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The Relationship Between Audiovisual Binding Tendencies and Prodromal Features of Schizophrenia in the General Population

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Abstract
Current theoretical accounts of schizophrenia have considered the disorder within the framework of hierarchical Bayesian inference, positing that symptoms arise from a deficit in the brain's capacity to combine incoming sensory information with preexisting priors. Here, we present the first investigation to examine the relationship between priors governing multisensory perception and subclinical, prodromal features of schizophrenia in the general population. We tested participants in two complementary tasks (one spatial, one temporal) and employed a Bayesian model to estimate both the precision of unisensory encoding and the prior tendency to integrate audiovisual signals (i.e., the "binding tendency"). Results revealed that lower binding tendency scores in the spatial task were associated with higher numbers of self-reported prodromal features. These results indicate decreased binding of audiovisual spatial information may be moderately related to the frequency of prodromal characteristics in the general population.

Keywords
binding tendency, schizophrenia, prodromal features, Bayesian causal inference, multisensory integration

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The last several years have seen increasing interest in the promise of computational approaches to better understand mental illness (Dayan, Dolan, Friston, & Montague, 2015; Huys, Maia, & Frank, 2016; Montague, Dolan, Friston, & Dayan, 2012). For example, recent theoretical accounts of schizophrenia have considered the disorder within the framework of hierarchical Bayesian inference, positing that symptoms arise from deficits in the incorporation of sensory information and prior beliefs about the world (Adams, Stephan, Brown, Frith, & Friston, 2013; Corlett, Frith, & Fletcher, 2009; Fletcher & Frith, 2009; Notredame, Pins, Deneve, & Jardri, 2014). While current theorists have hypothesized that features associated with schizophrenia may be related to impaired perceptual inferences, few empirical investigations have been conducted to directly investigate these claims.

In light of this intriguing theory, we conducted a simple exploratory investigation to answer the following question: Is there any relationship between priors governing multisensory perceptual inference and self-reported, prodromal features of schizophrenia in the general population? The term *prodrome* is used to refer to the period of subclinical features and symptoms that precede the onset of psychosis and can include disturbances in cognition, emotion, communication, and perception (Larson, Walker, & Compton, 2010). Although individuals that eventually develop psychosis are often afflicted in distressing ways by these disturbances, previous research has shown that these prodromal features may be quite prevalent in the general population, as many college-age students report experiencing some of

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the defining perceptual abnormalities of schizophrenia but do not appear to be negatively impacted by them (Loewy, Johnson, & Cannon, 2007). Therefore, many of these symptoms of the disorder exist along a *spectrum* characterized by varying prevalence, frequency, and severity of the impairments.

Recent work attempting to understand the underlying causes of perceptual deficits in schizophrenia has posited that when the brain makes impaired perceptual inferences about the states of the world producing particular sensations, various symptoms related to the disorder may arise (Adams et al., 2013). This hypothesis builds upon much work conducted in the last decade to understand the underlying computational principles governing how the brain makes inferences about our multisensory world. At any given moment, our brains must infer which sensory signals come from the same source and should be integrated and which signals come from different sources and should be segregated (Shams & Beierholm, 2010). This ability of the brain to infer which sources in the environment give rise to which sensory signals is *absolutely fundamental* to an individual's ability to integrate sensory information and perceive the world as a coherent whole.

Impaired multisensory perceptual inferences could potentially cause abnormal sensory experiences in two ways. For example, if an observer cannot integrate the sounds and images coming from a single object in the environment, it may not look like those sensations are produced by the same event, and this incorrect inference could potentially give rise to the experience of a hallucination. However, the opposite scenario is also a possibility: If an observer has too high of a tendency to integrate, then potentially, sensory information that should be segregated is fused, thereby leading to abnormal perceptions of events in the world. Thus, in this investigation, we aimed to quantify individuals' capacities to make multisensory inferences and evaluate whether these capacities were related to the prevalence of prodromal features of schizophrenia in the general population.

The inference about which sources gave rise to which signals has been well accounted for by computational models assuming that the brain performs the inference according to Bayes's rule (Beierholm, Quartz, & Shams, 2009; Körding et al., 2007; Wozny, Beierholm, & Shams, 2010; Wozny & Shams, 2011). In this modeling framework, the brain's final estimate about the location of sensory signals in the world is governed not only by the precision of unisensory encoding (modeled by likelihood distributions for each sensory modality) but also by a prior probability of inferring a common source for the signals, which we call the "binding tendency" (Odegaard & Shams, 2016).

As the binding tendency reflects observers' prior probability of binding sensory signals that are discrepant in either space or in time, it provides a quantitative measure of the strength of the tendency to integrate signals across modalities in a given task. For example, in an audiovisual spatial localization task where an observer is asked to estimate the locations of simultaneous visual and auditory signals, a binding tendency near 0 indicates that a given observer is likely to infer that all auditory and visual signals in the task originate from separate sources and should be segregated, even when they occur in close proximity to one another. On the other hand, a binding tendency near 1 indicates that a given observer is likely to infer that all auditory and visual signals in the task originate from a common source and should be integrated, even if they occur far away from one another in space. This measure works in an analogous fashion in our temporal numerosity judgment task. For instance, if an observer is asked how many brief visual flashes and auditory beeps have been presented in a short time window, individuals with a binding tendency of 0 will often report different numbers of flashes and beeps, regardless of whether similar numbers (e.g., 1 flash and 2 beeps) were presented. However, individuals with a binding tendency near 1 will often report the same number of flashes and beeps even if different numbers are presented (e.g., 1 flash and 4 beeps).

Previously, we have shown that the audiovisual binding tendency is task-specific, stable over time, and varies across individuals, modulating the strength of interactions between the auditory and visual modalities (Odegaard & Shams, 2016). In the present study, we used this Bayesian causal inference framework to investigate the relationship between psychometrically defined prodromal features and audiovisual binding tendencies in both the spatial and temporal domains in a large control population. Based on recent theories of schizophrenia, we hypothesized that there may be a negative correlation between an individual's binding tendency in a given task (either spatial or temporal) and the frequency of self-reported prodromal features, but as we note above, it seemed possible that either lower or higher binding tendencies could be related to the frequency of these prodromal features.

Materials and Methods

Subjects

A total of 103 subjects (40 male, 63 female; mean age = 21.5 years, *SD* = 5.1 years) participated in our experiment. We did not collect data on subjects' ethnicities or socioeconomic status in this study. Data from five subjects were excluded due to negligence with the response device during the localization task or eyetracker malfunctions, and three participants did not have sufficient time to complete all components of the study, leaving data from 95 subjects for further analysis. Subjects were recruited through flyers posted around the University of California, Los Angeles campus and were paid $10/hour for their participation. Subjects were ruled ineligible to participate if they had a history of neurological conditions (e.g., seizures, epilepsy, or stroke), had experienced head trauma recently, were under 18 years of age, or had uncorrected visual or auditory impairments. A subset of these subjects were included in a previous manuscript from our laboratory (Odegaard & Shams, 2016), as data from their first session in this study was included in the present analysis.

Tasks

Our study protocol was approved by an institutional review board (IRB) at the University of California, Los Angeles and was carried out in accordance with the provisions of the World Medical Association Declaration of Helsinki. Written, informed consent was obtained prior to the experiment. Our experiment consisted of three tasks: an audiovisual spatial localization task, an audiovisual temporal numerosity judgment task, and an assessment of psychometrically defined prodromal features. The order of the spatial and temporal tasks was counterbalanced across subjects, but all subjects completed the assessment of prodromal features after they had completed the two primary tasks.

Audiovisual spatial localization task

Our audiovisual spatial localization task proceeded as follows: Subjects were seated in a chinrest 52 cm away from a large, acoustically transparent black cloth that extended over much of the visual field (134° width × 60° height). A ceiling-mounted projector located above the subjects could display brief flashes of light at five different locations on the cloth along a one-dimensional, horizontal display axis (–13°, –6.5°, 0°, 6.5°, and 13°). This horizontal display axis was located 7° beneath an initial fixation point placed at 0° at the start of each trial. Five speakers located behind the cloth at those same locations (which could not be seen by participants) could play brief bursts of sound. Visual stimuli consisted of small, white discs (0.41 cd/m^2) masked with Gaussian noise, and auditory stimuli were ramped white-noise bursts played at a level of 58 dB from free-field speakers (5 × 8 cm; extended range, paper cone). Both types of stimuli were only presented for 35 ms.

Each trial would start by subjects fixating the central fixation cross at 0°. As soon as a ViewPoint Eyetracker (Arrington Research, Scottsdale, AZ) established the required fixation position and duration (250 ms), the stimulus presentation would begin. On any given trial, subjects could be presented with only a burst of sound, only a flash of light, or both a burst of sound and a flash of light and would have to localize where the stimuli occurred. On bisensory trials, the timing of the two stimuli was synchronous, and we verified timing precision with use of an oscilloscope. Four hundred and fifty milliseconds after the presentation of the stimuli, a cursor appeared on the screen in front of the subjects at a random location along the horizontal display axis, and subjects scrolled to move the cursor using the trackball on the mouse to report the locations of any stimuli that were presented. Subjects could take as long as they needed to respond during the task, and no feedback was given about the correctness of responses.

There were a total of 35 pseudorandomly interleaved conditions in the experiment: 5 unisensory visual conditions, 5 unisensory auditory conditions, and 25 bisensory audiovisual conditions. Each condition contained 15 trials, yielding a total of 525 trials. On bisensory trials, the audiovisual stimuli could either be spatially congruent or spatially incongruent, and subjects would always have to localize both the visual and auditory stimulus (with the response order counterbalanced across subjects). Most localization sessions lasted for approximately 45 min, and subjects were allowed to take breaks every 125 trials (approximately every 10 min).

Audiovisual temporal numerosity judgment task

In our audiovisual temporal numerosity judgment task, subjects were seated in a chinrest in front of a CRT monitor that was flanked by speakers on each side and were asked to count the number of flashes and beeps that occurred on a given trial. Visual flashes consisted of small, white discs that were 1.5° of the visual angle in diameter and were presented 7° below the fixation point on each trial, for a duration of one frame (~10 ms). Auditory beeps consisted of a 10-ms tone presented at 3.5 kHz carrier frequency at 68 dB from the chinrest where subjects were seated.

Subjects completed four blocks of 90 trials, for a total of 360 trials in this task. On any given trial, a subject could be presented with 1–4 beeps, 1–4 flashes, or some combination of beeps *and* flashes (ranging from 1–4 in each modality). This resulted in 24 possible stimulus conditions: four visual-only conditions (from 1–4 flashes), four auditory-only conditions (from 1–4 beeps), and 16 possible combinations of audiovisual stimuli (1 flash–1 beep, 1–2, 1–3, 1–4, 2–1, 2–2, 2–3, 2–4, 3–1, 3–2, 3–3, 3–4, 4–1, 4–2, 4–3, 4–4). There were 15 trials in each possible condition, yielding 360 total trials in the experiment.

The timing of the bisensory stimuli was as follows: On trials where the same number of beeps and flashes were presented, the stimulus trains were aligned to be perfectly synchronous, with a 60-ms gap in between each stimulus. On all other trials, the stimulus trains were centered with respect to one another. For example, some trials contained an even number of stimuli in one modality and an odd number of stimuli in the other modality (e.g., two beeps and one flash). If two beeps and one flash were presented, the beeps would be 60 ms apart, and the flash would be 30 ms after the first beep. On trials where an even number of stimuli that were different in number were presented in each modality (e.g., four beeps and two flashes), stimulus trains were centered so the modality with fewer stimulations was presented synchronously with the middle of the longer stimulus train. Finally, unisensory stimuli followed a similar timing pattern, with a 60-ms gap in between each stimulus. Timing arrangements for each stimulus condition were verified by use of an oscilloscope. We have previously demonstrated that these timing arrangements effectively produce the illusion and allow for accurate estimation of individuals' binding tendencies (see figures 2 and 3 in Odegaard & Shams, 2016).

After the stimuli were displayed, subjects were cued with written instructions on the screen to report either the number of flashes or the number of beeps using the numbers 1–4 on the wireless keyboard in front of them. For example, on bisensory trials, some subjects were first presented with a screen that stated, "Report the number of BEEPS you heard," and following their response, they were presented with a screen that stated, "Report the number of FLASHES you saw." The order of these screens was consistent for each subject within a session but was counterbalanced across sessions for different subjects. Subjects were given as long as necessary to respond, and no feedback about the correctness of responses was given.

Questionnaire

Following completion of the localization task, subjects completed the Prodromal Questionnaire–Brief Version (PQ-B) (Loewy, Pearson, Vinogradov, Bearden, & Cannon, 2011) to assess both the frequency and severity of their prodromal symptoms. Per the scoring guidelines from Loewy et al. (2011), we were primarily interested in how many "yes" responses subjects would give and followed the scoring guidelines listed in the supplemental materials of that paper regarding which questions to exclude in our analysis.

Model

We applied our quantitative Bayesian causal inference model (Körding et al., 2007; Wozny et al., 2010) to each subject's data to quantify the "binding tendency" in each individual subject (Odegaard & Shams, 2016). It is important to note that although unisensory trials can be modeled by simply combining the likelihood and spatial prior terms for a given modality (see Supplemental Materials Eqs. 5 and 6 available online), bisensory trials require the posterior probability of a common cause to be computed and thus are influenced by the binding tendency. The binding tendency reflects each individual's prior probability of binding audiovisual signals across space or time (i.e., localizing simultaneous auditory and visual signals near one another during the localization task or reporting the same number of auditory and visual signals during the temporal numerosity judgment task). The model for each task included three other parameters besides the binding tendency: the standard deviation of the visual likelihood, the standard deviation of the auditory likelihood, and the standard deviation of a prior distribution (over space or time, depending on the task). After modeling each individual subject's data to quantify the "binding tendency," we performed a correlational analysis to determine whether there was any relationship between each individual's *binding tendency* for audiovisual stimuli (for both tasks) and the number of psychometrically defined prodromal features reported by the individual.

When conducting several correlations using the same dataset, it is important to correct for multiple comparisons to avoid spurious findings. Although our primary analysis was evaluating the correlation between binding tendency and "yes" responses on the PQ-B, we were also curious as to whether our model's measure of unisensory precision (i.e., the visual and auditory likelihoods) would correlate with responses from the questionnaire. Thus, to account for our six comparisons, we compared our findings against a Bonferroni-corrected p value of .008 (.05/6).

Results

Overall, participants in our task responded with an average of 3.65 "yes" responses on the PQ-B questionnaire (SD = 3.87, range = 0–17). Regarding the main comparisons of interest, results show a significant negative correlation between subjects' binding tendencies in the spatial task and their scores on the PQ-B questionnaire ($r = -.33$, $p = .001$). As shown in Figure 1a, low binding tendencies in the spatial task were associated with a higher number of "yes" responses on the PQ-B questionnaire, indicating a modest link between lower multisensory spatial integration capacities and higher numbers of self-reported features along the psychosis spectrum. When visualizing this relationship, it becomes clear that the correlation was primarily influenced by six subjects

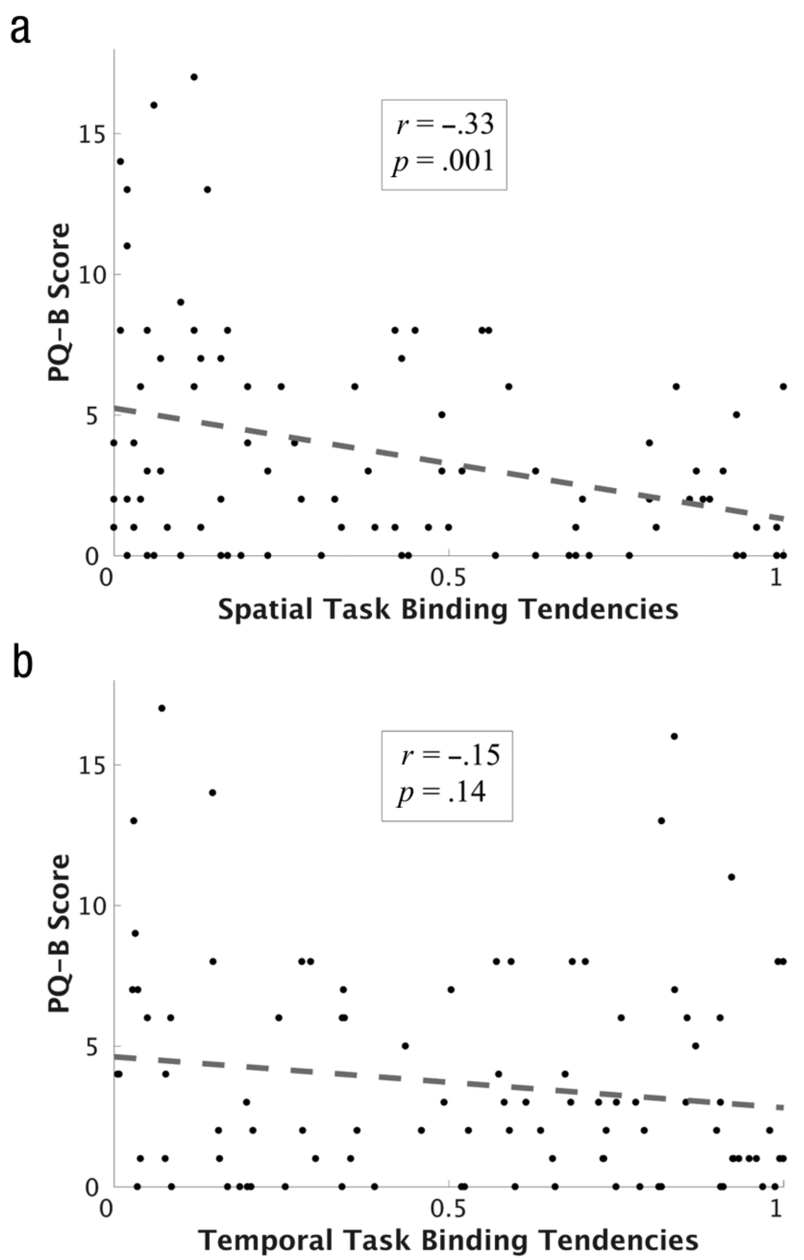

Fig. 1. Correlations between binding tendencies and PQ-B responses for both tasks. The binding tendency value for each subject is plotted along the *x* axis. The *y* axis represents the number of each participant's self-reported, psychometrically defined prodromal features, as measured by the number of "yes" responses to questions from the PQ-B questionnaire (Loewy et al., 2011). (a) A significant (p = 0.001), negative correlation (r = –.33) exists between the spatial-task binding tendencies and responses on the questionnaire. (b) No significant relationship (r = –.15, p = .14) emerged between binding tendencies on the temporal task and PQ-B responses.

with high scores on the questionnaire (i.e., a score greater than 10 on the PQ-B questionnaire), but the trend was still present in the rest of the sample (although nonsignificant when compared to the Bonferroni-corrected alpha value) even when these six subjects were removed (r = –.21, p = .047). Thus, although not all individuals with low audiovisual binding tendencies in the spatial task appear to have higher scores on the PQ-B questionnaire, individuals from the general population with a higher number of psychometrically defined prodromal features appear to have a reduction in the tendency to bind audiovisual signals across space.

Interestingly, measures of unisensory processing on the spatial task (as modeled by likelihoods for the visual and auditory modalities) did not indicate any deficits, as neither the visual likelihood (r = –.07, p = .52) nor the auditory likelihood (r = –.10, p = .35) were significantly correlated with the number of psychotic features reported on the questionnaire. Similarly, measures of unisensory processing on the temporal task did not correlate with the frequency of psychotic features (visual likelihood: r = –.03, p = .78; auditory likelihood: r = –.10, p = .34), and the temporal task binding tendency did not correlate with the frequency of psychotic features either, although there was a very minor trend in the hypothesized direction (Fig. 1b; r = –.15, p = .14). Visualization of the trend in the temporal task reveals a bimodal split in our most extreme subjects: Some subjects with higher numbers of reported prodromal features have low binding tendencies, whereas some of them have high binding tendencies. If we excluded the right-side outliers, the original trend strongly increased (r = –0.26, p = 0.01), but excluding the left-side outliers had a minimal effect (–0.02, p = 0.81).

Discussion

Although previous studies have provided preliminary evidence that the ability to process multisensory information is impaired in individuals with schizophrenia (de Gelder, Vroomen, Annen, Masthof, & Hodiamont, 2003; de Jong, Hodiamont, Van den Stock, & de Gelder, 2009; Ross et al., 2007; White et al., 2014; Williams, Light, Braff, & Ramachandran, 2010), it is still not apparent *where* the deficit in multisensory processing may arise. Deficits in multisensory processing could arise from impairments in the brain's ability to process unisensory signals (e.g., visual or auditory signals) or impairments in the brain's ability to make accurate inferences to bind sensory signals to perceive the world as a coherent whole. This ability of the brain to accurately infer which sources in the environment give rise to which sensory signals is essential to an individual's ability to accurately interpret and navigate a complex and changing world and has been accounted for quite effectively by models assuming that the brain performs Bayesian Causal Inference (Beierholm et al., 2009; Körding et al., 2007; Wozny et al., 2010; Wozny & Shams, 2011).

Based upon recent theoretical considerations of schizophrenia (Adams, Huys, & Roiser, 2016; Notredame et al., 2014), we hypothesized that individuals in the general population that report higher numbers of psychometrically defined prodromal features would exhibit lower values of a Bayesian prior (i.e., the "binding tendency") governing audiovisual integration. As a previous investigation has indicated that this binding prior is task-specific (Odegaard & Shams, 2016), it seemed possible that a reduced binding tendency may arise in one or both of the tasks that were tested. Results revealed that individuals with lower audiovisual spatial-task binding tendencies reported higher numbers of prodromal features on the PQ-B questionnaire, providing evidence of a moderate link between priors governing multisensory perception of space and self-reported experiences consistent with the "psychosis spectrum" in the general population. However, we also note that removal of a cluster of subjects with the highest numbers of prodromal features reduced this trend in the spatial task so that it did not survive Bonferroni correction; therefore, it appears that the trend in most individuals is small but that the strongest link between these constructs is in those exhibiting abnormally high numbers of prodromal features.

We think these results provide intriguing, novel evidence that demonstrates a relationship between these two constructs, and we think future studies should seek to investigate deficits in the binding tendency in clinical populations as well as study training protocol that may help improve an individual's capacity to bind sensory information across space. As recent work has shown that improving sensory information processing can improve higher level cognitive functioning in individuals with schizophrenia (Dale et al., 2015; Fisher et al., 2014), we think our results, if replicated in a clinical sample, represent an intriguing opportunity for clinical intervention.

Previous research has suggested that deficits in integrating multisensory information may be linked to the symptoms of schizophrenia. For instance, patients with negative symptoms show reduced reaction-time benefits to multisensory stimuli and patients with both visual and auditory hallucinations show less multisensory facilitation compared to patients with only auditory hallucinations (Williams et al., 2010). Previous research investigating the capacity of individuals with schizophrenia to understand speech have found that the deficits in speech comprehension are primarily for *multisensory* stimuli, not auditory stimuli (Ross et al., 2007), and abnormal cortical responses to speech stimuli across the higher level areas facilitating audiovisual integration have been observed (Stekelenburg, Maes, Van Gool, Sitskoorn, & Vroomen, 2013). Our results imply that a deficit in the capacity to integrate audiovisual spatial information may be specifically linked to positive symptoms in the disorder. Our null finding in the temporal domain does not necessarily imply that temporal deficits do not exist in schizophrenia (for example, see Stevenson et al., 2017); indeed, selective removal of the right-side outliers in our dataset revealed the same negative correlation as in the spatial task. It seems possible that if a relationship between prodromal features and temporal binding tendencies exists, it may involve more heterogeneous effects that we observed in our spatial task, but future work will be needed to investigate what mechanism(s) may be involved in the temporal task, and if the mechanisms involved are the same or different across the two tasks.

Our result of a significant, negative correlation between the spatial-task audiovisual binding tendency and self-reported experiences on the psychosis spectrum opens up an interesting question: How is this audiovisual spatial binding tendency implemented in the brain, and can this finding provide any insights regarding the impaired mechanism(s) in individuals with schizophrenia? One intriguing hypothesis centers on the connectivity between auditory and visual regions. Deficits in white-matter connectivity are thought to underlie many sensory processing impairments (Owen et al., 2013), and it has been posited that individual differences in connectivity between brain regions could modulate interactions governing multisensory integration (Nath & Beauchamp, 2012). As a number of studies have revealed abnormalities in long-range white matter connections in individuals with schizophrenia (Kubicki et al., 2007), it seems possible that a deficit in functional connectivity between brain regions may be a contributing factor to both a lower binding tendency and the disorder itself.

However, why should a connectivity-related impairment result in a reduced binding tendency only on the spatial task? Critically, past research has documented the importance of different higher level cortical regions for different tasks assessing multisensory integration. For instance, the multisensory *speech* task used by Nath and Beauchamp (2012) found responses in the superior temporal sulcus to be critical for explaining individual differences in integration; the multisensory *spatial* task used by Rohe and Noppeney (2015) found that responses in the intraparietal sulcus tracked spatial integration on a trial-by-trial basis quite effectively; the multisensory *temporal numerosity judgment* task used by Watkins et al. (2007) found that superior temporal sulcus, superior colliculus, and V1 activity were linked to multisensory integration. Thus, if indeed a deficit in white-matter connectivity underlies reduced audiovisual spatial-task binding tendencies, considering the heterogeneity in brain regions involved in multisensory speech, spatial, and temporal tasks, it should not come as a surprise that a given white-matter deficit may cause task-specific impairments.

We further emphasize one recent investigation using the same spatial task described here and functional Magnetic Resonance Imaging, which found a relationship between increased activity in the intraparietal sulcus and common-cause estimates from the same Bayesian Causal Inference model used in this investigation (Rohe & Noppeney, 2015). This finding highlights the possibility that impairments in the functioning of high-level association areas might underlie the lower audiovisual binding tendency scores. As noted in a recent review, several mechanisms of cortical functioning are known to be impaired in individuals with schizophrenia, including hypofunction of NMDA receptors, abnormalities in dopamine signaling pathways, and altered connectivity patterns between different cortical regions (Adams et al., 2016). Thus, if the binding tendency is manifested by cortical activity, it seems probable that deficits in cortical functioning could underlie a reduction in reliance on this prior and increased reliance on early-level sensory representations.

One other noteworthy finding of our investigation here is the number of young adults in our sample reporting relatively high numbers of prodromal features. Previous research using a clinical sample (i.e., individuals analyzed for evaluation at two prodromal psychosis research clinics) has reported that using a cutoff score of 3 balances sensitivity (the true positive rate) and specificity (the true negative rate) when evaluating clinical samples with this questionnaire (Loewy et al., 2011). This same study reported that ~13% of controls were at or above the cutoff score of 3 on this questionnaire (Loewy et al., 2011); we find a much higher percentage of our subjects from the general population score at 3 or above, as 46/95 (~48%) of our subjects received a score of 3 or more. However, it is important to note that (a) college-aged students (the majority of our sample) tend to respond with higher numbers of prodromal features on questionnaires than the rest of the general population and appear to rarely be negatively affected by these experiences (Loewy et al., 2007), (b) up to 20% of adults in the general population report some psychotic-like experiences (Hanssen, Bijl, Vollebergh, & Van Os, 2003), and (c) it seems plausible that college students and individuals filling this out at schizophrenia clinics may use different criteria when completing this questionnaire, as individuals at clinics would have an idea that it is assessing a clinical disorder, whereas our students were completely naïve regarding its primary aim. We also note that although the creators of this questionnaire do not endorse use of the prodromal questionnaire for strict screening of psychosis risk (Therman et al., 2014), whether or not prodromal features are *distressing* still appears to be a fairly effective indicator of susceptibility to the disease (Loewy et al., 2007).

To conclude, as noted in a recent review, it is tremendously important for the field of schizophrenia research to document cognitive and neural traits that can serve as markers that may change as an individual moves from a pre-onset stage to a fully psychotic state (Cannon, 2015). We posit that deficits in the capacity to bind audiovisual spatial information may well serve as one important marker of a deficit. If our results are replicated within an at-risk or clinical sample, future work should therefore aim to investigate the neural basis of a binding tendency deficit and whether modifying this tendency to improve integration capacities alleviates any of the positive symptoms associated with the disorder.

Author Contributions

L. Shams developed the study concept and study design. Testing and data collection were performed by B. Odegaard. B. Odegaard performed the data analysis and interpretation under the supervision of L. Shams. B. Odegaard drafted the paper, and L. Shams provided revisions of the manuscript. All authors approved the final version of the paper for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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