Why must we attribute our own action to ourselves? Auditory hallucination like-experiences as the results both from the explicit self-other attribution and implicit regulation in speech

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A R T I C L E  I N F O

Article history:
Received 26 April 2012
Received in revised form 10 September 2012
Accepted 12 September 2012

Keywords:
Sense of agency
Speech
Auditory hallucination proneness
Explicit self-other attribution
Implicit action regulation

A B S T R A C T

The sense of agency, which is the awareness that “I am the one who causes action,” is important in understanding passive schizophrenic symptoms and bodily self-consciousness. However, this potential linkage between subjective self-other attribution (explicit agency) and automatic self-monitoring of an action (implicit agency) has not been examined fully. The present study included two experiments conducted with the same group of healthy participants (N=48) in order to examine explicit (Exp. 1) and implicit (Exp. 2) measures of the sense of agency in speech. Exp. 1 suggested that participants who tend not to attribute a fed-back voice to themselves (the other-attribution group) might have a stronger tendency toward auditory hallucinations, as measured by the Auditory Hallucination Experience Scale 17 (AHES-17). Furthermore, the results of Exp. 2 suggested that this other-attribution group might not utilize auditory feedback during speech production, indicating the expected link between explicit and implicit agency. These results are discussed in relation to the sense-of-agency model, wherein people are understood to construct the online “self” monitoring of action.

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1. Introduction

The sense of agency — the awareness that “I am the one who is causing an action” — has attracted many researchers in various fields, as this sense might constitute a core component of the self and be underpinned by neural mechanisms (David et al., 2008; Gallagher, 2000). On the other hand, the term “sense of agency” has recently come to include more concepts than the original definition, e.g., “disembodied action,” which includes relationships such as that between key pressing and generated tones or visual stimuli (e.g., Cardoso-Leite et al., 2010; Sato and Yasuda, 2005). The original definition of sense of agency was a sense of “embodied action,” including relationships such as that between arm movement and visual feedback (Asai and Tanno, 2007; David et al., 2008). In addition, we also distinguish between higher and lower levels of agency (explicit “judging” and implicit “feeling,” respectively) (David et al., 2008; Synofzik et al., 2008). Though these two levels of agency could be dissociated from each other (e.g., Nielsen, 1963), they should be connected if controlled by the same neural mechanisms. Since explicit judging of agency could be subject to response bias (Wegner, 2003), implicit measures for agency (e.g., Gentsch and Schutz-Bosbach, 2011) have been developed. In addition to moving beyond subjective or explicit self-other judgments in order to develop objective or implicit measures of the sense of agency, we need to examine the potential relationships between explicit and implicit agency.

On the other hand, sense-of-agency research has been developed in tandem with schizophrenia research, because schizophrenia might be a disorder of agency (David et al., 2008; Gallagher, 2004). Many people with schizophrenia describe a sense of passivity, in that their experiences seem to have been created for them by some external agent (Gallagher, 2000). For example, one’s own speech could seem to consist of auditory hallucinations (McGuigan, 1966). The most influential theory proposes that auditory hallucinations occur when failure to recognize self-generated thoughts and actions (Feinberg, 1978; Jones and Fernyhough, 2007) is accompanied by false beliefs that these arise from external agents (Waters et al., 2010). The activation of Broca’s area, which is related to speech production but not comprehension, has also been associated with auditory hallucinations (McGuire et al., 1993). In addition, verbal self-monitoring (McGuire et al., 1996a, 1996b) might be impaired in schizophrenia patients who fail to activate cortical areas underlying normal monitoring of inner speech or verbal imagery (McGuire et al., 1996a, 1996b) or whose cortical maps of the self and non-self overlap in terms of verbal monitoring (Jardri et al., 2011a). These studies have been followed up by meta-analysis (Jardri et al., 2011b). Therefore, affected people may produce

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0165-1781/$ - see front matter © 2013 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.psychres.2012.09.055
actual or inner speech while believing that they did not produce it; they may hear their own voices as those of others or recognize their own verbal imagery/thoughts as those of others, even without producing audible output (Jones and Fernyhough, 2007; McGuire et al., 1996a, 1996b). The abnormal sense of agency in schizophrenia is a consistent finding (e.g., Waters et al., 2010).

External misattribution of agency has also been observed in healthy people with schizotypal personality traits (schizotypy) (Asai and Tanno, 2007, 2008; Johns et al., 2010; Sugimori et al., 2011a, 2011b). Schizotypal people, who can be identified via questionnaires or semi-structured interviews, may be predisposed to schizophrenia. Schizotypal traits may be expressed on a spectrum of schizophrenic disorders, and that range is at least partly genetically determined (Cyhlavova and Claridge, 2005; Hommes et al., 2011; Raine, 2006). Although schizotypal people may experience schizophrenic-like experiences, including auditory hallucinations, many can live normal lives (Daalman et al., 2011; Sommer et al., 2010). Individual differences in schizotypy have commonly been explored as a means of examining the nature and structure of schizophrenia symptoms and providing opportunities to study the markers of vulnerability to schizophrenia without the confounding effects of long-term hospitalization, medication, and severe psychotic symptoms (Raine, 2006). This distinction is especially salient for auditory verbal hallucinations, which are experienced by a considerable proportion of the general population (Badcock and Hgdahl, 2012). The similarities between healthy and psychotic patients, including the perceived location, number, loudness, and personification of voices, have been observed; differences between those groups include the emotional valence and frequency of the voice content and the degree to which subjects had control over their experiences (Daalman et al., 2011).

Although people with schizophrenia or schizotypy might have an abnormal sense of agency both at the explicit and implicit levels (Asai et al., 2008; Asai and Tanno, 2007; Blakemore et al., 2000; Delevoye-Turrell et al., 2003; Ford and Mathalon, 2004; Frith and Done, 1989; Hauser et al., 2011a, 2011b; Johns et al., 2001, 2006, 2010; Lindner et al., 2005; Sugimori et al., 2011a, 2011b; Synofzik et al., 2010), a comprehensive understanding of these has not been examined yet. The aim of the present study is to examine the relationships between both implicit and explicit measures of agency and schizotypal experiences in healthy participants due to abnormalities in the sense of agency at both the explicit and implicit levels. We focus on speech as an action, because auditory verbal hallucinations are a major symptom of schizophrenia (Chibbaro et al., 2005; Waters et al., 2012) and because previous results about agency in speech, including recordings of primate auditory neurons (Eliaides and Wang, 2008), have been coherent (Waters et al., 2012).

Experiment 1 examined explicit agency, the standard procedure for which consists of measuring subjective judgment of self-other attribution in the relationship between motor commands and sensory feedback. When required to make judgments about the origin of hand actions or movements on the basis of biased feedback (self-action recognition task), patients with schizophrenia and schizotypal individuals were more likely than normal controls to misattribute their own actions (Asai and Tanno, 2007; Daprati et al., 1997; Franch et al., 2001); this trend might be related to delusions of control (Synofzik et al., 2010). Moreover, schizophrenic patients who experience auditory hallucinations tend to misattribute their own speech (e.g., Johns et al., 2001, 2006). Therefore, we administered the speech attribution task in experiment 1 to measure explicit agency.

Previous studies suggested that attribution of agency is associated with detection of perceptual incongruity, i.e., the comparison of actual sensory information with the predicted consequences of action on the basis of internal, action-related signals, such as efference copies (David et al., 2008). However, our sense of agency is not always tantamount to the detection of incongruency cues: other factors may also contribute to explicit agency (Asai and Tanno, 2007; Synofzik et al., 2008; Wegner, 2003). We sometimes feel agency even under mismatch between the predicted and actual consequences of our own actions, as long as such mismatch is small and allowable (Asai and Tanno, 2007); this effect is observable even at early ages (Miyazaki and Hiraki, 2006). This positive bias toward feeling agency may allow agency to result from disembodied actions, including external agents, objects, or events (David et al., 2008), which must have inevitable mismatches like spatial or temporal bias. Schizophrenic individuals cannot detect perceptual mismatches well (Fourneret et al., 2001; Knoblich et al., 2004; Synofzik et al., 2010), and the phenomenon of schizophrenic passivity may result from a deficit in this extended comparator model (Synofzik et al., 2008). There may be an absence of a positive in terms of agency (Asai and Tanno, 2008) or schizophrenic patients may not feel explicit agency even when they do not detect perceptual mismatch. Accordingly, we compared detection of perceptual mismatch with explicit attribution of agency. We defined the other-attrtribution group (those who would not attribute feedback to themselves even without perceptual mismatch) and the self-attribute group (those who have the same positive bias of agency as the general population; Fourneret and Jeannerod, 1998). Although such individual differences have been examined in people with schizophrenia and normal controls (Daprati et al., 1997; Fourneret and Jeannerod, 1998; Franch et al., 2001; Synofzik et al., 2010), explicit sense of attribution and perceptual mismatch are usually not distinguished. Some studies have required participants to report the agent of action (self or other, e.g., “You have just seen the image of a moving hand. Was it your own hand?”) (Daprati et al., 1997), whereas others required participants to detect perceptual mismatches (such as, “Did the movement you saw on the screen exactly correspond to [that which] you have made with your hand?”) (Franch et al., 2001). In order to distinguish the abnormal, schizophrenic sense of agency from general dysfunction of cognition and perception (Daalman et al., 2011; van Os and Kapur, 2009), we should discuss explicit attribution of agency with reference to the detection of perceptual mismatches.

Experiment 2 examined implicit agency. Explicit agency is sometimes assumed to be closely related to action regulation or perceptual processing, wherein it is essential to discriminate between self- and externally oriented stimuli (Feinberg, 1978; Miall and Wolpert, 1996; Wolpert, 1997). Sensory processing related to the self is a possible expression of implicit agency (Cardoso-Leite et al., 2010; Synofzik et al., 2008). The most plausible mechanism for such would be the prediction of sensory outcomes on the basis of the computational model of agency (Blakemore et al., 2000; Jones and Fernyhough, 2007; Miall and Wolpert, 1996; Seal et al., 2004), based on such data as reaching trajectory (Asai and Tanno, 2008), sensory attenuation (Gentsch and Schütz-Bosbach, 2011), and online correction of action (Frith and Done, 1989). People with schizophrenia or schizotypy might be impaired in these aspects of sensory prediction. Frith and Done (1988) showed that schizophrenic patients are unable to rapidly correct their arm movements through feedback; further, people who have auditory hallucination-like experiences may have abnormalities in regulation of self-oriented predictive action (Asai et al., 2008). People with schizophrenia or schizotypal features showed more accurate force matching than controls, suggesting that they have a reduced tendency to predict and attenuate the sensory consequences of self-generated actions (Shergill et al., 2005; Teufel et al., 2010).

We focused on the online correction of speech as a predictor of implicit agency in experiment 2 because this phenomenon could have a strong linkage with the explicit sense of agency: the feedback
for online correction that is labeled as coming from oneself might be given enhanced priority over other forms of feedback (see the general discussion for a description of the computational model of agency). We focused on online monitoring (correction in speech) according to an implicit sense of agency as analogous to visual online correction of reaching movements (Asai et al., 2008, 2009; Nielsen, 1963): this can apply to both speech regulation and volume control, depending on online auditory feedback. This speech monitoring can be realized as long as the fed-back voice is attributed to the speaker (Toyomura and Omori, 2005). Asai et al. (2008) showed that people with strong tendencies to experience auditory hallucinations may have deficits in predictive motor control (mouse movement under a no-audio-feedback condition). We investigated speech by employing the predictive speech control paradigm, which requires the participants to trace voice stimuli as targets without auditory feedback.

Previous studies implied a relationship among explicit agency, implicit agency, and schizotypal experiences. Therefore, the comprehensive relationship among these must be examined next, although one study suggested that patients with schizophrenia may have deficits in detection of perceptual mismatches (i.e., distortions), instead instead easily adapting to distorted visual feedback to hand movement (Synofzik et al., 2010). We also examined self-reported schizotypy, including tendencies toward auditory hallucination, among our healthy sample. We then discussed the potential mechanism of auditory verbal hallucinations as atypical in both explicit and implicit agency.

2. General methods

2.1. Participants

Forty-eight university students (aged 18–22 years, mean = 19.3; 22 men, 26 women) participated in the two experiments and questionnaire. None of the subjects had histories of mental disease or hearing difficulties. We obtained written informed consent from all participants before conducting the experiments.

2.2. Apparatus

The experiments were conducted in a soundproof room equipped with a real-time auditory alteration system similar to those used in previous studies (Toyomura and Omori, 2005; Supplementary Fig. S1). Auditory input above and below 1 kHz in frequency was filtered at ±3 dB and ±3 dB, respectively, by using an equalizer to obtain a subjective approximation of each participant’s voice (Shuster and Durrant, 2003). To reduce any effects of bone conduction and to prevent participants from obtaining a subjective approximation of their own voices, pink noise was generated at 70 dB SPL and mixed into the feedback voice using a sound mixer (Toyomura et al., 2007). The subject’s speech was recorded for analysis.

2.3. Questionnaires

After the participants finished the experiments, they completed a battery of questionnaires. The battery included the following questionnaires, all of which except for the Auditory Hallucination Experience Scale 17 (AHES-17) have been translated into Japanese and have good reliability and validity.

2.3.1. Auditory hallucination proneness

The AHES-17 (Asai et al., 2011a) is a shortened version of the AHES (Sugimori et al., 2009); both have been used in previous studies (Asai et al., 2008, 2009, 2011b; Sugimori et al., 2011a, 2011b) to supplement previous scales measuring hallucination (the Launay–Slade Hallucination Scale; Launay and Slade, 1981). Ours was a 17-item self-report questionnaire containing items such as, “I heard someone’s voice, but nobody was actually around.” scored on a 5-point Likert scale. The total possible scores for this scale range from 17 to 85.

2.3.2. Positive schizotypal personality

The Oxford Schizotypal Personality Scale (STA; Claridge and Broks, 1984; Cyliaxova and Claridge, 2005; Gregory et al., 2003) is a 37-item true–false self-report questionnaire based on the DSM-III diagnostic criteria for schizotypal personality disorder. It measures such schizotypal traits as perceptual aberrations analogous to positive symptoms, e.g., auditory hallucinations, thought insertions, and delusions of control. The possible scores on this scale range from 0 to 37.

2.3.3. 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). The SPQB is a 22-item true–false self-report questionnaire that measures schizotypal personality traits. It consists of three subscales: Cognitive–Perceptual (positive schizotypy), Interpersonal (negative schizotypy), and Disorganization (disorganized schizotypy); the possible scores on this scale range from 0 to 22 (0–8, 0–8, and 0–6 for the three subscales, respectively).

2.3.4. Depression

The Self-Rating Depression Scale (SDS; Zung, 1965) is a well-known self-report questionnaire that comprises 20 items; responses are made on a 4-point Likert scale which measures depressive tendencies. Possible scores on this scale range from 20 to 80.

2.3.5. Anxiety

The State–Trait Anxiety Inventory (STAI-T; Spielberger et al., 1970) is a well-known self-report questionnaire consisting of 20 items; responses are made on a 4-point Likert scale which measures anxiety traits. Possible scores for this scale range from 20 to 80. Higher scores on all questionnaires indicate stronger characteristics on the relevant dimensions. The SDS and STAI were used as control measures. We predicted that among schizotypal features, the tendency to experience auditory hallucinations would be particularly related to experimental indices of agency.

3. Experiment 1: Measuring explicit agency

The purpose of experiment 1 was to examine individual differences in the explicit sense of agency in speech. Previous studies have suggested that people, including those with schizophrenia or schizotypy, might not explicitly attribute their own speech to themselves (e.g., Johns et al., 2001, 2010). We identified people who tend to attribute their own speech to themselves (self-attribute group) and people who tend not to (other-attribute group) using two tasks: an explicit self-other attribution task and a detection of audio-motor incongruency task. We assumed that people who feel a weaker explicit sense of agency — that is, those who cannot sense that their actions are generated by themselves — would not attribute auditory feedback to themselves even in the absence of audio-motor incongruency (Asai and Tanno, 2007, 2008).

3.1. Methods

3.1.1. Materials

We used 50 four-mora words (the mora is a prosodic unit in Japanese) selected from an established list of words for speech (Armano et al., 2009) as visual stimuli. The list was controlled for familiarity and phonological balance. We chose the 50 most familiar words in the list for the present experiment (5 for practice and 45 for experimental trials).

3.1.2. Procedure

Participants read the presented words into a microphone. They were required to finish reading within approximately 400 ms after the words were presented, following a countdown from three to one, during which they prepared to speak while viewing the words. The pitch was either unchanged (no distortion) or lowered or raised by 10 cents or 1, 2, 4 semitones (10 cents = 1 semitone) using an effecter and fed back to the subjects through headphones. The experiment included two tasks. In the detection of audio-motor incongruency (distortion) task, after participants heard the fed-back voice, they judged whether it was distorted. In the self-other attribution task, they judged whether the voice was their own. They were asked if the voice intuitively felt as if it were their own or someone else’s, irrespective of their perception of distortion—that is, they could answer that “this is my own voice” even when they could detect distortion, and vice versa. In each task, participants completed 45 trials (five repetitions under each of nine distortion conditions). The orders of the 45 words and the conditions were randomized so that each coupling would be varied among participants. The order of the two tasks was counterbalanced among the participants.
3.1.3. Data analysis

We categorized our participants according to the experimental measure of explicit agency and then compared schizotypy questionnaire scores between these groups. Although most previous studies, including our own (e.g., Asai and Tanno, 2007, 2008), have categorized participants according to self-report questionnaires in which the independent variable is the questionnaire score and the dependent variable is the experimental measure, schizotypal experiences should not be the cause (independent variable) but the effect (dependent variable). Nevertheless, for consistency with previous studies, the supplementary results contain a conventional analysis. When comparing experimental or questionnaire scores, each value was first transformed into a z-score (average = 0, variance = 1), because each of the scoring scales was different.

3.2. Results and discussion

Table 1 includes normative data from Japan and the West, which are drawn from our preliminary surveys and previous studies among Western populations (Annett and Moran, 2006; Fonseca-Pedrero et al., 2009), respectively. The sample means and distributions are broadly comparable to normative values, although the schizotypal personality scores of the current sample are relatively high.

We compared the two tasks by calculating the difference between them under each distortion condition for each participant, and then we averaged the results across distortion conditions: (self-other judgment) − (distortion detection). This index (self-other attribution index) was calculated after translation into z-scores, although similar results were obtained with non-translated values: positive values indicated strong voice self-attribution even when distortion was detected, and negative values indicated that the subject’s judgment of self and other was worse than his/her distortion detection (other attribution). To examine individual differences, we selected the participants with the highest, middle, and lowest self-other attribution indices (the thirds each contained 16 participants). This categorization followed our previous study, in which participants were split into three groups (Asai et al., 2008); however, other studies used different categorization methods, e.g., division into two or four groups and SD splitting. A one-way analysis of variance (ANOVA) with post hoc multiple comparisons (Ryan’s method) confirmed significant differences on this index among these groups (F(2, 45) = 25.2, p < 0.001). We termed the top third the “self-attribution group,” for which a follow-up two-way ANOVA (distortion condition × task) revealed significant main effects of task (F(1, 15) = 23.1, p < 0.001) and condition (F(8, 120) = 44.7, p < 0.001). In this group, responses of “my speech” were significantly more frequent than the results of a comparison between high- and low-AHES groups (F(2, 36) = 17.8, p < 0.001) (Fig. 1); this indicated that they sometimes attributed undistorted fed-back voices to others. There was no significant difference between the results of the two tasks among the third group. Next, we compared the questionnaire scores of the self- and other-attribution groups (Fig. 2). Only the AHES score was significantly higher in the other-attribution group (M = 59.1, SD = 7.77) than in the self-attribution group (M = 52.4, SD = 8.22) (F(15) = 5.32, p < 0.05). Psychologically pathological states (depressive and anxiety) and other schizotypal features (negative, disorganized, or positive schizotypy) were not significantly different between the groups (ps > 0.05), indicating that people who attribute their own speech to others might experience auditory hallucination-like experiences. This finding is in line with previous studies (e.g., Johns et al., 2001, 2010), though most previous studies that examined individual differences related to schizophrenia divided subjects according to questionnaire scores (e.g., high- vs. low-schizotypy groups: Asai and Tanno, 2007, 2008).

The present experiment divided participants into explicit agency groups according to their subtraction scores between the explicit attribution and distortion detection tasks, since the latter serves as a baseline for the former. An experiment-based individual-difference study suggested that even healthy participants could be divided into agency groups on the basis of hand-movement monitoring abilities (Fournier and Jeannerod, 1998); these agency groups showed completely opposite performances compared to baseline, as in the present experiment. On the other hand, high-positive schizotypal participants attribute little explicit agency to themselves, whereas they detect mismatches as effectively as participants with low-positive schizotypy (Asai and Tanno, 2007). Further, low-positive schizotypal participants may be biased toward the sense of agency, whereas high-positive schizotypal participants may not (Asai and Tanno, 2008). In the present experiment, the explicit self-other attribution score was used to divide participants into groups; group assignment was not based on schizotypy scores, because schizotypal experiences may not be the cause (independent variable) but the effect (dependent variable). We then compared the implicit measure of agency between these two groups in the following experiment. (We also provided the results of a comparison between high- and low-AHES groups in Supplementary Fig. S2, which indicates that the high-AHES group could neither detect non-distorted self-speech nor attribute non-distorted self-speech to themselves).

4. Experiment 2: Measuring implicit agency

In our second experiment, we examined feedback control in action (in this case, speech) as a measure of implicit agency; we assumed that people who do not experience explicit agency upon
hearing the feedback voice would not utilize that feedback in speech control because it was apparently not their own voice. We employed the predictive speech control paradigm, which requires participants to trace voice stimuli as targets without auditory feedback. We calculated the similarity between the target and participants' own speech. If a subject did not attribute the feedback voice to himself/herself, he/she would trace targets equally – even without auditory feedback – rather than depend on the voice of another. In addition, the Lombard effect (Lombard, 1911), which is used as a measure of feedback utilization, asserts that speakers adjust their vocal output/speech intensity depending on the level of background noise (Lane and Tranel, 1971). Such online monitoring of speech production might emerge even in non-humans (e.g., in budgerigars; Manabe et al., 1998). If the Lombard effect causes speech production to vary their coupling among participants.

4.1.3. Data analysis

To calculate the similarities between the targets' and participants' speech, we used an algorithm in MATLAB called Dynamic Time Warping (DTW; Ellis, 2003) to accommodate differences in timing between sample words and templates. The basic principle is to allow a range of “steps” within the time frames of the sample and template to find the path that maximizes local matching between the aligned time frames. The total “similarity cost” found by this algorithm is a good indication of how well the sample and template match which can be used to choose the best-matching template (Ellis, 2003). Many studies have used this algorithm to compare voices or identify speakers or sounds, including whale songs (Brown and Miller, 2007) and human footsteps (Itai and Yasukawa, 2008). Because this value is affected by the vocal differences between sexes (e.g., length of vocal cords, fundamental frequency (F0), and tonal features), we included only same-sex stimuli (e.g., male target voices for male participants) in statistical analysis. Smaller values of this similarity measure indicate better performance in tracing the target. To examine the Lombard effect, we also calculated root mean square (RMS) speech volume for each speech production event—larger RMS values indicate louder speech volume. The Lombard effect is defined as the difference in volume between the auditory-feedback and no-auditory-feedback conditions.
4.2. Results and discussion

We examined the relationship between speech-trace similarity, speech volume, and the presence vs. absence of auditory feedback within the other- and self-attribution groups (Figs. 3 and 4). Using speech-trace similarity as the dependent variable, a two-way ANOVA (group × feedback) revealed that the interaction was significant ($F(1, 30)$=5.39, $p<0.05$), and the simple main effects of group under the auditory-feedback condition ($F(1, 60)$=4.00, $p<0.05$) and of feedback in the self-attribute group ($F(1, 30)$=7.74, $p<0.01$) were also significant (Fig. 3). The self-attribute group traced the targets less well without auditory feedback, suggesting that their online monitoring, i.e., corrections to speech production, depended on auditory feedback. The other-attribute group traced the targets equally well with vs. without auditory feedback, suggesting that they might not self-monitor their speech or depend on auditory feedback for speech production. This could have occurred because they did not perceive the feedback voices as their own. This finding conforms to previous studies showing that when people who experience auditory hallucinations produce speech, the event-related-potential response is similar to that observed upon hearing speech produced by another; this suggests that other-attribution of the feed-back voice may be due to a neurological response (Ford and Mathalon, 2004). If people do not attribute the fed-back voice to themselves, they might not use such auditory feedback in self-monitoring. This finding links explicit subjective feelings and implicit, automatic action regulation. We can also see this relationship in the Lombard effect, as examined below.

Using speech volume as a dependent variable, a two-way ANOVA (group × feedback) revealed that the interaction between the two factors was significant ($F(1, 30)$=4.86, $p<0.05$); the simple main effects of group under the feedback condition ($F(1, 60)$=5.82, $p<0.05$) and of feedback in the self-attribution group ($F(1, 30)$=15.00, $p<0.01$) were also significant (Fig. 4). The self-attribute group tended to speak more loudly without auditory feedback, suggesting the presence of the Lombard effect, contrary to the findings among the other-attribution group. Given that the Lombard effect suggests online monitoring of speech production (Manabe et al., 1998), the results with regard to speech volume are congruent with those for trace similarity; that is, the self-attribute group spoke more loudly without than with auditory feedback so that they could seek and consult the feedback of “their own” voices.

5. General discussion

The aim of the present study was to examine the relationship among schizotypal traits – especially auditory hallucination proneness, self-voice recognition, and speech control (trace similarity and speech volume) – in terms of the sense of agency. The results of Experiments 1 and 2 indicate that subjective self-other attribution affects implicit speech control. When feedback is attributed to oneself, one can use it to make online corrections. This mechanism could construct a loop for online self-monitoring (see Fig. 5). In contrast, the other-attribute group might be accustomed to controlling predictive speech, as they make fewer online corrections. Indeed, they traced targets equally well with or without auditory feedback, and their performance is as good as that of the self-attribute group with auditory feedback (see Fig. 3).

These results can be interpreted according to the model of the sense of agency. Although an abnormal sense of agency in schizophrenia was first suggested by studies of auditory hallucinations (Feinberg, 1978; McGuigan, 1966), the model of the sense of agency has been practically applied to speech only recently (Fig. 5). Previous studies of the mechanism of auditory hallucination proposed a model for the sense of agency in speech that is congruent with the forward model of motor control (Jones and Fernyhough, 2007; Seal et al., 2004). Both models share the idea that motor commands for speech are accompanied by parallel efference copies. The comparator integrates efference...
copies with information about the current system state in order to predict speech outcomes. These researchers suggest that if actual sensory feedback matches prediction, the speech is regarded as emanating from the self. As shown below, abnormal sense of agency could be interpreted by this model; researchers have discussed which of its aspects could be impaired in people with schizophrenia or schizotypy (Frith, 2005).

Some studies have administered explicit agency tasks in which participants made self-other attributions of motor actions or speech (e.g., Franck et al., 2001; Johns et al., 2001). These tasks relied on one or both of two paradigms: feedback alteration and alien feedback. In the former tasks, participants offered self-other attributions in response to biased feedback on movement or speech (e.g., Asai and Tanno, 2007, 2008; Franck et al., 2001; Johns et al., 2001; Sato and Yasuda, 2005). They were either aware that no other person participated in the task and that the feedback associated with their actions was distorted (e.g., Asai and Tanno, 2007; Asai and Tanno, 2008; Franck et al., 2001; Sato and Yasuda, 2005) or were persuaded that another person actually did participate (e.g., Cahiil, 1996). In the alien-feedback tasks, either an actual person (experimenter or assistant) performed an action similar to that performed by the participants while observing their arm or lip movements (e.g., Daprati et al., 1997; Johns et al., 2001), or the pre-recorded voice of another individual was played in response to the speech of participants (e.g., Johns et al., 2006). These tasks have both advantages and disadvantages. Feedback-alteration tasks are affected by experimenter effects and response bias, including demand characteristics (feedback is produced by researchers or confederates) and the exclusivity principle (Wegner, 2003). When an action is not accompanied by conspicuous alternative causes for it (exclusivity), we experience conscious will and ascribe authorship to ourselves (that is, the sense of agency). On the other hand, alien-feedback tasks are affected by inevitable asynchrony between the participants’ and experimenter’s actions. Because participants might attend only to timing in making self-other judgments, these tasks might reflect their perceptual detection of mismatches.

Regarding explicit self-other attribution tasks, most previous studies have shown that people with schizophrenia or high levels of schizotypy might have a weaker sense of agency; that is, they might judge speech feedback as their own less often than controls (e.g., Johns et al., 2001, 2010). However, those studies conflated “attribution” and “detection.” One possible solution is to discuss the sense of agency in terms of the relationship between attribution and detection (Asai and Tanno, 2007, 2008). We hypothesized that the other-attribution group would have a weaker sense of agency and experience more auditory hallucination-like experiences in daily life, even without detecting distortions. This hypothesis was supported by experiment 1. One possible reason for the results of this group is related to Wegner’s priority principle (Wegner, 2003) or efferent-triggered agency (Bulot et al., 2007; Engbert et al., 2008). In addition to the fact that agency requires perceptual matching (simple comparator model or Wegner’s consistency principle (Wegner, 2003)), we experience the sense of agency when a thought or intention appears in consciousness just before an action (priority). The other-attribution group may lack this intention-driven agency (Haggard et al., 2003; Moore et al., 2011; Voss et al., 2010). We therefore need an “extended” or hierarchical model of agency (Synofzik et al., 2008); future studies should examine individual differences using this model.

According to the forward and inverse computational models of speech, participants must first transform the auditory signal (the target or desired state) into motor commands for speech (inverse modeling) to trace the target accurately. This stage might be related to the motor theory of speech perception (i.e., embodied cognition; Liberman, 1957), which suggests that people might perceive spoken words through their own articulation. That is, the generation of the spoken word is important in perceiving speech (e.g., the “McGurk effect”; McGurk and MacDonald, 1976). Once motor commands are generated, the forward model can compare actual with predicted sensory feedback to correct motor commands online when actual feedback becomes available. Deficits in the inverse model would impair target tracing regardless of auditory feedback, because speech is produced by motor commands calculated according to the inverse model under all conditions. As the present study did not find such differences, our results support the forward model rather than the inverse model, as did previous studies (e.g., Asai et al., 2008; Blakemore et al., 2000; Frith, 2005).

The other-attribution group’s better performance in predictive speech control superficially contradicts the notion that schizophrenic people have abnormal action-prediction systems (e.g., Blakemore et al., 2000, 2002). For example, highly schizotypal people with tendencies toward auditory hallucination underperformed compared with low-schizotypy individuals in terms of predictive control of arm movements (Asai et al., 2008).

Fig. 5. Computational model of the speech control and the sense of agency.
However, high-schizotypal people might outperform low-schizotypal people in predictive motor control tasks under some conditions (Asai et al., 2009). The results might depend upon whether the task would involve implicit or explicit predictions. In the study by Asai et al. (2008), participants had to predict their arm movements in each trial, whereas in Asai et al. (2009) and in the present study, the participants did not know whether they had to predict their arm movements (or speech) until they had actually produced them, because the conditions varied according to the presence vs. absence of feedback. Highly schizotypal people might be better at implicit predictive motor control but worse at explicit tasks compared with low-schizotypal individuals. Accordingly, Frith (2005) claimed that implicit, automatic use of forward modeling is unimpaired in schizophrenia and that problems are only seen when patients consciously attend to their actions, referring to studies by Delevoye-Turrell et al. (2003) and Knoblich et al. (2004). Patients exhibited normal anticipatory adjustments of grip force when picking up or holding objects in anticipation of a collision; however, when patients initiated the collisions, adjustment of grip force was abnormally delayed (Delevoye-Turrell et al., 2003). Moreover, patients drew circles on a writing pad connected to a computer and were asked to detect discrepancies between their hand movements and the visual consequences displayed on the computer screen. Patients with positive symptoms were impaired in their awareness of such discrepancies, but not in their ability to automatically adjust their hand movements to compensate for discrepancies (Knoblich et al., 2004). We thus need to consider the functions of implicit and explicit processes in terms of agency (Blakemore et al., 2002).

Other studies have developed implicit measures for agency according to the agency model. The flagship possibility is prediction of sensory outcome, including reaching trajectory (Asai and Tanno, 2008), sensory attenuation (Gentsch and Schutz-Bosbach, 2011), and online correction of action (Frith and Done, 1989). People with schizophrenia or schizotypy might be impaired in sensory prediction: for example, Frith and Done (1988) showed that people with schizophrenia cannot rapidly correct their arm movements by consulting feedback. These findings have also been suggested by neurophysiologic studies. There is electrophysiologic evidence of corollary discharge dysfunction in schizophrenia, showing that a corollary discharge from the frontal areas – where thoughts are generated – failed to alert the auditory cortex that those discharges were self-generated, leading to misattribution of inner speech and the experience of auditory hallucinations (Ford and Mathalon, 2004). Among various predictions of the agency model, we focused on the online correction of action, because this phenomenon could theoretically have a stronger linkage with the explicit sense of agency. For example, the mechanism of sensory attenuation is still unclear and a topic of controversy (Eliades and Wang, 2008). On the other hand, online action correction can be understood in terms of explicit agency: it means that we can correct “our own” actions by using online feedback. To achieve this aim, one first needs to discriminate between feedback from oneself and others. In other words, we can utilize feedback that is labeled as “self” first for online correction, as Experiment 2 suggested.

6. Conclusions

The present study administered two experiments (employing four experimental indices) to the same healthy participants (N=48) in order to assess explicit and implicit measures of the sense of agency in speech. Participants also completed a questionnaire battery, including questionnaires gauging proneness to auditory hallucinations. Our results show that the other-attribute group might not automatically depend on feedback in speech production. The weak sense of agency in speech among this group might cause auditory hallucination-like experiences, i.e., “I am not the one causing the speech.” The promising link between the explicit and implicit sense of agency might also suggest a causal relationship between the sense of agency and motor control, though previous studies have posited that the sense of agency might be the result of action (Synofzik et al., 2008; David et al., 2008). Rather, the sense of agency might affect action execution (see Fig. 5): the sense of agency might be not just a postdictive sense but also a core component of action whereby we must control “our own” actions.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.psychres.2012.09.055.

References


