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

RUNNING TITLE: Synchrony and body perception in schizophrenia

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Abstract

Body perception can be altered in individuals with schizophrenia resulting in experiences of undefined boundaries, loss of ownership, and size changes. 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 multisensory timing, which is thought to be fundamental for body perception, is altered in schizophrenia. We tested whether altered perception of the temporal relationship between visual and tactile signals in schizophrenia predicts self-reported perceptual aberrations and RHI susceptibility. We found that the sensitivity to detect temporal asynchronies is reduced in schizophrenia and this is a significant predictor for 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. Our findings provide new insight into factors that may underlie the report of unusual body perceptions in schizophrenia.

Keywords: synchrony perception; body perception; bodily illusions; schizophrenia; psychosis; perceptual aberration

1. Introduction

People with schizophrenia report unusual experiences of reality, including unusual perceptions of the body as reported by some, but not all, individuals diagnosed with schizophrenia and also by individuals who are psychosis-prone (Chapman et al., 1980; Chapman et al., 1994; Chapman et al., 1978). The perception of temporal relationships can also be altered. The ability to discriminate if sensory events occurred at the same time (synchronously) or at different times (asynchronously) is reduced relative to healthy controls (Foucher et al., 2007). Processing multisensory timing is fundamental for perceiving one's own body in space (Pritchard et al., 2016; Zopf et al., 2011). Thus, a deficit in this ability could contribute to body-related perceptual symptoms.

Our first study 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. To this end, we measured self-reported perceptual symptoms and the extent to which different sensory inputs can be asynchronous and yet still not be distinguished from synchronous inputs (i.e., temporal binding windows: TBWs) in people with schizophrenia and healthy controls.

Individuals with schizophrenia may also be more susceptible to unusual bodily experiences evoked in bodily illusions such as the rubber hand illusion (RHI), although the findings are mixed (Ferri et al., 2014; Graham et al., 2014; Kaplan et al., 2014; Peled et al., 2000; Prikken et al., 2018; Shaqiri et al., 2018; Thakkar et al., 2011). In the RHI, participants, including neurotypical populations, experience a fake body part (a rubber hand) as their own. The illusion is induced when participants simultaneously view touch on the rubber hand and feel touch on their own hand (which is hidden from sight) (Pritchard et al., 2016; Zopf et al., 2011). Processing the timing of multisensory stimuli is crucial for the RHI as the strength of the illusion diminishes when the tactile and visual stimuli are asynchronous.

Decreased ability to process temporal synchrony in schizophrenia could influence susceptibility to the RHI and explain the mixed findings. Studies using the technique of synchronous manual stroking with brushes or fingers of the real and rubber hands reported increased illusion susceptibility in schizophrenia compared to controls (Kaplan et al., 2014; Peled et al., 2000; Thakkar et al., 2011), although not all such studies found differences (Prikken et al., 2018). Manual stroking 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). In contrast to manual stroking, the use of technologies such as video projections or virtual reality controls the timing of stimulation in RHI paradigms or full body variants. While there might still be temporal discrepancies between the visual-tactile stimulations, these are likely smaller and highly consistent. With these methods, there are no reported differences between schizophrenia and control groups in body ownership illusions (Graham et al., 2014; Shaqiri et al., 2018). It may thus be that increased bodily illusion susceptibility in schizophrenia depends on the timing between the inducing stimuli.

For individuals who are better at detecting slight asynchronies (narrower TBWs), perceiving temporal differences between tactile and visual stimuli could reduce the illusion. In contrast, those with poorer asynchrony detection sensitivity (wider TBWs), including people with schizophrenia, may not detect slight temporal differences and therefore show greater RHI susceptibility (Foucher et al., 2007). Previous research exploring how TBWs influence the RHI in the healthy population has shown that participants with wider TBWs indeed require greater asynchrony between visual and tactile stimuli to prevent the experience of the RHI (Costantini et al., 2016).

Here, our second aim was to test if temporal perception ability can account for previous mixed RHI findings in schizophrenia. We used manual stimulation, for which we expected greater effects of wider TBWs due to some variance in timing, compared to 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 also to indicate their felt hand position to estimate “proprioceptive drift” towards the rubber hand, as is typical in RHI research (Riemer et al., 2019).

Previous research has also reported a link between the RHI and perceptual aberration in non-clinical psychosis-prone individuals (Asai et al., 2011; Germine et al., 2013). 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 with schizophrenia and 25 healthy controls participated. Data for one control were lost due to technical error. Data for one patient and three controls were excluded due to poor psychometric function fit in the visual-tactile asynchrony detection task (see below). Data for an additional patient were removed due to extreme detection values. The final sample comprised 23 individuals with schizophrenia (mean age 49 years, range 33-64 years) and 21 controls (mean age 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). Due to time constraints, NART data was not collected on one control participant. The groups differed in years of education, however, both groups had an average of > 12 years of formal education (Table 1).

Exclusion criteria included: history of neurological disease, head injury or 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 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 et al., 1997).

Schizophrenia participants were recruited from the Macquarie University Belief Formation and the Australian Schizophrenia Research Bank (ASRB, Loughland et al., 2010) registers. Individuals in the schizophrenia group were stable and medicated outpatients (see Table 1 for Chlorpromazine (CPZ) equivalences for antipsychotics, Woods, 2003). 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). Controls were recruited through the Cognitive Science community participant pool. Participants also took part in a separate study on belief formation (see below). The combined study was approved by the Macquarie University Human Ethics Review Committee. Participants provided written consent and received $15 per hour.

Table 1. Demographics of the schizophrenia and control groups.

	Schizophrenia Group (*n* =23)	Control Group (*n* = 21)	Group comparison	
Basic Demographics				
Age	49.0 (8.4)	50.1 (11.1)	$t_{42} = 0.39$,	$p = 0.699$
Gender (male: female)	15:8	12:9	$\chi^2 = 0.06$,	$p = 0.811$
Handedness (right: left)	21:1[a]	19:2	$\chi^2 = 1.35$,	$p = 0.510$
Years of education	12.3 (2.3)	14.5 (2.1)	$t_{42} = 3.27$,	$p = 0.002$
NART IQ	106.3 (9.5)	108.3 (8.6)	$t_{41} = 0.73$,	$p = 0.468$
Self-Report Measures				
Perceptual Aberration	8.1 (6.9)	2.4 (5.0)	$t_{40.07} = 3.18$,	$p = 0.003$
SPQ-B – Cognitive-Perceptual	4.3 (2.3)	1.2 (1.7)	$t_{40.25} = 4.99$,	$p < 0.001$
Clinical Demographics				
Age illness onset (years)	24.6 (7.2)			
Illness duration (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)			

[a] One member of the schizophrenia group reported mixed handedness.

[b] Composite scores (sum of the individual item scores)

2.2 Self-reported perceptual symptoms

We used the Chapman Perceptual Aberration Scale (PAS, Chapman et al., 1978) and the Schizotypal Personality Questionnaire (SPQ-B, Raine and Benishay, 1995) as self-report measures for perceptual symptoms. We calculated a *body-related perceptual symptom score* on the basis of the 28 body-specific PAS items and a *non-body-related perceptual symptom score* combining the 7 non-body PAS items with the cognitive-perceptual subscale SPQ-B.

2.3 Visual-tactile asynchrony detection task

We measured an individual's ability to detect visual-tactile asynchronies (Figure 1A, Keys et al., 2018). Visual stimuli consisted of 10ms LED (5 mm) illuminations. Tactile stimuli consisted of 10 ms vibrations of a miniature electromagnetic tactile stimulator (200Hz, 18mm diameter and 12mm height; Dancer Design, St. Helens, UK). The tactor was attached to the right index finger joint between the distal and intermediate phalanges. The top of the tactor could be seen such that the vibrating probe was not visible. The participants placed their right hand in a comfortable position and the LED sat ~ 3 cm above the tactor. Participants wore headphones (Seinheisser HD280) to block tactor sounds. Participants responded using a custom-built button box with the left index and middle fingers. Presentation® software (Version 0.70) controlled stimulus presentation.

Each asynchrony detection trial consisted of two intervals separated by 1000 ms (Figure 1A). The first or second interval (randomly assigned) contained a visual-tactile pair separated by a delay; the other interval a synchronous visual-tactile pair. Participants made forced choice responses as to whether a delay was present in the first (index finger button press) or second (middle finger button press) interval. Responses were recorded from 500 ms after the second stimulus and the next trial started 500 ms after the response. The visual and tactile stimulus onset asynchronies (SOAs) for the interval with the delay were 40, 80, 120, 160, 200, 240 or 280 ms, set in random order. Each SOA was repeated 20 times (total 140 trials, a break after every 20 trials). To become familiar with the task, participants completed a block of practice trials.

We fitted sigmoid functions (cumulative Gaussian) to the mean proportion asynchrony detection across all asynchronies using the MATLAB Palamedes toolbox (Prins and Kingdom, 2018). We then calculated an individual's detection threshold at the 75% point for which participants could reliably detect the asynchrony. We excluded data sets 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.

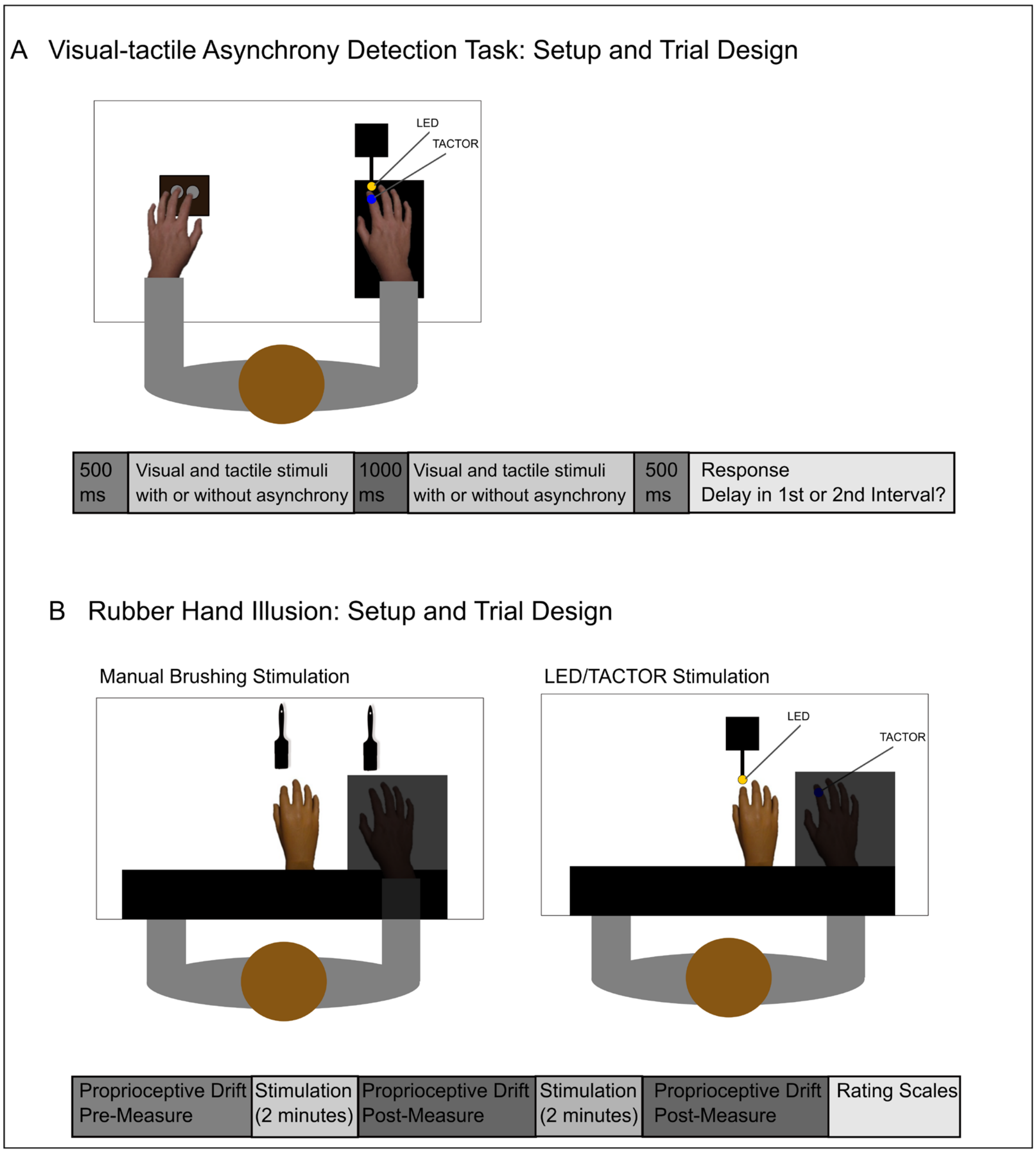

Figure 1. Setup and trial design asynchrony detection task (A) and RHI (B).

2.4 Rubber Hand Illusion

We implemented 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 hand. Participants wore headphones and were instructed to keep their right hand still and look at the fake hand.

In the brushing conditions (Figure 1B, left panel), stimulation was applied using two round paintbrushes (~ 1 cm diameter) and the experimenter listened to a metronome indicating stimulation time via headphones. In the LED/tactor conditions (Figure 1B, right panel), a miniature electromagnetic tactor was attached to the joint between distal and intermediate phalanges. A dummy tactor was attached in the same position on the fake rubber hand and an LED was placed just above that tactor.

In the *synchronous brushing* condition, the experimenter administered brushstrokes 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. In the *synchronous LED/tactor* condition, the visual and tactile stimulation (10 ms duration) occurred at the same time and was repeated every second. In the *asynchronous LED/tactor* condition, there was a visual-tactile asynchrony of between 450 to 550 ms (randomised time and order). In the *slightly asynchronous LED/tactor* condition, the asynchrony was between 50 and 150 ms, selected because participants should on average be able to detect such visual-tactile asynchronies in the control group (Costantini et al., 2016; Keys et al., 2018; Smit et al., 2019), but not in the schizophrenia group due to the expected reduced sensitivity for asynchrony detection.

We measured perceived index finger position before stimulation, after two minutes stimulation and again after a further two minutes. We covered the RHI box and placed a ruler on top. Participants reported the number corresponding to the location of their right index finger. Four possible ruler offsets were randomised across judgements. Proprioceptive drift was calculated as the difference between pre- and mean post-stimulation measures. At the end of each RHI trial, participants completed a 12-item rating scale presented in a random order (Supplementary Table 1, Botvinick and Cohen, 1998; Longo et al., 2008). Participants responded on a Likert scale of -3 (disagree strongly) to +3 (agree strongly). We calculated condition illusion scores by averaging across rating scales.

Testing took place with slightly dimmed lights enabling good visibility of the fake hand and LED stimulation. Participants initially completed the first section of a separate belief formation experiment (not reported here, ~ 30 minutes). To spread out the RHI trials, we then completed one RHI trial, followed by the asynchrony detection task, followed by the PAS and SPQ, and then two more RHI trials (~ 40 minutes). Participants then completed the remainder of the belief formation experiment (~ 30 minutes), before the final two RHI trials (~ 10 minutes). Clinical interviews 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 administered together. Thus, the first and last two RHI trials were a LED/tactor stimulations (order of synchronous, slightly asynchronous and asynchronous counterbalanced) and the second and third trial involved brushing (synchronous versus asynchronous counterbalanced).

2.5 Statistical Analysis

To investigate the relationship between perceptual aberration and asynchrony detection we used correlation and regression analyses. We compared RHI conditions using ANOVAs with between-subject factor Group and within-subject factor Induction condition (5 conditions). Furthermore, we ran an ANCOVA with the covariates TBW, body-related and non-body-related perceptual symptoms and a mediation analysis. We also ran Bayes t-tests to evaluate the evidence for a null result (default Cauchy prior of $r=0.707$) (Dienes, 2014). 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). We used R for analyses and plotting (data, scripts available on OSF: https://osf.io/dxp6n/?view_only=5850828897fd4b9481fb6af189eab486).

3. Results

3.1 Visual-tactile asynchrony detection task

We found larger visual-tactile asynchrony detection thresholds in the schizophrenia group compared to controls ($t(42)=2.88$, $p=0.006$, $d=0.87$, $M_{diff}=70.29$ 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], Supplementary Figure 1). There were no significant correlations between asynchrony detection thresholds and clinical symptom ratings (SAPS global mean, SANS global mean, SAPS delusions and hallucinations scores) within the patient group.

3.2. Perceptual aberration and visual-tactile asynchrony detection

We found that body-related perceptual symptom scores were on average higher in the schizophrenia compared to the control group (Figure 2A, $M_{diff\_group} = 4.09$, 95%CI [1.13, 7.06], $t(39.1)=2.79$, $p= 0.008$, $d= 0.83$). At an individual level, not all participants with schizophrenia had higher scores compared to the control mean and there were two control participants with relatively high scores (Figure 2A).

The correlation between temporal asynchrony detection thresholds and body-related perceptual aberration across both groups was significant (Figure 2B, $r=0.59$, $p<0.001$). This correlation was also significant within the patient ($r=0.47$, $p=0.025$) and the control ($r=0.65$, $p=0.001$) groups. This suggests that a temporal perception deficit could contribute to body-related symptoms. However, altered temporal perception and body-related perceptual aberrations may be both due to broadly aberrant perception.

To examine this, we tested if temporal perception can predict body-related perceptual aberrations when controlling for self-reported broader perceptual aberrations (non-body-related perceptual aberration including unusual sight and sound experiences). The regression model was significant ($F(2,41)=41.67$, $p<0.001$), with an R^2 of 0.670, and both temporal asynchrony detection threshold ($b=0.018$, 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. This shows that temporal perceptual changes can predict body-related perceptual aberration independently of a broader perceptual deficit, although only to some extent.

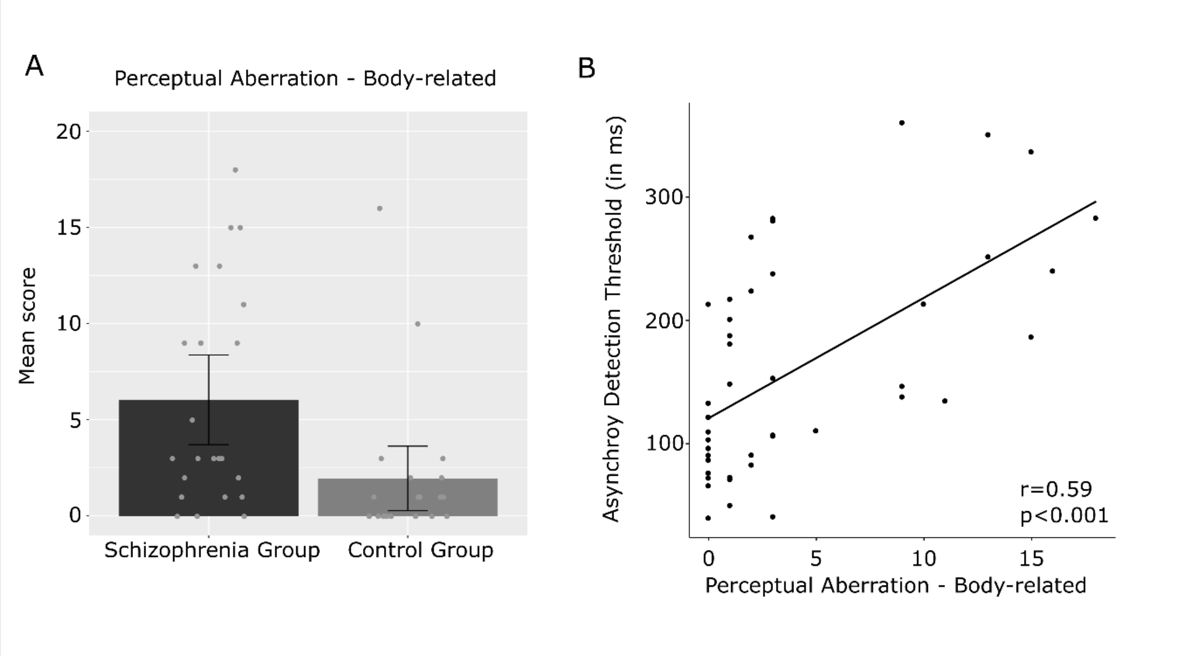

Figure 2. Results of perceptual aberration. A) We found higher body-related perceptual aberration scores in the schizophrenia compared control group in some but not all individuals and also in two controls. Individual data points are represented as dots and error bars represent 95% confidence intervals. B) We found a significant positive correlation between asynchrony detection thresholds and the report of body-related perceptual aberrations.

3.3 Rubber hand illusion and visual-tactile asynchrony detection

For the RHI, we found an effect of Induction condition (Figure 3A, *F*[4,168]=3.04, *p*=0.019, η_p^2=0.07). The manual *synchronous brushing* condition led to higher illusion scores compared to *asynchronous brushing*. In contrast, the LED/tactor condition scores were similar. The rating scores were relatively low overall and below zero on average even in the *synchronous brushing* condition. 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 an effect of Group (*F*[1,42]=4.52, *p*=0.039, η_p^2=0.10), as individuals with schizophrenia had higher RHI ratings 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, η_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 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 (Figure 3B). In contrast to the rating scale data, we found no significant Induction condition effect (*F*[4,168]= 0.24, *p*=0.918, $\eta_p^2 < .01$), and also no Group effect (*F*[1,42]=0.83, *p*=0.367, $\eta_p^2 = 0.02$) or interaction (*F*[4,168]=0.26, *p*=0.906, $\eta_p^2 < .01$).

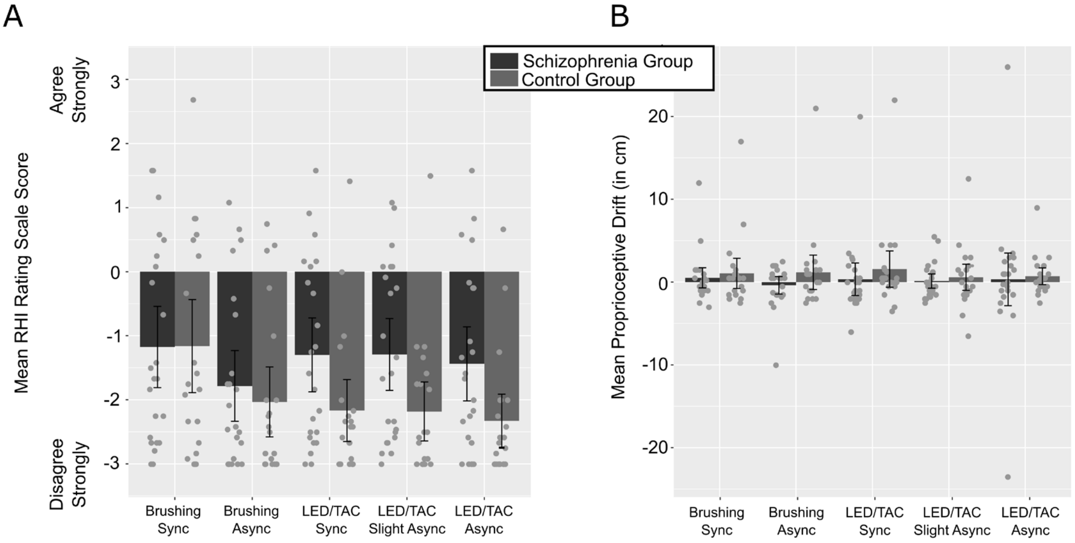

Figure 3. Results RHI. Condition means for the schizophrenia (dark grey) and control groups (light grey) for A) rating scores and B) Mean proprioceptive drift. Individual data points are represented as dots and error bars represent 95% confidence intervals.

Using an ANCOVA we examined effects of individual asynchrony detection thresholds and perceptual symptoms on RHI scores. Body-related perceptual symptom scores were significantly related to RHI scores (*F*[1,39]= 4.63, *p*=0.038, $\eta_p^2 = 0.106$). This was not the case for temporal asynchrony detection thresholds (*F*[1,39]= 0.059, *p*=0.810, $\eta_p^2 = 0.002$) or non-body-related perceptual symptom scores (*F*[1,39]= 0.001, *p*=0.973, $\eta_p^2 < 0.001$).

Furthermore, when including body-related perceptual aberration in the statistical model, the effect of Group was no longer significant (*F*[1,39]= 0.461, p=0.501, η_p^2=0.012).

In line with the above analyses, a mediation analysis (Figure 4) revealed that the direct effect of temporal asynchrony detection thresholds on RHI scores is not significant. In contrast the indirect effect of temporal asynchrony detection thresholds on RHI scores through body-related perceptual aberration is significant.

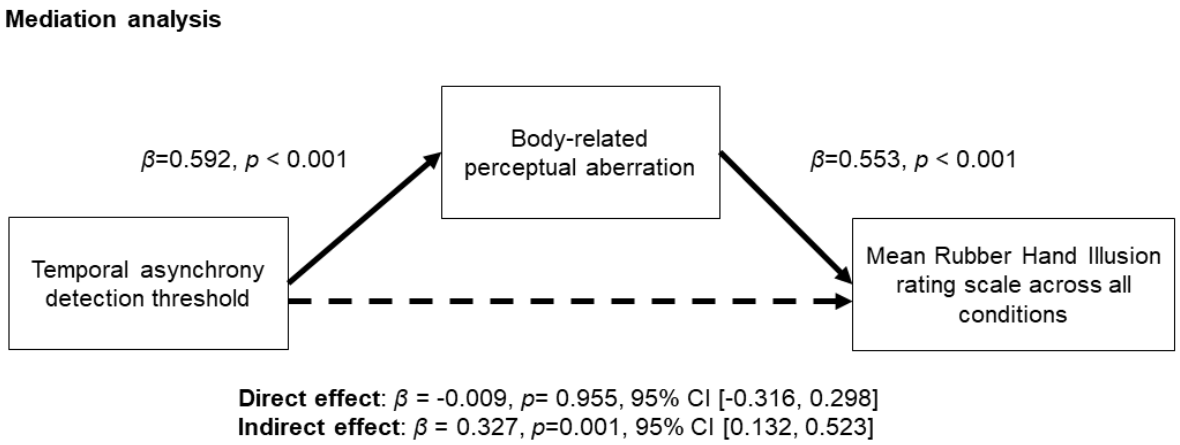

Figure 4. Mediation analysis. The mediation analysis revealed a significant indirect effect of temporal asynchrony detection thresholds on rubber hand illusion scores through body-related perceptual aberration.

4. Discussion

As expected, we found that 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 et al., 2011; Foucher et al., 2007; Stevenson et al., 2017). We found that individuals with higher asynchrony detection thresholds were also more likely to report body-related perceptual symptoms such as changed bodily experiences of ownership, boundaries, and size. This was the case also when controlling for the presence of broader perceptual aberrations and is consistent with experimental evidence showing that temporal information is one important factor for linking multisensory signals and estimating where one’s own body is in space (Pritchard et al., 2016; Zopf et al., 2011). On this basis we suggest that changes in temporal perception might be one factor that contributes to unusual body perceptions.

A Bayesian framework can provide possible accounts for how temporal perception deficits could contribute to unusual body perceptions. A central view of Bayesian accounts of psychosis is that positive symptoms in schizophrenia arise because stored information or perceptual priors are relatively imprecise (Fletcher and Frith, 2009; Sterzer et al., 2018) or, in the case of hallucinations, hyper-precise (Corlett et al., 2019). In the case of stored models or priors for one’s own body position, size and shape (Gadsby, 2017; Tame et al., 2019), a deficit in processing temporal asynchronies may lead to increased uncertainties and thus low precision. In other words, there might be imprecise spatial parameters for one’s body, because the association of spatial multisensory information for one’s own body through temporal cues is imprecise. Low precision priors could in turn lead to aberrant body experiences because perceptual inference is more strongly influenced by noisy sensory data (Sterzer et al., 2018). Alternatively, it may also be possible that hyper-precise priors underpin aberrant perception. If the priors are overly specific, then when incoming sensory information is noisy or imprecise, this may lead to an over-reliance (stronger weighting) on the prior, leading to perceptual aberration and increased RHI in schizophrenia.

We also tested if asynchrony detection deficits can account for mixed findings in RHI susceptibility. In contrast to our prediction, participants with schizophrenia on average gave higher RHI ratings than controls, irrespective of illusion induction technique. A Bayesian analysis indicated that the schizophrenia group ***does 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). An ANCOVA and mediation analyses further showed that differences in temporal perception cannot directly account for RHI susceptibility.

Overall, we found low illusion scores and proprioceptive drifts in both groups. This could have resulted in a floor effect and a null finding for the predicted effects. Relatively low RHI scores have also been reported in several previous schizophrenia studies (Kaplan et al., 2014; Peled et al., 2000; Thakkar et al., 2011). The use of middle-aged clinical and control samples may have contributed to this: a recent study found significant RHI reductions in a middle-aged group (44-55 years) compared to young (20-22 years) and older (60-72) adults(Marotta et al., 2018). In addition, our findings for subjective rating scales and objective proprioceptive drift did not converge. Only one previous schizophrenia 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). It has been suggested that both subjective and objective measures should converge when arguing for a perceptual effect in the RHI (Kalckert and Ehrsson, 2014). Thus, on the basis of our and previous results we argue that there is no strong evidence that differences in schizophrenia for the RHI can be explained by alterations to perceptual mechanisms.

Instead, our ANCOVA findings show that experiencing body-related perceptual symptoms can account for differences in RHI ratings between the schizophrenia and control group. This was the case only for body-related, and not non-body-related, aberrations and accords with previous work, which 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). This suggests that body-related cognitions due to a history of unusual bodily experiences could affect experiencing body illusions. Body-related perceptual symptoms could also simply shift the criterion for endorsing unusual bodily experiences. In either case, it is thus possible that differences in severity of body-related perceptual aberrations in schizophrenia samples could explain inconsistent RHI findings. Future research should take body-related symptoms and cognitions into account when investigating body perception and bodily illusions in schizophrenia and other populations.

In conclusion, we found that deficits in temporal perception can predict body-related perceptual symptoms. We propose that temporal perception deficits contribute to unusual spatial body perceptions because the associations between multisensory signals are less reliable. Furthermore, we found that visual-tactile temporal perception cannot account for differences in RHI susceptibility in schizophrenia compared to controls. However, the relatively low illusion scores, which may be due to the age of the sample, 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 found that symptoms of bodily perceptual aberration, but not a schizophrenia diagnosis itself, can be linked to increased RHI ratings.

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