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Research Paper

Self-monitoring in schizophrenia: Weighting exteroceptive visual signals against self-generated vestibular cues

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ABSTRACT

Disturbances in self-monitoring are core symptoms of schizophrenia. Some research suggests an over-reliance on exteroceptive cues and a reduced weighting of self-generated interoceptive signals to guide perception. The vestibular sense provides important self-generated information about the body in space. Alterations of vestibular function are reported in schizophrenia, but it is unknown whether internally generated vestibular information is discounted in favour of exteroceptive input. In this study, we test for evidence of an over-reliance on exteroceptive visual cues and a reduced weighting of vestibular signals in guiding perception. In a group of individuals with schizophrenia and healthy controls, we used a well-studied visual illusion – the Tilt Illusion – to probe the respective weight given to visual and vestibular cues in judging line orientation. The Tilt Illusion reveals that perceived orientation of a vertical grating is biased by the orientation in its surround. This illusion increases when the head is tilted, due to the reduced reliability of vestibular information that would otherwise provide an internally generated reference for vertical. We predicted that an over-reliance on exteroceptive cues in schizophrenia would lead to a reduced susceptibility to the effects of head position on Tilt Illusion strength. We find no difference between patients and controls. Both groups show comparable Tilt Illusion magnitudes that increase when the head is tilted. Thus, our findings suggest that chronic patients with schizophrenia adequately combine self-generated vestibular cues and exteroceptive visual input to judge line verticality. A stronger reliance on exteroceptive information over internally generated signals in guiding perception is not evident in our data. Deficits in self-monitoring might therefore be modality specific or state dependant.

Schizophrenia is a severe mental illness characterised by a plethora of symptoms. One set of symptoms attracting much attention is the disturbance of self and the processing of internal bodily cues. For instance, it is well-documented that patients experience numerous perceptual distortions of self-generated stimuli (Bleuler, 1950; Frith et al., 2000; Haggard, 2017; Kraepelin, 1913; Schneider, 1959). This includes the commonly reported feeling that one's own actions and thoughts are caused by another agent (Brunelin et al., 2007; Farrer and Franck, 2007; Fourneret et al., 2001; Fourneret et al., 2002; Knoblich et al., 2004; Nordgaard et al., 2019, 2020; Synofzik et al., 2010; Whitford, 2019). Unusual bodily sensations (e.g., feelings of movement, pain, numbness, or of being electrified) (Rajender et al., 2009; Röhricht and Priebe, 2002; Stanghellini et al., 2014) are also commonly reported in schizophrenia and are among the earliest subjectively experienced symptoms (Schultze-Lutter, 2009). Research also shows that patients have difficulties monitoring their own heartrate (Ardizzi et al., 2016; Koreki et al., 2021; Torregrossa et al., 2022), temperature (Chong and Castle, 2004; Mahintamani et al., 2015), pain (De la Fuente-Sandoval et al., 2010; Zhou et al., 2020), and satiety levels (Waltz et al., 2015), suggesting that a general deficit in interoception may be associated with the illness (Bonaz et al., 2021; Postmes et al., 2014; Yao and Thakkar, 2022).

Deficits in self-monitoring may suggest patients rely more on exteroceptive signals (visual, auditory, tactile, taste, smell) and give less weight to self-generated interoceptive cues (Asai et al., 2011; Fourneret et al., 2001; Fourneret et al., 2002; Germine et al., 2013). In support of this, experiments using the rubber hand illusion show an enhanced illusion in schizophrenia (Peled et al., 2003; Peled et al., 2000; Thakkar et al., 2011) (but see (Prikken et al., 2019)). In the rubber hand illusion, the stroking of a rubber hand synchronously with a participant's real

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hand, while visually observing the rubber hand, leads to the experience that the rubber hand is part of participant's own body (Botvinick and Cohen, 1998). This demonstrates a tendency for humans to rely more on vision rather than proprioception to generate a percept of body ownership (Ernst and Banks, 2002). Because the size of the illusion is seen to be larger in schizophrenia, patients may show an even greater reliance more on exteroceptive input compared to controls.

Vestibular signals are self-generated cues that aid spatial perception (Blanke et al., 2015; Kaliuzhna et al., 2015; Lopez, 2013; Serino et al., 2013). Located in the inner ear, the otolith organs and semicircular canals encode linear and angular accelerations respectively to help provide an accurate perception of one's own body in space. Deficits in multisensory integration involving the vestibular sense lead to alterations of self-consciousness, such as out-of-body experiences (Blanke et al., 2015; Kaliuzhna et al., 2015), which are reported in schizophrenia (Gerretsen et al., 2017; Thakkar et al., 2011). It is also reported that patients with schizophrenia experience abnormal postural sway (Kent et al., 2012; Marvel et al., 2004), smooth pursuit and vestibular-ocular cancellation deficits (Levy et al., 2010; O'Driscoll and Callahan, 2008; Warren and Ross, 1998), altered electrovestibulographic responses (Haghgooie et al., 2009), and cerebellar abnormalities (Andreasen and Pierson, 2008; Picard et al., 2008). While these deficits suggest dysfunction in visuo-vestibular integration, it is unclear whether they reflect a reduced weighting of self-generated vestibular information in favour of exteroceptive visual input.

Over the past decade, the use of visual illusions in schizophrenia research has allowed researchers to probe basic brain mechanisms with superior experimental precision (Carter et al., 2017; Caruana and Seymour, 2021; Caruana et al., 2019; Grzeczkowski et al., 2018; Kaliuzhna et al., 2019; Kaliuzhna et al., 2020; King et al., 2017; Notredame et al., 2014; Palmer et al., 2018a, 2018b; Silverstein, 2016; Tibber et al., 2013; Yang et al., 2013). The Tilt Illusion (Gibson and Radner, 1937) offers particular promise, not only because the underlying neural mechanisms are largely understood (Blakemore et al., 1970; Blakemore et al., 1973; Clifford et al., 2000; Schwartz et al., 2007; Schwartz et al., 2009; Series et al., 2003; Seymour et al., 2018; Solomon and Morgan, 2006), but because its simplicity offers potential diagnostic utility. The Tilt Illusion occurs when the perceived orientation of a vertical grating is biased by the orientation of a surrounding grating (Fig. 1). Previous studies in healthy participants show that when participants tilt their head to the side, the Tilt Illusion increases (Prinzmetal and Beck, 2001; Wenderoth and Burke, 2006). When the head is upright it is aligned with gravity (i.e., vertical) and can thus provide additional vestibular information for judging the grating's orientation. When the head is tilted away from the gravitational axis, this vestibular information becomes unreliable and more weight is placed on the exteroceptive visual input, allowing the surround visual context to have a greater effect (DiLorenzo and Rock, 1982; Wenderoth and Burke, 2006; Witkin and Asch, 1948).

Fig. 1. Tilt Illusion (Gibson and Radner, 1937). The orientation of a central vertical grating is perceived to be tilted away from the orientation of the surrounding visual context.

Because the magnitude of Tilt Illusion is susceptible to changes in self-generated vestibular input, the illusion offers a novel tool to test whether this input is outweighed in favour of exteroceptive cues in schizophrenia. An over-reliance on exteroception in schizophrenia would predict a reduced susceptibility to the effects of head position on illusion strength.

1. Participants

Nineteen patients with schizophrenia (6 female) and 19 healthy age- and gender-matched controls (3 female) took part in the experiment. There was no difference between groups in terms of mean age (patients 53.8 SD = 6.8; controls 49.5, SD = 9.06, $p = 0.1$). For both groups the exclusion criteria were history of neurological illness or trauma, current or previous substance abuse, and less than 8 years of formal education. The clinical interview was conducted by an experienced psychologist. We used the diagnostic interview for psychosis (DIP; Jablensky et al., 1999) to confirm a DSM-IV diagnosis of schizophrenia for the patients. Controls were screened for the presence of affective and psychotic disorders, and substance abuse, using the screening modules from the Structured Clinical Interview for DSM-IV Axis 1 Disorders (SCID: First, 1997). Symptoms were assessed using the Scale for the Assessment of Positive and Negative Symptoms (SAPS-SANS) (Andreasen, 1984, 1989). All patients took second generation antipsychotics and the general levels of symptomatology were mild. Mean illness duration was 30.6 years, SD = 11.4; SAPS global 4.6, SD = 2.3; SANS global 10.1, SD = 4.7. All participants had normal or corrected-to-normal visual acuity. Participants gave written informed consent and the study was approved by Macquarie University's Ethics Committee.

2. Apparatus

Participants were seated 57 cm away from a computer display. Participants positioned their head on a headrest that was either set in an upright position or titled to achieve a 30° head tilt. The experiment was run in the dark.

Stimuli were presented on a 15-inch gamma-corrected CRT monitor (refresh rate of 60 Hz, 1024 × 768 pixel resolution, background luminance: 50 cd/m) and viewed through a black cylindrical tube. Stimuli were generated in Matlab (Mathworks, MA) and Psychtoolbox (Kleiner et al., 2007). Responses were collected via a standard keyboard.

3. Design and procedure

We measured the Tilt Illusion using the standard stimulus configuration (Fig. 1). Stimuli consisted of two concentric sinusoidal gratings presented simultaneously with spatial frequency 1 cycle/deg, mean luminance 50 cd/m^2 and 100% Michelson contrast. The central grating extended to an eccentricity of 1.5 degree of visual angle and the surrounding contextual grating extended from 1 to 3 deg eccentricity.

During the experiment, we presented the central grating with a surrounding context of −15°. We also included a 'no surround' baseline condition, where only the central grating was presented. These conditions were presented as randomly interleaved staircases split across 2 blocks. Order of block type was balanced across participants within each group (i.e., every second participant completed the first block with their head tilted and the second block with their head in the upright position.

The remaining participants did the opposite). Each condition had 5 separate staircases of 20 trials (Fig. 2).

Stimuli were presented for 100 ms. Participants were required to indicate, by pressing the left or right arrow key, whether the central grating was tilted clockwise or counter clockwise from vertical. Depending on the response, the orientation of the central grating was adjusted (1 degree in the opposite direction) on the subsequent trial of that staircase. The trials were not time restricted. Each trial commenced 800 ms after the participant gave their response. Each staircase had a starting central orientation assigned randomly from 5 deg. or 10 deg.

4. Analysis

An estimate of each participant's point of subjective vertical (PSV), was calculated based on an average of the last two reversals for each condition across the 20 trials of each staircase. The magnitude of the illusion in each block (i.e., head upright or head tilted) was calculated by subtracting PSV measured in the 'no surround' baseline condition from the PSV measured under the 'with surround' condition. A repeated measure ANOVA assessed statistically significant differences in mean illusion magnitude against the factors head position and group.

All analyses were performed using JASP (JASP Team, 2022, Version 0.9) software. We first used a classical frequentist approach to analyse our results. We then applied Bayesian statistics to determine whether our null effects were genuine evidence for the null hypothesis relative to the alternative hypotheses. Bayes Factors (BF_{10}) were calculated using a default Cauchy prior width of 0.707 and were interpreted using established guidelines (Jeffreys, 1961; Lee and Wagenmakers, 2013).

5. Results

A repeated measures ANOVA with factors head position and group assessed statistical significance (Fig. 3). Corroborating previous work, we found a main effect of head position ($F(36,1) = 9.45$, $p = 0.004$, $\eta^2 = 0.058$; $BF_{10} = 10.3$), with participants demonstrating an increase in Tilt Illusion magnitude when the head was tilted. Contrary to our main hypothesis, we found no effect of group ($p = 0.65$; $\eta^2 = 0.004$; $BF_{10} = 0.38$) and no group * head position interaction ($p = 0.62$; $\eta^2 = 0.002$; $BF_{10} = 0.34$). Thus, patients and controls experienced the illusion to the same extent and the increase in illusion strength elicited by head tilt was comparable across groups.

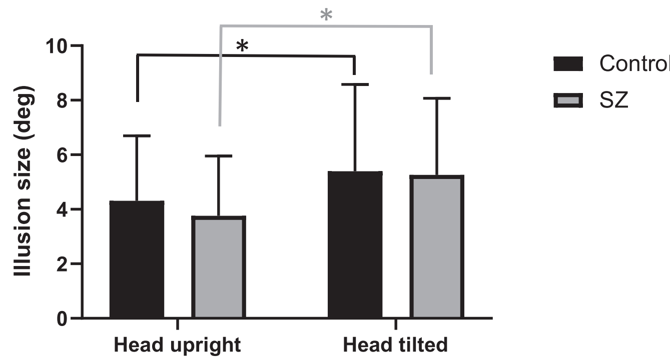

Fig. 3. The Tilt Illusion in patients with schizophrenia and healthy controls under two conditions; head upright (reliable vestibular cue for vertical) and head tilted (unreliable vestibular cue for vertical). Error bars represent standard deviation.

6. Discussion

In the present work, we tested the Tilt Illusion in schizophrenia and specifically the effects of head tilt – a manipulation known to increase the size of this visual illusion in healthy participants (Prinzmetal and Beck, 2001; Wenderoth and Burke, 2006). Based on the idea that patients with schizophrenia rely less on self-generated cues and favour exteroceptive signals to guide perception, we hypothesised that Tilt Illusion strength would depend less on head position in schizophrenia. We replicated previous findings of an increased Tilt Illusion when the

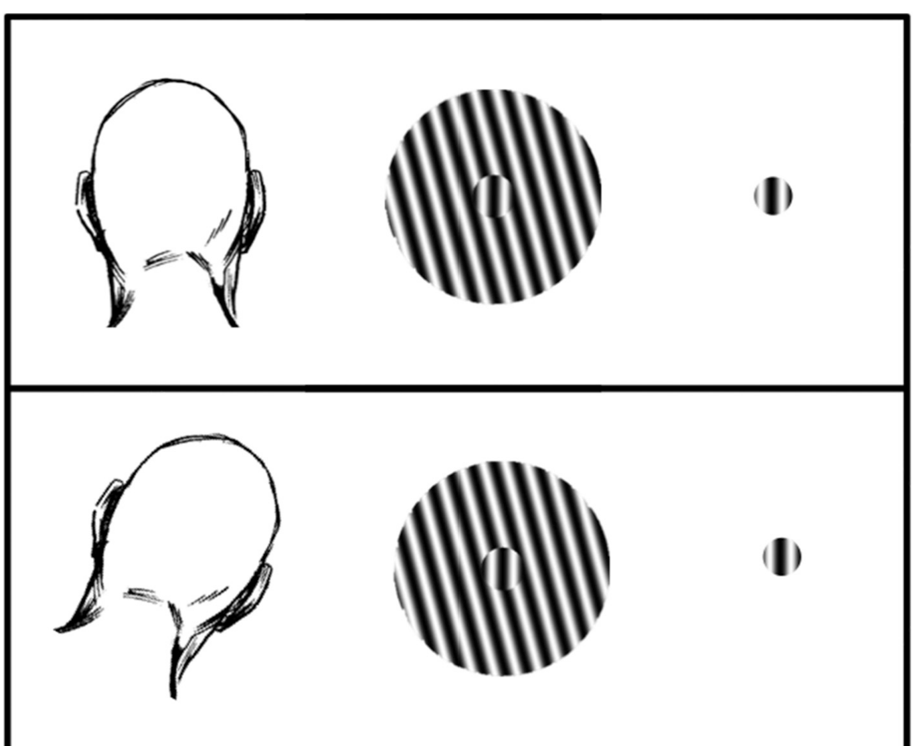

Fig. 2. The Tilt Illusion measured in two blocks: head upright and head tilted.

head is tilted (Wenderoth and Burke, 2006). We did not find any differences between patients and controls in the head upright or the head tilted condition. These data suggest that patients show a normal ability to combine exteroceptive visual cues with interoceptive vestibular information to judge grating orientation.

The results of our study do not indicate an over-reliance on exteroceptive information or a reduced weighting of vestibular signals in schizophrenia. We tested for evidence of this by directly manipulating the reliability of the vestibular signals in guiding perception and found no difference between patients and control participants. We had hypothesised that if patients showed a bias to favour exteroceptive visual information when making verticality judgements, they would be less sensitive to changes in the internal reference cues for vertical generated as a result of tilting the head. While our results provide no evidence for this, some previous studies have reported larger tilt illusions in schizophrenia using standard upright head conditions. These findings could be interpreted to suggest that patients rely less on the additional helpful vestibular information to offset the illusory effects of the visual context (Thakkar et al., 2021; Yang et al., 2013). However, previous studies examining the Tilt Illusion in schizophrenia have not directly manipulated the strength of vestibular input, so the results are unclear. Moreover most studies report no group differences between patients and controls (Grzeczkowski et al., 2018; Tibber et al., 2013; Yang et al., 2013) and those that do report larger tilt illusions in patients suggest a dependence on illness severity or medication status (Yang et al., 2013). In the current study, our sample exhibited only mild symptoms. While illness severity may explain our failure to detect an abnormality in our patient group, our results suggest that if assigning relative weight to interoceptive and exteroceptive information is indeed perturbed in schizophrenia, it is restricted to more acute illness states.

Our hypothesis that Tilt Illusion magnitude in schizophrenia would be less affected by head position was also based on previous reports of visuo-vestibular integration deficits in schizophrenia (Andreasen and Pierson, 2008; Haghgooie et al., 2009; Levy et al., 2010; O'Driscoll and Callahan, 2008; Pawlak-Osinska et al., 2000; Picard et al., 2008). We expected patients to ignore vestibular cues in the upright and head-tilt positions and therefore show less modulation of Tilt Illusion magnitude in response to changes in head position. We did not directly measure vestibular function in our participants, but our results may suggest intact processing. However, it is also possible that an altered vestibular sense only has a limited impact on judgements of verticality. For instance, patients with Menière's disease who experience vestibular symptoms, show identical performance to controls in making visual vertical judgements (Lopez et al., 2008). Similarly, patients with unilateral and bilateral vestibular loss show no difference in performance compared to controls on the rod-and-frame test – a similar task to the Tilt Illusion (Grabherr et al., 2011). Vestibular complaints such as dizziness and vertigo are also not common in chronic schizophrenia (although macro-/micropsia hallucinations could have a vestibular component (Lopez, 2013)) which may suggest that vestibular dysfunction, even if present, has no significant impact on visual perception, and that other modalities may compensate for the dysfunction. Indeed, during our task, participants were seated – a position that yields additional proprioceptive information for the perception of vertical. It is important to note, however, that if such a compensation exists, this would be evidence against a general deficit of interoception (Bonaz et al., 2021; Postmes et al., 2014; Yao and Thakkar, 2022). To sum up, our results show that a reduction in the processing of body-related cues is not a general feature in schizophrenia, as no such reduction was present in our cohort.

Finally, although we acknowledge a small sample size may have reduced our power to detect a group difference in this study, our data suggests that the magnitude of patients' Tilt Illusions is in accordance with other published studies (Grzeczkowski et al., 2018; King et al., 2017; Tibber et al., 2013; Yang et al., 2013). Moreover, Bayesian statistics adds support for our conclusions by providing strong evidence of there being a true effect of head tilt in both groups. An interesting direction for future research is combining multiple interoceptive paradigms in the same patient cohorts to establish which bodily cues are affected. Importantly, processing of bodily-related cues might be mostly affected in schizophrenia during the prodrome or in acute stages, where basic symptoms (such as illusory body size and form changes, as well as motion, pain and heat sensations) are most evident (Priebe and Röhricht, 2001; Rajender et al., 2009; Schultze-Lutter, 2009; Stanghellini et al., 2014). Future studies with a bigger sample of more acute patients will prove valuable.

CRediT authorship contribution statement

KS: Conceptualisation; Methodology; Project administration; Software; Supervision; Validation; Writing – original draft; Writing – review & editing.

MK: Formal analysis; Funding acquisition; Resources; Visualization; Writing – original draft; Writing – review & editing.

Declaration of competing interest

We declare no conflict of interest.

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References

Andreasen, N.C., 1984. Scale for the assessment of positive symptoms. Group 17 (2), 173–180.
Andreasen, N.C., 1989. The Scale for the Assessment of Negative Symptoms (SANS): conceptual and theoretical foundations. Br. J. Psychiatry 155 (S7), 49–52.
Andreasen, N.C., Pierson, R., 2008. The role of the cerebellum in schizophrenia. Biol. Psychiatry 64 (2), 81–88.
Ardizzi, M., Ambrosecchia, M., Buratta, L., Ferri, F., Peciccia, M., Donnari, S., Gallese, V., 2016. Interoception and positive symptoms in schizophrenia. Front. Hum. Neurosci. 10, 379.
Asai, T., Mao, Z., Sugimori, E., Tanno, Y., 2011. Rubber hand illusion, empathy, and schizotypal experiences in terms of self-other representations. Conscious. Cogn. 20 (4), 1744–1750.
Blakemore, C., Carpenter, R.H., Georgeson, M.A., 1970. Lateral inhibition between orientation detectors in the human visual system. Nature 228 (5266), 37–39.
Blakemore, C., Muncey, J.P., Ridley, R.M., 1973. Stimulus specificity in the human visual system. Vis. Res. 13 (10), 1915–1931.
Blanke, O., Slater, M., Serino, A., 2015. Behavioral, neural, and computational principles of bodily self-consciousness. Neuron 88 (1), 145–166.
Bleuler, E., 1950. Dementia praecox or the group of schizophrenias.
Bonaz, B., Lane, R.D., Oshinsky, M.L., Kenny, P.J., Sinha, R., Mayer, E.A., Critchley, H.D., 2021. Diseases, disorders, and comorbidities of interoception. Trends Neurosci. 44 (1), 39–51.
Botvinick, M., Cohen, J., 1998. Rubber hands 'feel'touch that eyes see. Nature 391 (6669), 756-756.
Brunelin, J., d'Amato, T., Brun, P., Bediou, B., Kallel, L., Senn, M., Saoud, M., 2007. Impaired verbal source monitoring in schizophrenia: an intermediate trait vulnerability marker? Schizophr. Res. 89 (1–3), 287–292.
Carter, O., Bennett, D., Nash, T., Arnold, S., Brown, L., Cai, R., Burr, D., 2017. Sensory integration deficits support a dimensional view of psychosis and are not limited to schizophrenia. Transl. Psychiatry 7 (5) e1118-e1118.
Caruana, N., Seymour, K., 2021. Bottom-up processing of fearful and angry facial expressions is intact in schizophrenia. Cogn. Neuropsychiatry 26 (3), 183–198.
Caruana, N., Stein, T., Watson, T., Williams, N., Seymour, K., 2019. Intact prioritisation of unconscious face processing in schizophrenia. Cogn. Neuropsychiatry 24 (2), 135–151.
Chong, T.W., Castle, D.J., 2004. Layer upon layer: thermoregulation in schizophrenia. Schizophr. Res. 69 (2–3), 149–157.
Clifford, C.W., Wenderoth, P., Spehar, B., 2000. A functional angle on some after-effects in cortical vision. Proc. R. Soc. Lond. Ser. B Biol. Sci. 267 (1454), 1705–1710.
De la Fuente-Sandoval, C., Favila, R., Gómez-Martin, D., Pellicer, F., Graff-Guerrero, A., 2010. Functional magnetic resonance imaging response to experimental pain in drug-free patients with schizophrenia. Psychiatry Res. Neuroimaging 183 (2), 99–104.

DiLorenzo, J.R., Rock, I., 1982. The rod-and-frame effect as a function of the righting of the frame. J. Exp. Psychol. Hum. Percept. Perform. 8 (4), 536.
Ernst, M.O., Banks, M.S., 2002. Humans integrate visual and haptic information in a statistically optimal fashion. Nature 415 (6870), 429–433.
Farrer, C., Franck, N., 2007. Self-monitoring in schizophrenia. Curr. Psychiatry Rev. 3 (4), 243–251.
First, M.B., 1997. User's Guide for the Structured Clinical Interview for DSM-IV Axis I Disorders SCID-I: Clinician Version. American Psychiatric Pub.
Fourneret, P., Franck, N., Slachevsky, A., Jeannerod, M., 2001. Self-monitoring in schizophrenia revisited. Neuroreport 12 (6), 1203–1208.
Fourneret, P., Vignemont, F.D., Franck, N., Slachevsky, A., Dubois, B., Jeannerod, M., 2002. Perception of self-generated action in schizophrenia. Cogn.Neuropsychiatry 7 (2), 139–156.
Frith, C.D., Blakemore, S.-J., Wolpert, D.M., 2000. Explaining the symptoms of schizophrenia: abnormalities in the awareness of action. Brain Res. Rev. 31 (2–3), 357–363.
Germine, L., Benson, T.L., Cohen, F., Hooker, C.I.L., 2013. Psychosis-proneness and the rubber hand illusion of body ownership. Psychiatry Res. 207 (1–2), 45–52.
Gerretsen, P., Pothier, D.D., Falls, C., Armstrong, M., Balakumar, T., Uchida, H., Graff-Guerrero, A., 2017. Vestibular stimulation improves insight into illness in schizophrenia spectrum disorders. Psychiatry Res. 251, 333–341.
Gibson, J.J., Radner, M., 1937. Adaptation, after-effect and contrast in the perception of tilted lines. I. Quantitative studies. J. Exp. Psychol. 20 (5), 453.
Grabherr, L., Cuffel, C., Guyot, J.-P., Mast, F.W., 2011. Mental transformation abilities in patients with unilateral and bilateral vestibular loss. Exp. Brain Res. 209 (2), 205–214.
Grzeczkowski, L., Roinishvili, M., Chkonia, E., Brand, A., Mast, F.W., Herzog, M.H., Shaqiri, A., 2018. Is the perception of illusions abnormal in schizophrenia? Psychiatry Res. 270, 929–939.
Haggard, P., 2017. Sense of agency in the human brain. Nat. Rev. Neurosci. 18 (4), 196–207.
Haghgooie, S., Lithgow, B.J., Gurvich, C., Kulkarni, J., 2009. Quantitative Detection And Assessment of Schizophrenia Using Electrovestibulography.Paper Presented at the 2009 4th International IEEE/EMBS Conference on Neural Engineering.
Jablensky, A., McGrath, J., Herrman, H., Castle, D., Gureje, O., Morgan, V., Korten, A., 1999. People living with psychotic illness: an Australian study 1997–98. In: National Survey of Mental Health and Wellbeing Report, 4, pp. 1–20.
JASP Team (2022). JASP (Version 0.16.2)[Computer software].
Jeffreys, H., 1961. The Theory of Probability. The Clarendon Press, Oxford.
Kaliuzhna, M., Vibert, D., Grivaz, P., Blanke, O., 2015. Out-of-body experiences and other complex dissociation experiences in a patient with unilateral peripheral vestibular damage and deficient multisensory integration. Multisens. Res. 28 (5–6), 613–635.
Kaliuzhna, M., Stein, T., Rusch, T., Sekutowicz, M., Sterzer, P., Seymour, K.J., 2019. No evidence for abnormal priors in early vision in schizophrenia. Schizophr. Res. 210, 245–254.
Kaliuzhna, M., Stein, T., Sterzer, P., Seymour, K.J., 2020. Examining motion speed processing in schizophrenia using the flash lag illusion. Schizophr. Res. Cogn. 19, 100165.
Kent, J.S., Hong, S.L., Bolbecker, A.R., Klaunig, M.J., Forsyth, J.K., O'donnell, B.F., Hetrick, W.P., 2012. Motor deficits in schizophrenia quantified by nonlinear analysis of postural sway.
King, D.J., Hodgekins, J., Chouinard, P.A., Chouinard, V.-A., Sperandio, I., 2017. A review of abnormalities in the perception of visual illusions in schizophrenia. Psychon. Bull. Rev. 24 (3), 734–751.
Kleiner, M., Brainard, D., Pelli, D., 2007. What's new in Psychtoolbox-3?.
Knoblich, G., Stottmeister, F., Kircher, T., 2004. Self-monitoring in patients with schizophrenia. Psychol. Med. 34 (8), 1561–1569.
Koreki, A., Funayama, M., Terasawa, Y., Onaya, M., Mimura, M., 2021. Aberrant interoceptive accuracy in patients with schizophrenia performing a heartbeat counting task. Schizophr. Bull. Open 2 (1), sgaa067.
Kraepelin, E., 1913. Psychiatrie; ein Lehrbuch für Studierende und Ärzte, Vol. 3.
Lee, M.D., Wagenmakers, E.-J., 2013. Bayesian Cognitive Modeling: A Practical Course. Cambridge University Press, Cambridge.
Levy, D.L., Sereno, A.B., Gooding, D.C., O'Driscoll, G.A., 2010. Eye tracking dysfunction in schizophrenia: characterization and pathophysiology. In: Behavioral Neurobiology of Schizophrenia And Its Treatment, pp. 311–347.
Lopez, C., 2013. A neuroscientific account of how vestibular disorders impair bodily self-consciousness. Front. Integr. Neurosci. 7, 91.
Lopez, C., Lacour, M., Léonard, J., Magnan, J., Borel, L., 2008. How body position changes visual vertical perception after unilateral vestibular loss. Neuropsychologia 46 (9), 2435–2440.
Mahintamani, T., Ram, D., Mitra, S., 2015. Inside the mind of poor Tom–a multidimensional approach to determine causes for redundant clothing in patients with schizophrenia. Psychiatry Res. 227 (2–3), 219–223.
Marvel, C.L., Schwartz, B.L., Rosse, R.B., 2004. A quantitative measure of postural sway deficits in schizophrenia. Schizophr. Res. 68 (2–3), 363–372.
Nordgaard, J., Henriksen, M.G., Berge, J., Nilsson, L.S., 2019. First-rank symptoms and self-disorders in schizophrenia.
Nordgaard, J., Henriksen, M.G., Berge, J., Nilsson, L.S., 2020. Associations between self-disorders and first-rank symptoms: an empirical study. Psychopathology 53 (2), 103–110.
Notredame, C.-E., Pins, D., Deneve, S., Jardri, R., 2014. What visual illusions teach us about schizophrenia. Front. Integr. Neurosci. 8, 63.
O'Driscoll, G.A., Callahan, B.L., 2008. Smooth pursuit in schizophrenia: a meta-analytic review of research since 1993. Brain Cogn. 68 (3), 359–370.
Palmer, C.J., Caruana, N., Clifford, C.W., Seymour, K.J., 2018a. Adaptive sensory coding of gaze direction in schizophrenia. R. Soc. Open Sci. 5 (12), 180886.
Palmer, C.J., Caruana, N., Clifford, C.W., Seymour, K.J., 2018b. Perceptual integration of head and eye cues to gaze direction in schizophrenia. R. Soc. Open Sci. 5 (12), 180885.
Pawlak-Osinska, K., Kazmierczak, H., Osinski, P., Michorzewski, A., 2000. Electronystagmographic study in chronic schizophrenia. Int.Tinnitus J. 6 (2), 172–174.
Peled, A., Ritsner, M., Hirschmann, S., Geva, A.B., Modai, I., 2000. Touch feel illusion in schizophrenic patients. Biol. Psychiatry 48 (11), 1105–1108.
Peled, A., Pressman, A., Geva, A.B., Modai, I., 2003. Somatosensory evoked potentials during a rubber-hand illusion in schizophrenia. Schizophr. Res. 64 (2–3), 157–163.
Picard, H., Amado, I., Mouchet-Mages, S., Olié, J.-P., Krebs, M.-O., 2008. The role of the cerebellum in schizophrenia: an update of clinical, cognitive, and functional evidences. Schizophr. Bull. 34 (1), 155–172.
Postmes, L., Sno, H., Goedhart, S., Van Der Stel, J., Heering, H., De Haan, L., 2014. Schizophrenia as a self-disorder due to perceptual incoherence. Schizophr. Res. 152 (1), 41–50.
Priebe, S., Röhricht, F., 2001. Specific body image pathology in acute schizophrenia. Psychiatry Res. 101 (3), 289–301.
Prikken, M., Van der Weiden, A., Baalbergen, H., Hillegers, M.H., Kahn, R.S., Aarts, H., Van Haren, N.E., 2019. Multisensory integration underlying body-ownership experiences in schizophrenia and offspring of patients: a study using the rubber hand illusion paradigm. J. Psychiatry Neurosci. 44 (3), 177.
Prinzmetal, W., Beck, D.M., 2001. The tilt-consistency theory of visual illusions. J. Exp. Psychol. Hum. Percept. Perform. 27 (1), 206.
Rajender, G., Kanwal, K., Rathore, D.M., Chaudhary, D., 2009. Study of cenesthesias and body image aberration in schizophrenia. Indian J. Psychiatry 51 (3), 195.
Röhricht, F., Priebe, S., 2002. Do cenesthesias and body image aberration characterize a subgroup in schizophrenia? Acta Psychiatr. Scand. 105 (4), 276–282.
Schneider, K., 1959. Clinical Psychopathology. Grune & Stratton.
Schultze-Lutter, F., 2009. Subjective symptoms of schizophrenia in research and the clinic: the basic symptom concept. Schizophr. Bull. 35 (1), 5–8.
Schwartz, O., Hsu, A., Dayan, P., 2007. Space and time in visual context. Nat. Rev. Neurosci. 8 (7), 522–535.
Schwartz, O., Sejnowski, T.J., Dayan, P., 2009. Perceptual organization in the tilt illusion. J. Vis. 9 (4), 19-19.
Series, P., Lorenceau, J., Frégnac, Y., 2003. The "silent" surround of V1 receptive fields: theory and experiments. J. Physiol. Paris 97 (4–6), 453–474.
Serino, A., Alsmith, A., Costantini, M., Mandrigin, A., Tajadura-Jimenez, A., Lopez, C., 2013. Bodily ownership and self-location: components of bodily self-consciousness. Conscious. Cogn. 22 (4), 1239–1252.
Seymour, K.J., Stein, T., Clifford, C.W., Sterzer, P., 2018. Cortical suppression in human primary visual cortex predicts individual differences in illusory tilt perception. J. Vis. 18 (11), 3-3.
Silverstein, S.M., 2016. Visual perception disturbances in schizophrenia: a unified model. In: The Neuropsychopathology of Schizophrenia, pp. 77–132.
Solomon, J.A., Morgan, M.J., 2006. Stochastic re-calibration: contextual effects on perceived tilt. Proc. R. Soc. B Biol. Sci. 273 (1601), 2681–2686.
Stanghellini, G., Ballerini, M., Blasi, S., Mancini, M., Presenza, S., Raballo, A., Cutting, J., 2014. The bodily self: a qualitative study of abnormal bodily phenomena in persons with schizophrenia. Compr. Psychiatry 55 (7), 1703–1711.
Synofzik, M., Thier, P., Leube, D.T., Schlotterbeck, P., Lindner, A., 2010. Misattributions of agency in schizophrenia are based on imprecise predictions about the sensory consequences of one's actions. Brain 133 (1), 262–271.
Thakkar, K.N., Nichols, H.S., McIntosh, L.G., Park, S., 2011. Disturbances in body ownership in schizophrenia: evidence from the rubber hand illusion and case study of a spontaneous out-of-body experience. PloS one 6 (10), e27089.
Thakkar, K.N., Ghermezi, L., Silverstein, S.M., Slate, R., Yao, B., Achtyes, E.D., Brascamp, J.W., 2021. Stronger tilt aftereffects in persons with schizophrenia. J. Abnorm. Psychol. 130 (2), 186.
Tibber, M.S., Anderson, E.J., Bobin, T., Antonova, E., Seabright, A., Wright, B., Dakin, S. C., 2013. Visual surround suppression in schizophrenia. Front. Psychol. 4, 88.
Torregrossa, L.J., Amedy, A., Roig, J., Prada, A., Park, S., 2022. Interoceptive functioning in schizophrenia and schizotypy. Schizophr. Res. 239, 151–159.
Waltz, J.A., Brown, J.K., Gold, J.M., Ross, T.J., Salmeron, B.J., Stein, E.A., 2015. Probing the dynamic updating of value in schizophrenia using a sensory-specific satiety paradigm. Schizophr. Bull. 41 (5), 1115–1122.
Warren, S., Ross, R.G., 1998. Deficient cancellation of the vestibular ocular reflex in schizophrenia. Schizophr. Res. 34 (3), 187–193.
Wenderoth, P., Burke, D., 2006. Testing the tilt-constancy theory of visual illusions. Perception 35 (2), 201–213.
Whitford, T.J., 2019. Speaking-induced suppression of the auditory cortex in humans and its relevance to schizophrenia. Biol. Psychiatry Cogn. Neurosci. Neuroimaging 4 (9), 791–804.
Witkin, H.A., Asch, S.E., 1948. Studies in space orientation. IV. Further experiments on perception of the upright with displaced visual fields. J. Exp. Psychol. 38 (6), 762.
Yang, E., Tadin, D., Glasser, D.M., Hong, S.W., Blake, R., Park, S., 2013. Visual context processing in schizophrenia. Clin. Psychol. Sci. 1 (1), 5–15.
Yao, B., Thakkar, K., 2022. Interoception abnormalities in schizophrenia: a review of preliminary evidence and an integration with Bayesian accounts of psychosis. Neurosci. Biobehav. Rev. 132, 757–773.
Zhou, L., Bi, Y., Liang, M., Kong, Y., Tu, Y., Zhang, X., Hu, L., 2020. A modality-specific dysfunction of pain processing in schizophrenia. Hum. Brain Mapp. 41 (7), 1738–1753.