Perception of visual-tactile asynchrony, bodily perceptual aberrations, and bodily illusions in schizophrenia

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Abstract

Body perception can be dramatically altered in individuals with schizophrenia resulting in experiences of undefined bodily boundaries, loss of body ownership, and size changes for parts of the body. These individuals may also be more susceptible to the rubber hand illusion (RHI: an illusion of body perception that can also be induced in neurotypical populations), but the findings are mixed. Furthermore, the perception of timing information about multisensory stimuli, which is thought to be fundamental for body perception, has been reported to be altered in schizophrenia. We tested here whether altered perception of the temporal relationship between visual and tactile signals in schizophrenia can predict self-reported perceptual aberrations and RHI susceptibility (indexed by both illusion self-ratings and a more objective proprioceptive-drift measure). We found that the sensitivity to detect temporal asynchronies is reduced in schizophrenia and this predicts bodily perceptual symptoms. In contrast, we found no evidence for a direct relationship between asynchrony detection sensitivity and RHI susceptibility. Instead, our findings suggest that experiencing more bodily perceptual symptoms increases the likelihood of endorsing unusual bodily experiences, resulting in higher RHI self-ratings but not higher proprioceptive-drift scores. Overall, our findings provide evidence for both direct and indirect links between temporal and body perception and thus new insight into the mechanisms that may underlie unusual body perceptions in schizophrenia.

Keywords: synchrony perception, body perception, body ownership, schizophrenia, psychosis, perceptual aberration, bodily illusions

General Scientific Summary

The perception of one's own body is thought to depend on the processing of signals from different senses (e.g., vision and touch). This study provides evidence that those individuals with schizophrenia who are poorer at discriminating temporal relationships between multisensory signals are also more likely to report body-related perceptual symptoms.

Furthermore, we found that the experience of body-related perceptual symptoms can, in turn, affect the extent to which individuals endorse experiencing bodily illusions, highlighting the need to assess and account for such experiences in future body illusion research.

1. Introduction

People with schizophrenia report unusual experiences of reality, often affecting perceptions of their body. Such unusual bodily experiences can include changes in body boundaries, ownership and size. Perceptual aberrations with respect to the body are reported by some, but not all, individuals diagnosed with schizophrenia and can also be reported by other individuals who demonstrate high psychosis-proneness (J. C. Chapman, Edell, & Chapman, 1980; L. J. Chapman, Chapman, Kwapil, Eckblad, & Zinser, 1994; L. J. Chapman, Chapman, & Raulin, 1978). More basic aspects of perceptual processing, such as the perception of temporal relationships, can also be altered in schizophrenia. For example, the ability to discriminate if different sensory events occurred at the same time (synchronously) or at different times (asynchronously) is reduced relative to healthy controls (Foucher, Lacambre, Pham, Giersch, & Elliott, 2007). This basic ability to process timing information about multisensory stimuli is fundamental for perceiving one's own body in space (Pritchard, Zopf, Polito, Kaplan, & Williams, 2016; Zopf, Truong, Finkbeiner, Friedman, & Williams, 2011), which suggests a deficit in this ability could contribute to body-related perceptual symptoms in schizophrenia.

There is also some evidence that individuals with schizophrenia may be more susceptible to bodily illusions such as the rubber hand illusion (RHI). In the RHI, participants, including neurotypical populations, experience an artificial body part (a rubber hand) as their own following synchronous multisensory stimulation. The illusion is induced when participants view touch on the rubber hand and feel touch on their own hand (which is hidden from sight) at the same time (Pritchard et al., 2016; Zopf et al., 2011). The strength of the illusion

diminishes when the visual and tactile stimuli are asynchronous. However, there is variability in the results of studies of the RHI in schizophrenia. Studies using the traditional technique of synchronous manual stroking of the real and rubber hands have often reported increased illusion susceptibility in schizophrenia compared to controls (Peled, Ritsner, Hirschmann, Geva, & Modai, 2000; Thakkar, Nichols, McIntosh, & Park, 2011; Kaplan, Enticott, Hohwy, Castle, & Rossell, 2014), although not all such studies found differences (Prikket et al., 2018). Manual stroking with brushes or fingers is likely to have some variance in timing, as the stroking of the real and rubber hands cannot be perfectly timed even in the “synchronous” condition (Foucher et al., 2007). For individuals who are better at detecting slight asynchronies, perceiving temporal differences between visual and tactile stimuli could reduce the illusion experience. In contrast, those with poorer asynchrony detection sensitivity, including people with schizophrenia, may not detect slight temporal differences and consequently show greater susceptibility to the RHI, particularly when manual stroking is used (Foucher et al., 2007).

In contrast to manual stroking, the use of technologies such as video projections or virtual reality tightly controls the timing of visual-tactile stimulation in RHI paradigms or full body variants. While there might still be some temporal discrepancies between the visual-tactile stimulations, these are likely smaller and highly consistent. With these induction methods, there are no reported differences between schizophrenia and control groups in body ownership illusions (Graham, Martin-Iverson, Holmes, Jablensky, & Waters, 2014; Shaqiri et al., 2018). Furthermore, perceptual processing of visual-tactile asynchronies does not play a role when there is no actual touch event and the illusion is induced with predicted touch: lower illusion susceptibility in schizophrenia has been reported in a study that used this

technique (Ferri et al., 2014). It may be that there are no robust differences in bodily illusion susceptibility in schizophrenia (Shaqiri et al., 2018). Alternatively, it may be that the reported differences between studies depend on how the bodily illusion is induced and, more specifically, on the exact timing between sensory stimuli.

Our first aim was to investigate whether bodily perceptual aberrations are linked to the ability to process temporal synchrony. Specifically, we tested if individuals with decreased ability to process temporal synchrony are also those who are more likely to report bodily perceptual symptoms. If this is the case, then this would provide evidence for a link between a deficit in temporal perception and unusual spatial body perceptions. To this end, we measured self-reported perceptual symptoms and the extent to which different sensory inputs can be asynchronous and yet still be perceived as simultaneous (i.e., temporal binding windows: TBWs) in people with schizophrenia and healthy controls.

Our second aim was to test if temporal perception ability might account for previous mixed findings regarding the RHI in schizophrenia. Previous research exploring how TBWs influence the RHI in the healthy population has shown that participants with wider TBWs require greater asynchrony between visual and tactile stimuli to prevent the experience of the RHI (Costantini et al., 2016). When the visual-tactile stimulation is slightly asynchronous, the temporal asynchronies tend to be within the TBW for participants with a wider window (inducing the illusion) and outside the TBW for those with a narrower window (illusion is not induced). This suggests that differences in processing multisensory asynchronies can contribute to individual differences in RHI susceptibility. Hence, individual differences in

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TBW in a clinical sample of people with schizophrenia, who tend to have larger TBWs (Foucher et al., 2007; Noel, Stevenson, & Wallace, 2018), on average, compared to controls, could potentially explain the previous mixed findings on bodily illusion susceptibility in schizophrenia. We used both manual stimulation, for which we expected greater effects of wider TBWs in schizophrenia, due to the expected (small) variance in timing, and better temporally controlled multisensory stimulation delivered by LEDs and tactors. The LED/tactor method allowed us to implement a synchronous condition, as well as the typical clearly-asynchronous baseline. In addition, we implemented a slightly asynchronous LED/tactor condition with small differences in the timing of the visual and tactile stimulation.

On average, individuals with schizophrenia require larger asynchronies to detect temporal asynchronies (Foucher et al., 2007; Noel et al., 2018), so we predicted wider TBWs in schizophrenia and an overall increase in illusion susceptibility compared to controls in RHI conditions where we expect or know that slight asynchronies occur (manual brush stroking, LED/tactor stimulation with slight asynchrony). In contrast, we did not expect group differences when the manipulation was perfectly synchronous (LED/tactor synchronous stimulation). To measure illusion susceptibility we asked participants to rate illusion statements and indicate their felt hand position to estimate “proprioceptive drift” towards the rubber hand, as is typical in RHI research (Riemer, Trojan, Beauchamp, & Fuchs, 2019).

Previous research has also reported a link between the RHI and perceptual aberration in non-clinical psychosis-prone individuals (Germine, Benson, Cohen, & Hooker, 2013; Asai, Mao, Sugimori, & Tanno, 2011). Our third aim was therefore to explore whether any differences in

the RHI between schizophrenia and control groups, if found, might be associated with reports of bodily aberration symptoms.

2. Method

2.1 Participants

Twenty-five individuals diagnosed with schizophrenia and 25 healthy controls participated. Data for one control were lost due to a technical error during data collection. Data for one patient and three controls were removed from all analyses due to poor psychometric function fit in the visual-tactile asynchrony detection task (see below for details). Data for an additional patient were removed due to extreme values in the asynchrony detection task. The final sample thus comprised 23 individuals with schizophrenia (mean age of 49 years, range 33-64 years) and 21 controls (mean age of 50 years, range 28-67 years), matched on age, gender, handedness (self-reported) and premorbid IQ, estimated using the National Adult Reading Test (NART, Nelson, 1982) (see Table 1). Due to time constraints during testing, NART data was not collected on one control participant. The groups differed in years of education, however both groups had at least 12 years of formal education on average (see Table 1).

Exclusion criteria included: neurological disease; history of serious head injury; pervasive developmental disorder; less than seven years of formal education; IQ less than 75.

Individuals in the Schizophrenia group met DSM-5 criteria for schizophrenia (n=18) or schizoaffective disorder (n=5) based on responses to the Diagnostic Interview for Psychosis (DIP; Castle et al., 2006) and clinical history. Individuals in the healthy control group were

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screened for presence of affective and psychotic disorders, and substance use disorder, using the screening modules from the Structured Clinical Interview for DSM-IV Axis 1 Disorders (SCID; First, Spitzer, Gibbon, & Williams, 1997).

Schizophrenia participants were recruited from the Belief Formation Register at Macquarie University and the Australian Schizophrenia Research Bank Volunteer Register (ASRB; Loughland et al., 2010). Individuals in the schizophrenia group were all stable outpatients, medicated at the time of testing. Chlorpromazine (CPZ) equivalences for antipsychotics (Woods, 2003) are reported in Table 1. Symptoms were assessed using the Scale for the Assessment of Positive Symptoms (SAPS; Andreasen, 1984) and Scale for the Assessment of Negative Symptoms (SANS; Andreasen, 1983). Healthy control participants were recruited through the Cognitive Science community participant pool.

Participants also took part in a separate study on belief formation (see details about the timing below). The combined study was approved by the Macquarie University Human Ethics Review Committee. Participants provided written consent and received \$15 per hour to cover travel costs.

Table 1. Demographics of the schizophrenia and healthy control groups.

	Schizophrenia Group (<i>n</i> =23)	Healthy Control Group (<i>n</i> = 21)	Group comparison	
Basic Demographics				
Age	49.0 (8.4)	50.1 (11.1)	<i>t</i> ₄₂ = 0.39,	<i>p</i> = 0.699
Gender (male: female)	15:8	12:9	χ^2 = 0.06,	<i>p</i> = 0.811
Handedness (right: left)	21:1 ^a	19:2	χ^2 = 1.35,	<i>p</i> = 0.510
Years of education	12.3 (2.3)	14.5 (2.1)	<i>t</i> ₄₂ = 3.27,	<i>p</i> = 0.002
NART IQ Estimate	106.3 (9.5)	108.3 (8.6)	<i>t</i> ₄₁ = 0.73,	<i>p</i> = 0.468
Self-Report Measures				
Perceptual Aberration	8.1 (6.9)	2.4 (5.0)	<i>t</i> _{40.07} = 3.18,	<i>p</i> =0.003
SPQ-B – Cognitive- Perceptual	4.3 (2.3)	1.2 (1.7)	<i>t</i> _{40.25} = 4.99,	<i>p</i> <0.001
Clinical Demographics				
Age of illness onset (years)	24.6 (7.2)			
Duration of illness (years)	24.4 (9.6)			
SAPS ^b	10.8 (8.5)			
SANS ^b	31.7 (11.8)			
CPZ Equivalent (mg/day)	400.0 (295.9)			

^aOne member of the schizophrenia group reported mixed handedness.^bComposite scores (sum of the individual item scores)

2.2 Self-report perceptual symptom scales

We used the Chapman Perceptual Aberration Scale (PAS) (L. J. Chapman et al., 1978, Table 1) to measure the self-report of perceptual symptoms. It consists of 28 body-specific and 7 non-body items that are rated on a dichotomous true-false scale. Furthermore, we used the short form of the Schizotypal Personality Questionnaire (SPQ) - a self-report measure of schizotypal personality traits (SPQ-B; Raine & Benishay, 1995). It contains 22 items rated on a dichotomous yes-no scale. The cognitive-perceptual (positive schizotypy) subscale (8 items) taps into unusual perceptual and cognitive experiences that are not specifically related to the body (Table 1). For our analyses, we calculated a body-related perceptual symptom score on the basis of the 28 body-specific PAS items, as well as a non-body-related perceptual symptom score combining the 7 non-body PAS items with the cognitive-perceptual subscale of the SPQ-B.

2.3 Visual-tactile asynchrony detection task

To measure an individual's ability to detect visual-tactile asynchronies, we used a visual-tactile asynchrony detection task (Keys, Rich, & Zopf, 2018). This task differs from the synchrony judgement task that has been used in other studies to measure TBWs (Costantini et al., 2016; Foucher et al., 2007; Stevenson et al., 2017). We selected the asynchrony detection task because it measures perceptual asynchrony detection performance while better controlling for potential cognitive biases which can affect yes/no synchrony judgements (Vroomen & Keetels, 2010).

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Visual and tactile stimuli were presented with varying asynchronies (Figure 1A). For visual stimulation, we used 5mm light emitting diodes (LEDs) mounted on a black stand. Each visual stimulus consisted of a 10ms LED illumination. For tactile stimuli, we used a miniature electromagnetic tactile stimulator (18mm diameter and 12mm height, Dancer Design, St. Helens, UK, dancerdesign.co.uk) with a small moveable probe in the centre. Each tactile stimulus consisted of a small movement of the probe (200Hz vibrations for 10ms). The tactor was attached to the joint of the distal and intermediate phalanges on the top of the right index finger just below the fingernail. Only the top of the tactor could be seen such that the movement of the probe that created the stimulation was not visible. The LED sat approximately 3cm above the vibrotactile device. The participants placed their right hand in a comfortable position to the right of the body midline and rested it on a black-covered rubber platform to diminish auditory signals created by tactor vibrations. In addition, all participants wore headphones (Seinheisser HD280) during the task to block out any noise from the tactors. Participants placed their left hand on a custom-built button box and made button presses using the index and middle fingers. Presentation® software (Version 0.70, www.neurobs.com) was used to control the presentation of visual and tactile stimuli.

Each asynchrony detection trial consisted of two intervals separated by 1000 ms (Figure 1A). Either the first or second interval (randomly assigned for each trial) contained a visual-tactile pair separated by a delay; in the other interval the visual-tactile pair was presented simultaneously. Participants made a forced choice response as to whether a delay was present in the first (index finger button press) or second (middle finger button press) interval (i.e., a two-interval forced-choice). Responses were recorded from 500 ms after the second stimulus. The next trial started 500 ms after a response was given. Using the method of constant

stimuli, we set the stimulus onset asynchronies (SOAs) for the interval with the delay so that the visual stimulus started 40, 80, 120, 160, 200, 240 or 280 ms before the tactile stimulus, in random order. Each SOA was repeated 20 times resulting in a total of 140 trials. Participants were able to take a break after every 20 trials. To become familiar with the stimuli and the task, participants completed a block of practice trials.

To estimate an individual's asynchrony detection threshold, we fitted sigmoid functions (cumulative Gaussian distributions) to the mean proportion asynchrony detection across all asynchronies using the MATLAB Palamedes toolbox (Prins & Kingdom, 2018). We then calculated an individual's detection threshold at the 75% point for which participants could reliably detect the asynchrony (Figure 2A). We excluded data sets for participants based on three criteria: (1) incomplete data; (2) failing to converge on a solution for fitting a sigmoid function (we visually checked if the fitted function was s-shaped and excluded straight lines or mirrored s-shaped fits); or (3) an asynchrony detection threshold larger than 2.5 standard deviations from the group mean.

Figure 1. Setup and trial design asynchrony detection task and RHI. A) In the visual-tactile asynchrony detection task, participants detected asynchronies between LED and tactor stimuli that were presented to the right index finger. We implemented a two-interval forced-choice (2 IFC) task and participants indicated whether the asynchrony between the visual and tactile stimuli was present in the first or second interval using a button box with their left hand. B) We used two types of RHI stimulation conditions: manual brush stroking and LED/tactor stimulation. For each of the RHI trials, we measured perceived index finger position before stimulation, after two minutes and again after four minutes of stimulation (i.e., proprioceptive drift). At the end of each RHI trial, participants also filled out a set of rating scales.

2.4 Rubber Hand Illusion

We implemented both manual brushing and LED/tactor stimulation in a repeated measures design. Participants were seated at a table with their right hand inside the box (Figure 1B) and their shoulder covered by a black cloak. The box could be opened to reveal a right prosthetic hand (Otto Bock Australia Pty Ltd) placed 20 cm away from the participant's concealed real hand and approximately 10 cm towards the right of the body midline. Participants were instructed to keep their right hand as still as possible throughout the task and look at the artificial hand.

Visual-tactile stimulation was applied on the index finger either using two round paintbrushes (approximately 1 cm diameter) or the LED and miniature electromagnetic tactile stimulator (Figure 1B). In the brushing conditions, the experimenter used earphones to listen to a metronome that indicated stimulation time and frequency. In the LED and tactile stimulation conditions, a tactor was attached to the joint of the distal and intermediate phalanges on the top of the right index finger just below the fingernail using an adhesive sticker. A dummy tactor was attached in the same position on the artificial rubber hand and an LED was placed just above that tactor. Participants wore headphones during all RHI trials to block out noise from the tactors and to be consistent in the brushing trials.

We used five different RHI conditions. In the *synchronous brushing* condition, the experimenter administered synchronous brushstrokes bimanually every second matching the brushing on the fake and real hands as closely as possible. In the *asynchronous brushing*

condition, there was a 500 ms gap between brushing the fake and real hand creating a noticeable mismatch.

In addition, we used three LED / tactor stimulation conditions. In the *synchronous* condition, the visual and tactile stimulation (10 ms duration each) occurred at the same time and was repeated every second. In the *asynchronous* condition, stimuli also occurred on average every second, but there was an asynchrony of between 450 to 550 ms between the visual and tactile stimuli, with which came first and the actual asynchrony duration randomised on each trial. In the *slightly asynchronous* condition, the asynchrony was only between 50 and 150 ms, selected because participants should on average be able to detect such visual-tactile asynchronies in the control group (Keys et al., 2018; Costantini et al., 2016; Smit, Rich, & Zopf, 2019), but not in the schizophrenia group where we expected a reduced sensitivity for asynchrony detection. In each RHI trial, the experimenter ensured that participants looked at the artificial hand during stimulation.

For each of the RHI trials, we measured perceived index finger position for the proprioceptive drift measure before stimulation, after two minutes and again after a further two minutes of stimulation. The drift measure involved covering the RHI box and placing a ruler on top of the box. Participants were asked to report verbally which number they felt corresponded to the location of their right index finger if they drew a straight line from the finger up to the ruler. The ruler offset was randomised across judgements.

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At the end of each RHI trial, participants completed a 12-item rating scale presented in a random order (Botvinick & Cohen, 1998; Longo, Schuur, Kammers, Tsakiris, & Haggard, 2008). We used statements relating to embodiment of the artificial hand and two further statements related to hand location and touch (Table 2). Participants responded using a Likert scale of -3 (disagree strongly) to +3 (agree strongly).

Table 2. RHI rating scale items.

It seemed like the rubber hand was my hand.

It seemed like I was looking directly at my own hand rather than a rubber hand.

It seemed like the rubber hand began to resemble my real hand.

It seemed like the rubber hand belonged to me.

It seemed like the rubber hand was part of my body.

It seemed like my hand was in the location where the rubber hand was.

It seemed like the touch I felt was caused by the light flash/paintbrush at the rubber hand.

It seemed like the rubber hand was in the location where my hand was.

It seemed like I was in control of the rubber hand.

It seemed like I could have moved the rubber hand if I had wanted.

It felt as though my hand had changed position and was located closer to the rubber hand.

It seemed like I was feeling the touch in the location where I saw the rubber hand.

Testing took place with slightly dimmed lights enabling good visibility of the artificial hands and also the LED stimulation. Participants initially completed the first section of a separate belief formation experiment (not reported here, approximately 30 minutes). To spread out the RHI trials, we completed one RHI trial, followed by the asynchrony detection task, followed by the PAS and SPQ, and then two more RHI trials. Participants then completed the remainder of the belief formation experiment (approximately 30 minutes), before the final two RHI trials. Clinical interviews (SAPS/SANS for schizophrenia participants; SCID screener for HCs) were completed at the end of the session. We counterbalanced the order of the RHI trials; due to the time required to change the RHI setup, the brushing conditions were always administered together. Thus, the first and last two RHI trials were always a

LED/tactor stimulations (order of synchronous, slightly asynchronous and asynchronous conditions counterbalanced) and the second and third trial involved brushing (synchronous versus asynchronous brushing counterbalanced).

We calculated illusion mean scores by averaging across all rating scales for each of the five conditions. The proprioceptive drift is the difference between the pre- and post-stimulation judgements.

2.5 Statistical Analysis

To investigate the relationship between perceptual aberration and asynchrony detection thresholds we used correlation and regression analyses, applying Bonferroni correction for multiple comparisons. We compared the RHI measures using ANOVAs with two levels on the between-subject factor Group and five levels on the within-subject factor Induction condition. To explore the effects of TBWs and perceptual symptoms on the RHI, we also used an ANCOVA with the covariates of TBW, body-related and non-body-related perceptual symptoms as well as a mediation analyses. Our significance threshold was $p=0.05$. For theoretically interesting comparisons, we also ran Bayes t-tests to evaluate the evidence for a null result (Dienes, 2014). We used a default Cauchy prior ($r=0.707$) for the size of the effect and specified a non-directional alternative hypothesis. We considered a Bayes Factor of smaller than 1/3 as moderate and between 1/3 and 1 as anecdotal evidence for the null hypothesis (Jeffreys, 1961). To plot and analyse our data we used R. The data and analysis script can be found at our OSF project page (https://osf.io/dxp6n/?view_only=5850828897fd4b9481fb6af189eab486).

3. Results

3.1 Visual-tactile asynchrony detection task

As predicted, we found larger visual-tactile asynchrony detection thresholds in the schizophrenia group compared to controls ($t(42)=2.88$, $p=0.006$, $d=0.87$, $M_{\text{diff}}=70.29$ ms, 95%CI [21.09, 119.49]; schizophrenia $M=193.20$ ms, 95%CI [151.33, 235.07]; control $M=122.91$ ms, 95%CI [96.40, 149.43], Figure 2). We also found that the range of thresholds was larger in schizophrenia and noted that the distributions overlap: not all participants with schizophrenia exhibited larger asynchrony detection thresholds compared to the control group sample (Figure 2B). The asynchrony detection thresholds in the control group were somewhat lower compared to thresholds we previously found for visual-leading conditions (152 ms, Keys et al., 2018), but that is probably because here we only had visual-leading and not intermingled visual-leading and tactile-leading conditions as in the earlier study (also see Keys et al., 2018 for reduced tactile leading thresholds when presented not intermingled). The lower thresholds do not affect our ability to test our predictions with regard to the RHI conditions, as for the *slightly asynchronous* condition (50 to 150 ms asynchronies), the ‘average’ person in the control group should be able to detect these (mean threshold 122.91 ms) but not the ‘average’ person in the schizophrenia group (mean threshold 193.20 ms).

Figure 2. Results visual-tactile asynchrony detection task. A) Group averages for fitted sigmoid function to the mean proportion correct asynchrony detection across SOAs (standard deviation in grey, estimated 75% detection threshold as dashed line). B) We found significant larger asynchrony detection thresholds for the schizophrenia group (black) compared to controls (light grey). Individual data points are represented as dots and error bars represent 95% confidence intervals.

3.2. Perceptual aberration and visual-tactile asynchrony detection

As expected, we found that body-related perceptual symptom scores were on average higher in the schizophrenia compared to the control group (Figure 3A, body-related: $M_{\text{diff_group}} = 4.09$, 95%CI [1.13, 7.06], $t(39.1)=2.79$, $p= 0.008$, $d= 0.83$). At an individual level, however, not all participants with schizophrenia had higher scores compared to the control mean and there were two control participants with relatively high scores.

Figure 3. Results of perceptual aberration. A) We found higher perceptual aberration scores for body-related items compared to the control group in some but not all individuals with schizophrenia and also in two controls. B) We found a significant positive correlation between asynchrony detection thresholds and the report of body-related perceptual aberrations. Error bars represent 95% confidence intervals.

Investigating the link between temporal asynchrony detection thresholds and body-related perceptual aberration, we found a significant positive correlation across both groups (Figure 3B, $r=0.59$, $p<0.001$). This correlation was also significant within just the patient ($r=0.47$, $p=0.025$) and the control ($r=0.65$, $p=0.001$) groups. Although correlational, this suggests that a temporal perception deficit could contribute to the self-reported body-related aberrations. However, reduced asynchrony detection sensitivity and the report of body-related perceptual aberrations may also be both part of a broader aberrant perception.

To examine this, we tested if temporal perception can predict body-related perceptual aberrations when controlling for self-reported broader perceptual aberrations beyond body perception (non-body-related perceptual aberration including unusual sight and sound experiences). This allowed us to test if there is a specific contribution of temporal perception to bodily aberrations, or if all perceptual differences are simply part of broader perceptual aberration in schizophrenia. To this end, we conducted a multiple linear regression analysis to predict body-related perceptual aberration based on asynchrony detection thresholds and non-body-related perceptual symptom scores. The regression model was significant ($F(2,41)=41.67$, $p<0.001$), with an R^2 of 0.670. Both temporal asynchrony detection thresholds ($b=0.018$, 95%CI[0.006,0.030], $\beta=0.297$, $t=2.931$, $p=0.006$) and a broader perceptual aberration ($b=0.872$, 95%CI[0.593,1.152], $\beta=0.638$, $t=6.301$, $p<0.001$) were significant predictors for body-related perceptual aberration. Although this shows that both temporal and broader perceptual changes can predict body-related perceptual aberration, it also suggests that asynchrony detection thresholds can specifically predict body-related perceptual aberration.

3.3 Rubber hand illusion and visual-tactile asynchrony detection

For the rating scale measure, the 2 x 5 ANOVA revealed a main effect of Induction condition ($F[4,168]=3.04, p=0.019, \eta_p^2=0.07$). As can be seen in Figure 4A, manual brushing the *synchrony* condition led to relatively higher illusion scores compared to asynchronous brushing. In contrast, the LED/tactor illusion scores were on average lower than for synchronous and higher than for asynchronous brush stroking and were quite similar across synchrony conditions. The rating scores were relatively low overall and below zero on average even in the synchronous condition across both groups. Thus, although we did find an effect of Induction condition, many participants in both groups did not report a strong illusion experience.

We also found a main effect of Group ($F[1,42]=4.52, p=0.039, \eta_p^2=0.10$), as individuals with schizophrenia reported higher RHI ratings, across all Induction conditions, compared to controls. In contrast to our predictions, we did not find a significant interaction between Group and Induction condition ($F[4,168]=1.61, p=0.173, \eta_p^2=0.04$). Because schizophrenia participants have increased temporal asynchrony detection thresholds, we predicted that they would experience an increased illusion in the *synchronous brushing* and *slightly asynchronous* LED/tactor manipulations, but experience a similar illusion to controls in the completely *synchronous* LED/tactor manipulation. For the *slightly asynchronous* LED/tactor manipulation participants did show relatively increased illusion scores, however, this was also the case for the *synchronous* LED/tactor condition and the Bayes Factor for the difference (interaction) was 0.298. Thus, overall, and counter to our hypotheses, we found moderate evidence that the exact timing of the stimuli (*synchronous* versus *slightly*

asynchronous) did *not* modulate illusion susceptibility in schizophrenia patients compared to controls, despite the wider TBWs in the schizophrenia group.

The proprioceptive drifts were not statistically different from zero (see Figure 4B, which shows that all confidence intervals are overlapping with zero). In contrast to the rating scale data, we found no significant Induction condition main effect ($F[4,168]=0.24, p=0.918, \eta_p^2 < .01$) and also no Group main effect ($F[1,42]=0.83, p=0.367, \eta_p^2 = 0.02$) or interaction ($F[4,168]=0.26, p=0.906, \eta_p^2 < .01$).

Figure 4. Results RHI. A) Mean rating scores for all RHI conditions for the schizophrenia (dark grey) and control groups (light grey). We found significant main effects for condition and group, but no significant interaction. B) Mean proprioceptive drift values for all RHI conditions for the schizophrenia (dark grey) and control groups (light grey). We found no significant effects for condition and group. Individual data points are represented as dots and error bars represent 95% confidence intervals.

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To explore if there are any effects of individual TBWs or perceptual symptoms on the RHI scores, we also ran an ANCOVA with the covariates of TBW, body-related perceptual and non-body-related symptoms. We found that the body-related perceptual symptom score was significantly related to the overall RHI rating ($F[1,39]= 4.63, p=0.038, \eta_p^2=0.106$). This was not the case for the temporal asynchrony detection thresholds ($F[1,39]= 0.059, p=0.810, \eta_p^2=0.002$) or the non-body-related perceptual symptom score ($F[1,39]= 0.001, p=0.973, \eta_p^2<0.001$). Furthermore when controlling for body-related perceptual aberration, the main effect of Group was no longer significant ($F[1,39]= 0.461, p=0.501, \eta_p^2=0.012$). In other words, higher RHI self-ratings in schizophrenia compared to control groups can be predicted by higher body-related perceptual aberration scores, but not by a schizophrenia diagnosis *per se*.

Using a mediation analyses, we further explored the relationship between the three variables TBW, body-related perceptual symptoms and RHI (Figure 5). In line with the above analyses, the direct effect of temporal asynchrony detection thresholds on RHI scores was not significant. We found a significant indirect effect of temporal asynchrony detection thresholds through body-related perceptual aberration.

Mediation analysis

Figure 5. Mediation analysis. The mediation analysis revealed a significant indirect effect of temporal asynchrony detection thresholds on rubber hand illusion scores through body-related perceptual aberration.

4. Discussion

We tested if changes in the perception of temporal synchrony are linked to self-reported unusual body perceptions and bodily illusion susceptibility. As expected, individuals with schizophrenia had on average larger temporal binding windows and required larger temporal differences before they could reliably detect an asynchrony between a visual and tactile stimulus. This is consistent with well-documented perceptual changes in the temporal domain in schizophrenia (Arzy, Mohr, Molnar-Szakacs, & Blanke, 2011; Foucher et al., 2007; Stevenson et al., 2017). It is important to note that, although the group level effects are robust, the data plots show that not all individuals diagnosed with schizophrenia have increased asynchrony detection thresholds compared to the control group mean.

With respect to body-related perceptual aberration, we found that individuals with higher asynchrony detection thresholds also tended to have higher self-reported body-related perceptual aberration. Asynchrony detection ability is a significant predictor for body-related perceptual symptoms even when controlling for the presence of broader perceptual aberrations. These correlational findings suggest that changes in temporal perception might contribute to unstable and unusual body perceptions. This interpretation requires more testing but it is consistent with experimental evidence showing that temporal information is important for linking multisensory signals and estimating where one's own body is in space (Pritchard et al., 2016; Zopf et al., 2011). Here we provide correlational evidence that a disruption in temporal perception can specifically predict self-reported unusual body perceptions such as changed bodily experiences of ownership, boundaries, and size.

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Bodily perception does not just rely on the integration of tactile and visual signals but also other sensory signals. For example, vestibular input is important for perceiving one's own body in space (Lopez, Halje, & Blanke, 2008). The temporal-parietal cortex plays an important role in integrating visual, somatosensory and vestibular bodily signals for bodily self-awareness (Blanke, 2012). Meehl (1990), in his theory of schizophrenia and schizotypy, suggests that spatial-kinesthetic-vestibular system aberrations could account for bodily aberrations. Interestingly, previous neurophysiology research using electroencephalography (EEG) recordings found that bodily perceptual aberration (in participants without a schizophrenia diagnosis) was positively correlated with the duration but not the strength of activation of temporal-parietal cortex during a body transformation task (Arzy, Mohr, Michel, & Blanke, 2007; Arzy et al., 2011). This change in duration of neural activity suggests that temporal processing changes also influence the integration of visual, somatosensory with vestibular inputs and provides further indirect evidence for the role of temporal processing for aberrant spatial body perception.

A central view of Bayesian accounts of psychosis is that positive symptoms in schizophrenia, such as perceptual aberrations as well as hallucinations and delusions, arise because stored information or perceptual priors are relatively imprecise (Sterzer et al., 2018; Fletcher & Frith, 2009). In the case of stored models or priors for one's own body such as for the relative position of body parts and their size and shape (Tame, Azanon, & Longo, 2019; Gadsby, 2017), a deficit in processing temporal asynchronies may lead to increased uncertainties about what is and what is not one's own body and thus to stored body-related priors with a relatively low precision. In other words, there might be imprecise spatial parameters for one's body, because the binding of spatial, visual and somatosensory information for one's own

body through temporal multisensory cues is imprecise. According to Bayesian accounts of psychosis, low precision priors can in turn lead to aberrant experiences because perceptual inference is more strongly driven by sensory data which in turn can be noisy (Sterzer et al., 2018). Thus, when relatively weak or noisy sensory incoming information for bodily parameters (which may occur in daily life for example when there are no multisensory or visual cues) is combined with an imprecise prior, this can increase the occurrence of unusual perceptions for one's own body.

We also tested if perceptual capacities to discriminate visual-tactile asynchrony can account for previous mixed findings in susceptibility to the RHI across different induction techniques in schizophrenia. We predicted that the influence of this reduction in temporal asynchrony detection on RHI susceptibility in schizophrenia would depend on the illusion induction technique, in particular, on the exact timing of the visual-tactile stimulation. However, in contrast to our predictions, participants with schizophrenia tended to give on average higher RHI ratings than healthy controls irrespective of stimulus timing. A Bayesian analysis provided evidence that the schizophrenia group who, on average, have higher asynchrony detection thresholds, **do not** have higher illusion scores in a slightly asynchronous illusion condition (when detecting asynchronies can influence the illusion) compared to a completely synchronous condition (when detecting asynchronies should not play a role). A mediation analyses provided further evidence that differences in temporal perception in schizophrenia cannot directly account for susceptibility to experimentally induced bodily illusions across different induction techniques.

Overall, we found relatively low illusion scores and proprioceptive drifts in both groups, suggesting that most participants did not experience a strong RHI. This could have resulted in a floor effect and consequently in a null finding for the predicted modulations by induction technique. Relatively low RHI scores (lower or close to zero for most or some RHI items) have also been reported in previous studies in schizophrenia and also in controls (Kaplan et al., 2014; Peled et al., 2000; Thakkar et al., 2011). A recent general population study comparing the RHI across different age groups found significant reductions in a middle-aged group (44-55 years) compared to young (20-22 years) and older (60-72) adults (Marotta, Zampini, Tinazzi, & Fiorio, 2018). Although other studies did not report age differences for the RHI, they did not specifically test a middle-aged group (Campos, El-Khechen Richandi, Taati, & Keshavarz, 2018; Palomo et al., 2018). The mean age of our schizophrenia and control groups was 49 years and 50 years respectively, making it possible that the age of our clinical and control samples contributed to their low RHI scores.

In addition, our findings with respect to the subjective rating scale and more objective proprioceptive drift measure of the RHI did not converge. We found main effects for the subjective measure for both condition and group, but we did not find any significant effects for the objective measure. This finding aligns with existing literature: of those studies that have used both rating scale and drift measures in schizophrenia or schizotypy, only one study reported significant group differences for both measures (Thakkar et al., 2011), whereas the vast majority report no significant group effects for proprioceptive drift (Germine et al., 2013; Kaplan et al., 2014; Prikken et al., 2018; Shaqiri et al., 2018). This is in contrast to other RHI effects in other disorders characterised by abnormal body perception, such as eating disorders, where group effects for both subjective and objective measures have been

reported (Eshkevari, Rieger, Longo, Haggard, & Treasure, 2012, 2014; Zopf, Contini, Fowler, Mondraty, & Williams, 2016; although only a trend for drift after correction for multiple comparisons: Keizer, Smeets, Postma, van Elburg, & Dijkerman, 2014). It has been suggested that both subjective and objective measures should converge when arguing for a perceptual effect in the RHI (e.g., Kalckert & Ehrsson, 2014). Thus, given the present and previous findings showing that the results for different RHI measures do not converge, there is no strong evidence that differences in schizophrenia for the RHI reflect alterations to perceptual mechanisms.

Instead, our exploratory findings suggest that other factors associated with experiencing perceptual symptoms, especially with respect to the body, could account for group differences in RHI ratings between schizophrenia and control groups. This suggests that experiencing more bodily perceptual symptoms increases the likelihood of endorsing unusual bodily experiences, resulting in higher RHI self-ratings. In accord with this suggestion, a previous study found significant correlations between RHI ratings and a measure of positive schizotypy that included items for perceptual aberrations in non-clinical adults (Germine et al., 2013). Although Kaplan et al. (2014) used a perceptual aberration measure and found no significant correlations with illusion ratings, that study included people with a body dysmorphic disorder as well as people with schizophrenia, making comparison with the present findings difficult. Of particular importance, we found that only body-related (and not non-body-related) perceptual aberrations could account for our group difference in RHI ratings. We therefore suggest that future research should take body and non-body perceptual aberration symptoms into account when investigating body perception and bodily illusions in schizophrenia and other clinical and non-clinical populations.

Overall, we found that individual differences in temporal perception can predict bodily perceptual aberrations. We propose that temporal perception deficits potentially contribute to more unstable and unusual body perceptions that can occur in some (but not all) individuals with schizophrenia or those who are prone to psychosis. Furthermore, deficits in perceiving asynchronies between sensory stimuli in schizophrenia do not directly explain alterations of body perception in the experimental RHI setting. However, the relatively low illusion scores in our study, which may reflect the mature ages of our clinical and control groups, may have resulted in floor effects that obscured such evidence, suggesting the need for future research with early psychosis or at-risk youth. Instead, we provide preliminary evidence that perceptual symptoms of bodily aberration, but not a schizophrenia diagnosis itself, can be linked to increased RHI ratings. Thus, the severity of body-related perceptual aberrations in clinical schizophrenia samples could potentially explain previous inconsistent RHI findings. Indeed, since we found group differences for self-report RHI scores, but not for the more objective measure of proprioceptive drift, it may be that experiences of perceptual bodily aberrations in people with schizophrenia simply increase preparedness to endorse unusual bodily experiences, including self-report RHI items.

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Data and analysis script are available on the Open Science Framework (OSF):

https://osf.io/dxp6n/?view_only=5850828897fd4b9481fb6af189eab486.

References

- Andreasen, N. C. (1983). *The Scale for the Assessment of Negative Symptoms (SANS)*. Iowa City, Iowa: The University of Iowa.
- Andreasen, N. C. (1984). *Scale for the Assessment of Positive Symptoms (SAPS)*. Iowa City, Iowa: University of Iowa.
- Arzy, S., Mohr, C., Michel, C. M., & Blanke, O. (2007). Duration and not strength of activation in temporo-parietal cortex positively correlates with schizotypy. *Neuroimage*, 35(1), 326-333. doi:10.1016/j.neuroimage.2006.11.027
- Arzy, S., Mohr, C., Molnar-Szakacs, I., & Blanke, O. (2011). Schizotypal perceptual aberrations of time: correlation between score, behavior and brain activity. *PloS One*, 6(1), e16154. doi:10.1371/journal.pone.0016154
- Asai, T., Mao, Z., Sugimori, E., & Tanno, Y. (2011). Rubber hand illusion, empathy, and schizotypal experiences in terms of self-other representations. *Consciousness and Cognition*, 20(4), 1744–1750. doi:10.1016/j.concog.2011.02.005
- Blanke, O. (2012). Multisensory brain mechanisms of bodily self-consciousness. *Nature Reviews Neuroscience*, 13, 556-571. doi:10.1038/nrn3292
- Botvinick, M., & Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. *Nature*, 391(6669), 756. doi:10.1038/35784
- Campos, J. L., El-Khechen Richandi, G., Taati, B., & Keshavarz, B. (2018). The Rubber Hand Illusion in Healthy Younger and Older Adults. *Multisensory Research*, 31(6), 537-555. doi:10.1163/22134808-00002614
- Castle, D. J., Jablensky, A., McGrath, J. J., Carr, V., Morgan, V., Waterreus, A., . . . Farmer, A. (2006). The diagnostic interview for psychoses (DIP): development, reliability and applications. *Psychological Medicine*, 36(1), 69-80. doi:10.1017/S0033291705005969
- Chapman, J. C., Edell, W. S., & Chapman, J. P. (1980). Physical anhedonia, perceptual aberration, and psychosis proneness. *Schizophrenia Bulletin*, 6(4), 639-653.

- Chapman, L. J., Chapman, J. P., & Raulin, M. L. (1978). Body-image aberration in schizophrenia. *Journal of Abnormal Psychology*, 87(4), 399-407.
- Chapman, L. J., Chapman, J. P., Kwapil, T. R., Eckblad, M., & Zinser, M. C. (1994). Putatively psychosis-prone subjects 10 years later. *Journal of Abnormal Psychology*, 103(2), 171-183.
- Costantini, M., Robinson, J., Migliorati, D., Donno, B., Ferri, F., & Northoff, G. (2016). Temporal limits on rubber hand illusion reflect individuals' temporal resolution in multisensory perception. *Cognition*, 157, 39-48. doi:10.1016/j.cognition.2016.08.010
- Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology*, 5. doi:10.3389/fpsyg.2014.00781
- Eshkevari, E., Rieger, E., Longo, M. R., Haggard, P., & Treasure, J. (2012). Increased plasticity of the bodily self in eating disorders. *Psychological Medicine*, 42(4), 819-828. doi:10.1017/S0033291711002091
- Eshkevari, E., Rieger, E., Longo, M. R., Haggard, P., & Treasure, J. (2014). Persistent body image disturbance following recovery from eating disorders. *The International Journal of Eating Disorders*, 47(4), 400-409. doi:10.1002/eat.22219
- Ferri, F., Costantini, M., Salone, A., Di Iorio, G., Martinotti, G., Chiarelli, A., . . . Gallese, V. (2014). Upcoming tactile events and body ownership in schizophrenia. *Schizophrenia Research*, 152(1), 51-57. doi:10.1016/j.schres.2013.06.026
- First, M. B., Spitzer, R. I., Gibbon, M., & Williams, J. B. (1996). *User's Guide for the Structured Clinical Interview for DSM-IV Axis I Disorders, Research Version*. New York, NY: New York State Psychiatric Institute, Biometrics Research Department.
- First, M. B., Spitzer, R. L., Gibbon, M., & Williams, J. B. W. (1997). *User's Guide for the Structured Clinical Interview for DSM-IV Axis I Disorders SCID-I: Clinician Version*: American Psychiatric Press.

- Fletcher, P. C., & Frith, C. D. (2009). Perceiving is believing: a Bayesian approach to explaining the positive symptoms of schizophrenia. *Nature Review Neuroscience*, 10(1), 48-58. doi:10.1038/nrn2536
- Foucher, J. R., Lacambre, M., Pham, B. T., Giersch, A., & Elliott, M. A. (2007). Low time resolution in schizophrenia Lengthened windows of simultaneity for visual, auditory and bimodal stimuli. *Schizophrenia Research*, 97(1-3), 118-127. doi:10.1016/j.schres.2007.08.013
- Gadsby, S. (2017). Explaining body size beliefs in anorexia. *Cognitive Neuropsychiatry*, 22(6), 495-507. doi:10.1080/13546805.2017.1401531
- Germine, L., Benson, T. L., Cohen, F., & Hooker, C. I. (2013). Psychosis-proneness and the rubber hand illusion of body ownership. *Psychiatry Research*, 207(1-2), 45-52. doi:10.1016/j.psychres.2012.11.022
- Graham, K. T., Martin-Iverson, M. T., Holmes, N. P., Jablensky, A., & Waters, F. (2014). Deficits in agency in schizophrenia, and additional deficits in body image, body schema, and internal timing, in passivity symptoms. *Front Psychiatry*, 5, 126. doi:10.3389/fpsyt.2014.00126
- Jeffreys, H. (1961). *The Theory of Probability* (3rd ed.). Oxford, England: Oxford University Press.
- Kalckert, A., & Ehrsson, H. H. (2014). The moving rubber hand illusion revisited: comparing movements and visuotactile stimulation to induce illusory ownership. *Consciousness and Cognition*, 26, 117-132. doi:10.1016/j.concog.2014.02.003
- Kaplan, R. A., Enticott, P. G., Hohwy, J., Castle, D. J., & Rossell, S. L. (2014). Is body dysmorphic disorder associated with abnormal bodily self-awareness? A study using the rubber hand illusion. *PloS One*, 9(6), e99981. doi:10.1371/journal.pone.0099981
- Keizer, A., Smeets, M. A., Postma, A., van Elburg, A., & Dijkerman, H. C. (2014). Does the experience of ownership over a rubber hand change body size perception in anorexia nervosa patients? *Neuropsychologia*, 62C, 26-37. doi:10.1016/j.neuropsychologia.2014.07.003

- Keys, R. T., Rich, A. N., & Zopf, R. (2018). Multisensory temporal processing in own-body contexts: plausibility of hand ownership does not improve visuo-tactile asynchrony detection. *Experimental Brain Research*, 236(5), 1431-1443. doi:10.1007/s00221-018-5232-4
- Longo, M. R., Schuur, F., Kammers, M. P., Tsakiris, M., & Haggard, P. (2008). What is embodiment? A psychometric approach. *Cognition*, 107(3), 978-998. doi:10.1016/j.cognition.2007.12.004.
- Lopez, C., Halje, P., & Blanke, O. (2008). Body ownership and embodiment: vestibular and multisensory mechanisms. *Clinical Neurophysiology*, 38(3), 149-161. doi:10.1016/j.neucli.2007.12.006
- Loughland, C., Draganic, D., McCabe, K., Richards, J., Nasir, A., Allen, J., . . . Carr, V. (2010). Australian Schizophrenia Research Bank: A Database of Comprehensive Clinical, Endophenotypic and Genetic Data for Aetiological Studies of Schizophrenia. *Australian and New Zealand Journal of Psychiatry*, 44(11), 1029-1035. doi:10.3109/00048674.2010.501758
- Marotta, A., Zampini, M., Tinazzi, M., & Fiorio, M. (2018). Age-related changes in the sense of body ownership: New insights from the rubber hand illusion. *PloS One*, 13(11), e0207528. doi:10.1371/journal.pone.0207528
- Meehl, P. E. (1990). Toward an integrated theory of schizotaxia, schizotypy, and schizophrenia. *Journal of Personality Disorders*, 4(1), 1-99.
- Nelson, H. E. (1982). *The National Adult Reading Test (NART): For the Assessment of Premorbid Intelligence in Patients with Dementia*. Windsor, UK: NFER-Nelson.
- Noel, J.-P., Stevenson, R. A., & Wallace, M. T. (2018). Atypical audiovisual temporal function in autism and schizophrenia: similar phenotype, different cause. *European Journal of Neuroscience*, 47(10), 1230-1241. doi:10.1111/ejn.13911
- Palomo, P., Borrego, A., Cebolla, A., Llorens, R., Demarzo, M., & Banos, R. M. (2018). Subjective, behavioral, and physiological responses to the rubber hand illusion do not

vary with age in the adult phase. *Consciousness and Cognition*, 58, 90-96.

doi:10.1016/j.concog.2017.10.014

Peled, A., Ritsner, M., Hirschmann, S., Geva, A. B., & Modai, I. (2000). Touch feel illusion in schizophrenic patients. *Biological Psychiatry*, 48(11), 1105-1108.

Prikken, M., van der Weiden, A., Baalbergen, H., Hillegers, M. H., Kahn, R. S., Aarts, H., & van Haren, N. E. (2018). Multisensory integration underlying body-ownership experiences in schizophrenia and offspring of patients: a study using the rubber hand illusion paradigm. *Journal of Psychiatry and Neuroscience*, 44(1), 1-8.

doi:10.1503/jpn.180049

Prins, N., & Kingdom, F. A. A. (2018). Applying the Model-Comparison Approach to Test Specific Research Hypotheses in Psychophysical Research Using the Palamedes Toolbox. *Frontiers in Psychology*, 9, 1250. doi:10.3389/fpsyg.2018.01250

Pritchard, S. C., Zopf, R., Polito, V., Kaplan, D. M., & Williams, M. A. (2016). Non-hierarchical influence of visual form, touch, and position cues on embodiment, agency, and presence in virtual reality. *Frontiers in Psychology*, 7, 1649.

doi:10.3389/fpsyg.2016.01649

Raine, A., & Benishay, D. (1995). The SPQ-B: A brief screening instrument for schizotypal personality disorder. *Journal of Personality Disorder*, 9(4), 346-355.

Riemer, M., Trojan, J., Beauchamp, M., & Fuchs, X. (2019). The rubber hand universe: On the impact of methodological differences in the rubber hand illusion. *Neuroscience and Biobehavioral Reviews*, 104, 268-280. doi:10.1016/j.neubiorev.2019.07.008

Shaqiri, A., Roinishvili, M., Kaliuzhna, M., Favrod, O., Chkonia, E., Herzog, M. H., . . . Salomon, R. (2018). Rethinking Body Ownership in Schizophrenia: Experimental and Meta-analytical Approaches Show no Evidence for Deficits. *Schizophrenia Bulletin*, 44(3), 643-652. doi:10.1093/schbul/sbx098

Smit, S., Rich, A. N., & Zopf, R. (2019). Visual body form and orientation cues do not modulate visuo-tactile temporal integration. *PloS One*, 14(12), e0224174.

doi:10.1371/journal.pone.0224174

- Sterzer, P., Adams, R. A., Fletcher, P., Frith, C., Lawrie, S. M., Muckli, L., . . . Corlett, P. R. (2018). The Predictive Coding Account of Psychosis. *Biological Psychiatry*, 84(9), 634-643. doi:10.1016/j.biopsych.2018.05.015
- Stevenson, R. A., Park, S., Cochran, C., McIntosh, L. G., Noel, J. P., Barense, M. D., . . . Wallace, M. T. (2017). The associations between multisensory temporal processing and symptoms of schizophrenia. *Schizophrenia Research*, 179, 97-103. doi:10.1016/j.schres.2016.09.035
- Tame, L., Azanon, E., & Longo, M. R. (2019). A Conceptual Model of Tactile Processing across Body Features of Size, Shape, Side, and Spatial Location. *Frontiers in Psychology*, 10, 291. doi:10.3389/fpsyg.2019.00291
- 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. doi:10.1371/journal.pone.0027089
- Vroomen, J., & Keetels, M. (2010). Perception of intersensory synchrony: a tutorial review. *Attention, Perception & Psychophysics*, 72(4), 871-884. doi:10.3758/APP.72.4.871
- Woods, S. W. (2003). Chlorpromazine equivalent doses for the newer atypical antipsychotics. *Journal of Clinical Psychiatry*, 64(6), 663-667. doi:10.4088/JCP.v64n0607
- Zopf, R., Truong, S., Finkbeiner, M., Friedman, J., & Williams, M. A. (2011). Viewing and feeling touch modulates hand position for reaching. *Neuropsychologia*, 49(5), 1287-1293. doi:10.1016/j.neuropsychologia.2011.02.012
- Zopf, R., Contini, E., Fowler, C., Mondraty, N., & Williams, M. A. (2016). Body distortions in Anorexia Nervosa: Evidence for changed processing of multisensory bodily signals. *Psychiatry Research*, 245, 473-481. doi:10.1016/j.psychres.2016.09.003