychophysics, where the stimulus is always manipulated continuously. Taking schizotypy as a continuum among a large sample is advantageous in statistical analysis as well, where we can identify the schizotypy factor responsible for the results (see also Questionnaire and Results). I, on the basis of the current results, discuss how we can measure self-other discriminability (i.e., agency) and the methodological difficulties that have to be overcome. This is an essential question when we think about what is “pure” self-originated sensory information in our sensorimotor system. The answer might depend on whether the required action is “embodied or disembodied” (David et al., 2008b).

2. Method

2.1. Participants

A hundred-and-four healthy participants participated in the current experiment (male=25, average age=32.1, SD=7.1). All participants were right-handed (H.N. handedness inventory for Japanese, Hatta and Nakatsuka, 1975). All provided written informed consent before the experiments were conducted. All participants reported normal or corrected-to-normal vision and hearing. The experiment was conducted in accordance with the Declaration of Helsinki. The protocol of the present study was approved by the local ethics committee.

2.2. Apparatus

The basic experimental apparatus and procedure were almost the same as in my previous study (Asai, 2015). A LED monitor (PTFLBF-22W, Princeton) and a digitizing tablet (Intuos4 PTK-1240/K0, Wacom) was used for a visually guided reaching task. The physical size of the input area of the digitizer and that of the plotting area of the monitor were almost the same (488×305 mm). The monitor was set 20 cm vertically above the digitizer. Participants manipulated the pen device on the digitizer with its visual feedback (the cursor) on the monitor (Fig. 2). The visual or auditory stimuli were controlled by Hot Soup Processor 3.3 (Onion Software) installed on a Windows computer.

2.3. Procedure

Participants were required to trace the target line (sin wave) as accurately as possible in accordance with 1-Hz metronomic sounds. Specifically, they first set their pen position at the starting point (lower left) within five countdown sounds. Then they started to move it from count 0. After that, they smoothly moved the pen (i.e., the cursor) to the goal point (lower right) so that the timing of reaching each peak of the sin wave matched the timing of each metronomic sound. Since the onset and offset of the cursor movement must be sensitive to mismatch detection and then agency judgment (for example, the cursor could move even before their pen movement in the OTHER condition, see below), the cursor was masked during the first 1.5 and last 0.5 s. The longer mask was necessary for the onset because it takes time for participants to manage smooth movements from the static state at the starting position. Therefore, the cursor disappeared right after participants set their pen at the starting point, and they had to start moving without the cursor. After 1.5 s, the cursor reappeared. Similarly, after 9.5 s from the start, the cursor disappeared again and they had to try to reach the goal without it. White noise, as well as the metronomic sounds, was played through headphones (RP-WF7-K, Panasonic) to mask any pen scratching sounds. The refresh rate of the monitor was 60 Hz.

In my previous study (Asai, 2015), two kinds of visual feedback were presented: SELF or OTHER movement. The following is a summary. In the self-movement condition, participants received the visual feedback of their own pen movement as the cursor movement; in the others’ movement condition, they received cursor movement that was independent of their own pen movement. This was, however, actually their own pre-recorded movement that was secretly recorded in a practice session. This might be most preferable (e.g., Asai, 2015; Kaneko and Tomonaga, 2011), since the motor property is supposed to be almost the same between their own pen movement and OTHER movement. Because of this procedure, participants had to make agency judgments (see below), not on the basis of the difference in motor property (e.g., individualism) or on the aforementioned onset or offset timing between their own pen movement and the cursor movement, but by using online spatio-temporal correspondence between them during visually guided reaching (Asai, 2015).

The current experiment further applied this procedure to measure subjective agency in a continuous manner. Participants received the morphed visual feedback (i.e., cursor movement) between SELF and OTHER movement. There were 11 continuous conditions: self 0% (=other 100%) to self 100% (=other 0%) with every 10% step. The morphing policy was simple. The Euclidian distance between a participant’s own pen position and his/her pre-recorded one was calculated at every moment (60 Hz, synchronized with the refresh rate of the monitor) and the actual cursor position to be presented on the monitor was determined according to the morphing ratio. For example, under the self 50% condition, participants observed the cursor movements right in the middle between their own and others’ movements.

Fig. 2. Experimental set-up and motion morphing manipulation. Note: the motion morphing technique enables us to manipulate between self- and other-originated movement continuously such as self 0% (other 100%) to self 100% feedback. For example, under the self 50 % feedback condition, participants observed the cursor movements right in the middle between their own and others’ movements.
Before the main experiment, participants were briefly trained to get accustomed to the device and procedures. In the practice trials, they just traced the target with the cursor as accurately as possible, and those movements were secretly recorded. These recorded movements were then used later in the main experiment as OTHER movement (see above). There were 40 practice trials, but the first ten were not used as the other-movement because participants had not yet become accustomed to the procedure: the other-movements were randomly chosen from the other 30 recorded movements. After that, they conducted the main experiment, which consisted of 110 trials (ten repetitions for each of the 11 morphing conditions) in a random order. Each trial took approximately 30 s and the total time for the current experiment including the questionnaire (see below) was within 2 h. Recorded movements were also used as a control variable in the subsequent analysis, where the accumulated vertical distance between the cursor position and the targeted sin wave line was calculated for participants’ movement error as the basis of their motor control performance (Asai, 2015).

2.4. Questionnaire

To assess the individual differences in schizotypal personality traits (schizotypy), the Japanese version of the self-report Oxford-Liverpool Inventory of Feelings and Experiences (O-LIFE, Mason et al., 1995) was administered after the experiment. The validity and reliability of this questionnaire have been confirmed (Asai et al., 2011). O-LIFE was chosen instead of other often-used schizotypy scales like the Schizotypal Personality Questionnaire (Raine, 1991), for the whole schizotypy, and the Magical Ideation Scale (Eckblad and Chapman, 1983), for specific symptom-like experiences, because it was newly developed, on the basis of those existing scales, for measuring comprehensive schizotypy with subfactors. In addition, it is important to use one self-report measure with distinct and interconnected subscales pertaining to schizotypy in order to control for potential confounders. O-LIFE is a 104-item true-false self-report questionnaire and has a four-factor structure: Unusual Experiences corresponding to positive symptomatology; Cognitive Disorganization corresponding to disorganized symptomatology; and Impulsive Nonconformity. The last factor, which refers to antisocial behaviors (disinhibited, violent, self-abusive, and reckless), emerges only in O-LIFE-measured schizotypy, indicating O-LIFE’s full coverage of schizotypal dimensions. The possible scores on this scale range from 0 to 104 (0–30, 0–27, 0–24, and 0–23 for the four subscales, respectively). Among these subscales, it was hypothesized that positive schizotypy (Unusual Experiences in O-LIFE) would be associated with the experimentally defined slope in the self-other discrimination task in the current study.

3. Results

The agency ratings for each morphing condition were averaged. Even though participants didn’t know about the morphing procedure, their subjective rating of agency linearly corresponded to the morphing ratio generally (estimated psychometric function or regression line: (agency rating)=−1.77+0.051×(morphing ratio), r=0.71 for 104 participants). It seems that participants could accumulate evidence (successful prediction errors) to feel agency over the whole cursor movement in each trial, indicating that agency is, theoretically, a continuous representation as a result of the probability estimation based on the accumulated prediction errors (i.e., Izawa et al., 2015).

In order to examine individual differences in terms of schizotypy, the 104 participants were simply divided into two groups on the basis of the median split in each score of schizotypal factors (positive, negative, disorganized, and impulsive schizotypy). If the median split was in the middle of the same-score participants, they were sorted on the basis of the O-LIFE total score and then the median split was applied again. As a result, high (N=52) or low (N=52) groups were identified for each schizotypy factor. The upper panels in Fig. 3 represent the relationship between the morphing ratio and agency rating in those two groups. Subsequently, in order to compare the slopes in those two groups, a regression line was fitted with each participant’s data and the estimated slope values received a t-test with group as the dependent variable. A significant group difference was revealed in positive schizotypy (t(102)=4.85, p < 0.05, Cohen’s d=0.44)
but not in other schizotypy factors \([t(102)]=0.00, p>0.50, \text{Cohen’s} d=0.02]\) in negative, \([t(102)]=1.00, p>0.30, \text{Cohen’s} d=0.20]\) in disorganized, and \([t(102)]=0.34, p>0.50, \text{Cohen’s} d=0.12]\) in impulsive schizotypy (Fig. 3, lower panels). The estimated regression line in the low positive group was \([\text{[agency rating]}]=-1.98+0.055\times(\text{morphing ratio}), r=0.73\) for lower 52 participants, while that for high positive group was \([\text{[agency rating]}]=-1.56+0.046\times(\text{morphing ratio}), r=0.69\) for upper 52 participants. The two regression lines are supposed to cross at the point \([46.7, 0.59, 0.59\text{[agency rating]}]\). This point is approximately right in the middle of the possible scoring range \([0–100\text{[morphing ratio]}], -4 \to +4 \text{[agency rating]}\), indicating that the two lines rotate around the approximate center point. Regarding potential gender differences, since the current sample unfortunately included many more females than males, it is difficult to make a fair gender comparison. I provide the result of gender difference as Supplementary information for readers’ interest (Fig. S1), though there was no significant gender difference revealed.

These results support the current hypothesis, where the slope is deeper (higher discriminability between self-other movements) for low schizotypy group and the two psychometric functions of agency cross (see Fig. 1). The follow-up correlation analysis was congruent with the group comparison. The correlation between the slope and positive schizotypy score with other schizotypy dimensions (negative, disorganized, and impulsive) controlled was significant (partial correlation, \(r=-0.20, p<0.05\)). This was necessary because the group comparison didn’t control for other potential confounding factors. In addition, participants’ motor performance (the accumulated vertical distance between the cursor position and the target sine wave line) recorded in practice session was not correlated with any schizotypy scores \((r=0.09\text{[positive]}, r=0.09\text{[disorganized]}, r=0.15\text{[negative]}, \text{and} r=0.06\text{[impulsive]}\) or with slope \((r=0.02)\). Therefore, when motor performance was also ruled out as well as other schizotypy dimensions in the partial correlation analysis, the correlation between the slope and positive schizotypy was still significant \((r=-0.20, p<0.05)\). Though people with schizotypy (and also schizophrenia) might have sensorimotor deficits, their motor deficits might only emerge in motor prediction (e.g., Asai et al., 2008), not in general motor performance (e.g., Asai et al., 2009; but Lenzenweger and Maher, 2002). Theoretically, motor prediction must always affect motor performance. This is especially true for “ballistic” movement (no utilization of sensory feedback). It is difficult to distinguish between motor prediction and motor performance by task. However, we can observe significantly or less affected motor performance even in patients with schizophrenia (e.g., Goldberg et al., 1993; Goldberg and Weinberger, 1988). This is possible because we can utilize the feedback control of an action (e.g., Asai, 2015), for example, like visually guided reaching in the current study. Even when patients have deficits in their motor prediction and those deficits affect their motor control, their poor motor control might be corrected or adjusted by visual feedback. In this situation, if we examine this additional correction in detail (e.g., trajectory, RT, and so on), we might find something important by using a special task for that purpose (e.g., Frith and Done, 1989). The current measure (accumulated simple movement error in visually-guided reaching), however, didn’t reveal potential individual differences. This doesn’t mean that their motor performance was not affected. Rather, their motor performance was superficially normal with an additional strategy that includes (meta)cognitive compensation, though the cognitive process for agency might also be impaired or over-driven as a result in schizophrenia (Sznyczik et al., 2010; van der Weiden et al., 2015 for review)(see also 4.3. Motor prediction or cognitive expectation).

Finally, in order to examine the interaction (positive schizotypy x morphing ratio), the hierarchical multiple regression analysis was conducted with rating as the dependent variable. For the first step, the morphing ratios and the positive schizotypy scores were submitted as independent variables. As a result, the morphing ratio significantly predicted the self-other rating \((\beta=0.71, t=33.6, p<0.001)\) while positive schizotypy didn’t \((\beta=-0.02, t=-0.86, p=0.39)\), as expected. For the second step, the interaction (the normalized morphing ratio x the normalized positive schizotypy score) was submitted as the independent variable and, as a result, this effect was significant at this stage \((\beta=-0.043, t=-2.05, p<0.05, \Delta R^2=0.002)\), supporting the above-mentioned group-comparison results (see Fig. 3). At last, a strong negative correlation between the slope and y-intercept \((r=-0.90, p=0.00)\) suggests that the “pivot” is somewhere in the first or fourth quadrant statistically in definition, because a positive correlation between them would mean a pivot in the second or third quadrant (this would mean no crossing in the possible scoring range of the current experiment). See also Fig. 4 for the graphical relationship between the slope and y-intercept among participants. Even when y-intercept was partialed out, the correlation between positive schizotypy and the slope was still significant \((r=-0.20, p<0.05)\). In what follows, the current results are discussed in terms of the essential methodological issue for measuring agency that has yielded the two-
tailed results in patients with schizophrenia.

4. Discussion

The current study examined individual differences in self-other sensory discrimination in motor control in terms of schizotypal traits. The deeper slope in stimuli-response coordination for low-positive schizotypal participants indicated higher discriminability, while high-positive schizotypal participants exhibited a shallower slope. This result is congruent with many previous studies that indicated “anomalous” agency for patients with schizophrenia and also schizotypal people, especially with the finding that disturbed agency is associated with their positive symptomatology (see for review, Cannon, 2015; Izawa et al., 2015; van der Weiden et al., 2015). The newly revealed finding in the current study, however, is that the psychometric functions of agency for high and low schizotypal participants crossed in the middle of the stimuli axis, which could cause the twisted misattribution errors at the same time (see Fig. 1). This was revealed because the current experiment used newly developed self-other morphing stimuli that allow us to see the wide range of agency response continuously. This is in contrast to most previous studies, which targeted a narrower range (some biases were inserted into self-movement or just self-or-other stimuli were given, see below for details). This is thought to be a methodological limitation that had produced superficially contradicting results (Hur et al., 2014; Waters et al., 2012). Indeed, they are not contradictory at all, which is what the current study wants to say.

In theory, when we do an action, we can predict its sensory consequence by using the forward model (Wolpert and Miall, 1996). In the current experiment, participants could predict their own arm movement (i.e., spatio-temporal position) and could therefore detect the prediction error between the predicted and actual cursor position. The brain might calculate this prediction error by probability distributions since both prediction and actual sensory inputs include inevitable noise (Bays and Wolpert, 2007), where the distance between the two distributions is thought to be the prediction error. Here the large error means other-agency. In addition, people with schizophrenia or schizotypal people might have a broad prediction with higher variance due to their unoptimized forward modeling. Patients have exhibited increased variability when predicting the visual feedback of their own movement in the absence of visual feedback (Synofzik et al., 2010). In addition, higher schizotypal participants point to a target more deviately without visual feedback (Asai et al., 2008). These studies suggested that their motor prediction is unoptimized and therefore becomes more distributed from trial to trial. In this case, over-lapped distributions must cause lower discriminability (i.e., a shallower slope) in stimuli-response coordination, and, more importantly, cause two-tailed detection errors (both miss and false alarm) compared to people with higher discriminability (Fig. 5).

4.1. Measuring agency in motor control

Asai (2015) discussed the methodology for measuring agency in motor control. So far, technically, there were two possible paradigms: feedback alteration and alien feedback. The former requires participants to judge self or other in response to biased feedback of their own action (e.g., Asai and Tanno, 2007; Franck et al., 2001; Johns et al., 2001). In the latter, either an experimenter performs an action similar to that performed by the participants (e.g., Daprati et al., 1997; Johns et al., 2001) or the pre-recorded feedback of others or even their own pre-recorded movement is presented (e.g., Asai, 2015; Johns et al., 2006; Kaneko and Tomonaga, 2011; Werner et al., 2014). These two paradigms have advantages and disadvantages (Asai, 2015; Asai and Tanno, 2012). The feedback-alteration task is susceptible to response bias since participants might realize that there is nobody else performing an action (e.g., Wegner, 2003). In this sense, the alien-feedback task is preferable, where there is an actual others’ feedback that is not coming from the participants. However, when we apply the alien feedback task, there are also some concerns. First, we have to be careful of an inevitable asynchrony between the participants’ and others’ actions (e.g., Werner et al., 2014) because participants can attend only to onset timing in making self-other judgments (see also Method again). Second, the alien feedback task, unlike the feedback alteration task, makes it difficult to manipulate the stimuli continuously: participants are always given “extreme” stimuli that might make it difficult to detect the slight differences between groups (i.e., a ceiling or flooring effect where the responses in both groups are saturated). Indeed, anomalous agency in schizophrenia might be detectable only in the “ambiguous” condition (Moore and Fletcher, 2012). The newly developed morphing task has overcome these problems by combining the two above-mentioned agency paradigms.

4.2. What is “pure” agency sensation in our sensorimotor system?

This methodological issue is not only about measuring agency. Theoretically, when self-like sensory information is given, patients make a MISS response for self-attribution, while they make an FA response for other-like information (see Fig. 1). Previous studies that suggested the former case (“other” response for self-stimuli) examined agency in the visuo-motor (using a digitizing tablet, Werner et al., 2014) or audio-motor (using a online speech conversion system, Johns et al., 2001) domain. On the other hand, previous studies that suggested the latter case (“self” response for other-stimuli) also conducted visuo-motor correspondence tasks (joystick manipulation (Franck et al., 2001) or used hand action (Daprati et al., 1997)). What is the difference between them, where the opposite attribution patterns have been suggested? It seems that we can see the difference in the specific procedures rather than in the targeted domain since some of those studies focused on the same visuo-motor domain.

A possible explanation concerns whether the required action (i.e., the correspondence between a motor command and sensory feedback) is “embodied or disembodied” (David et al., 2008b). Embodied action here means participants do not need additional learning of that correspondence for experimental tasks. For example, without learning or adaptation, participants can make a reaching movement with visual feedback on a monitor by using a digitizing tablet. This is because the visuo-motor correspondence is almost the same as the reaching movement with a visual of our own arm, which should be already learned over the years. However, if a joystick is used instead of a digitizer for example, participants have to learn its visuo-motor correspondence for the task de novo because tilting a joystick is converted into two-dimensional cursor movement and the conversion formula depends on the experimenter. In this disembodied action, even participants’ own nonbiased feedback might not produce a strong agency sensation in nature just after participants’ arbitrary adaptation, compared with that in the embodied action. This stimulus might still be not-so-self-like or other-like in our sensorimotor system so that the FA response is observed for patients. On the contrary, what about the biased feedback in an embodied action? Though participants’ own severely biased feedback might be regarded as others’ stimuli (should be attributed to others), at least a stereotypical or fixed bias (e.g., angular rotation) might soon be learnable to some extent during experiments (Imamizu et al., 2003). In this sense, even biased feedback in embodied action might still produce a weak agency sensation. This stimulus might still be not-so-other-like or self-like so that the MISS response is observed for patients. The self-other axis might represent the embodied-disembodied continuum: the maximum embodied action can produce totally controllable (or predictable) feedback, while the maximum disembodied action produces never-controllable feedback. In other words, the embodied action (even biased one) cannot produce never-controllable (i.e., others’) feedback, while the disembodied action (even a nonbiased one) cannot produce totally controllable (i.e., self) feedback (see Fig. 1).
Some studies, however, have implied that such people with schizophrenia have no awareness of being ill when they have high agency judgment (over- or under-attribution) in people with schizophrenia might be cognitive expectation (van der Weiden et al., 2010). Another possible explanation of the pattern of attribution error in schizophrenia or schizotypy depends on the S/N ratio (self/other ratio) of the stimuli (see also Fig. 5) and that S/N ratio might also be determined by the “embodiedness” of the action: embodied action would produce a higher S/N ratio, while disembodied action would produce a lower one in terms of motor prediction. For example, patients with schizophrenia exhibited over-attribute-intribution in joystick manipulation as a disembodied action (Franck et al., 2001), while they exhibited under-attribute-intribution in reaching on a digitizing tablet as an embodied action (Werner et al., 2014). Compared to patients, healthy people with elevated schizotypal traits seem to have a tendency to exhibit under-attributions (Asai and Tanno, 2007, 2008, 2012). This might be because high schizotypes can learn experimental requirements (e.g., motor control using some devices) more easily or quickly than patients with schizophrenia, where the required action would be more embodied (i.e., controllable) for healthy participants. As stated earlier, under-attributed agency should be observed for people with schizophrenia or schizotypy only within the range of embodied action (see Fig. 1). Hence, even the same motor control task could produce the opposite attribution errors between schizophrenia and schizotypy: over-attribute-intribution for patients and under-attribute-intribution for schizotypy. The experimental requirement in a motor control task might be harder to be embodied for patients so that the over-attribute-intribution should be more observed for them, depending on the task difficulty.

4.3. Motor prediction or cognitive expectation

To what extent, however, the action is embodied or not is difficult to see and this interpretation therefore still includes speculations. Another possible explanation of the pattern of attribution error in schizophrenia might be cognitive expectation (van der Weiden et al., 2015). If our motor prediction is less reliable and we know this even implicitly, cognitive inference or compensation for agency judgment might be driven (Moore et al., 2009; Synofzik et al., 2008). Patients with schizophrenia have no awareness of being ill when they have high confidence in their thoughts (Joyce, Averbeck, Frith, and Shergill, 2013). Some studies, however, have implied that such people “know” that their motor prediction is imprecise or unoptimized (e.g., Asai and Tanno, 2012; Synofzik et al., 2010) suggesting that the weighting or reliability for their motor prediction is reduced. As a result, they can take an additional strategy to compensate for its poorness; for example, they can put more weight on external cues than on internal ones (Synofzik et al., 2010; Werner et al., 2014). This cognitive compensation could be escalated from the sensorimotor level for motor control to a higher cognitive level like thought in terms of a hierarchic Baysien framework (Fletcher and Frith, 2009), thereby producing a high confidence in their weird belief as a by-product, without any error correction process. Since it is still unclear whether the twisted agency judgment in schizophrenia is the result of this exaggerated cognitive compensation or the result of unoptimized motor prediction alone, further study needs to consider how self or other sensation is discriminated and attributed in nature within our sensorimotor system both perceptually and cognitively. This would contribute to understanding the mechanism of agency and also its disturbance.

4.4. Conclusion

The current study explained schizotypal twisted self-other feelings in terms of the psychophysics of agency. Unless we manipulate self-other stimuli from one end to the other, two-tailed results will be observed independently for patients with schizophrenia. Since the current experimental procedure morphed between uncontrollable others’ movements and controllable participants’ own movements, the twisted agency response associated with schizotypal positive traits was revealed for the first time. For an accurate measure of agency in schizophrenia, we first have to develop a measurement tool for it. Schizotypal studies will be useful for optimizing such a tool because we can easily access schizotypal personality traits in healthy people in the general population and because there are fewer experimental constraints for them.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.psychres.2016.10.082.
References


