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Atypical Use of Visuospatial Context in Psychotic Psychopathology: A Meta-analysis

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***Background and Hypothesis*: Visual perception in people with psychotic disorders is thought to be minimally influenced by surrounding visual elements (ie, visuospatial context). Visuospatial context paradigms have the unique potential to clarify the neural bases of psychotic disorders because the neural mechanisms are well studied in both animal and human models. However, the published literature on the subject is conflicting and heterogeneous. A systematic consolidation and evaluation of the published evidence is needed. *Study Design*: We conducted a meta-analysis of 54 articles spanning over 50 years of research. Articles included behavioral, functional magnetic resonance imaging, and electroencephalogram reports of size, contrast, contour, lightness, orientation, and motion perception in schizophrenia (SCZ), bipolar disorder, and subclinical populations. *Study Results*: When pooling across all task types, we found weak evidence of reduced use of visuospatial context in SCZ (Hedges' $g = 0.20$) and bipolar disorder ($g = 0.25$). The strongest evidence was observed for altered contrast perception in SCZ ($g = 0.73$). With respect to subclinical populations, we observed immense heterogeneity in populations of interest and study designs. *Conclusions*: We observed surprisingly weak evidence that psychotic disorders are associated with generally reduced use of visuospatial context. Instead, we observed the strongest evidence for a specific alteration in contrast perception. We propose altered feedback to the primary visual cortex as a potential neural mechanism underlying this effect. Moderating factors such as stage and phase of illness may explain some of the heterogeneity we observed in effect sizes; further research is needed to clarify how disease state relates to altered use of visuospatial context.**

Key words: schizophrenia/bipolar/illusions/perception

Introduction

This manuscript focuses on a broad class of psychophysical paradigms that have received much attention due to their ability to clarify specific perceptual and neural mechanisms of psychotic psychopathology: visuospatial context tasks. The study of atypical use of visuospatial context in psychotic disorders is valuable because individuals with psychotic psychopathology are thought to make less biased judgments as compared with controls. Such a pattern of more veridical performance can be difficult to explain in terms of a generalized cognitive impairment (though see ref.[1]). Moreover, visuospatial context effects are well studied in both animals and humans, allowing for rich inferences regarding potential neural mechanisms. Identifying such neural mechanisms will be essential for clarifying etiology and developing novel interventions.

Though a wide range of visuospatial context tasks exist, they all modulate the perception of primary stimuli through manipulation of surrounding (ie, contextual) stimuli. A famous example of this manipulation is the Ebbinghaus illusion in which the perceived size of a central circle changes as a function of the size of surrounding circles (see figure 1). It has been argued that both clinical and subclinical psychosis populations are less affected by the surrounding visuospatial context. Thus, in the case of the Ebbinghaus illusion, psychotic psychopathology is thought to be associated with more veridical size judgments of the center circle. Indeed, such a pattern has been reported in individuals at clinical high risk for psychosis, individuals with high levels of schizotypal thought

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disorder, first-episode psychosis patients, outpatient and inpatient populations,[2–4] though also see ref.[5] Reports of insensitivity to surrounding contextual information in psychotic psychopathology are not exclusive to the Ebbinghaus illusion: Must et al reported patients' performance on a perceived contrast task was less affected by surrounding stimuli compared with controls.[6] One year later, seminal work by Dakin et al reported that individuals with schizophrenia (SCZ) were less biased by the contrast of visual surrounds than controls (CON) during a contrast-matching task.[7]

We are unaware of any published meta-analyses of atypical use of visuospatial context in psychotic psychopathology. Panton et al provided a meta-analysis of perceptual organization in psychotic psychopathology.[8] However, this review was much more restricted in scope: it exclusively focused on closed contour stimulus paradigms with the final meta-analysis only including 11 papers. A pair of papers[9,10] provided systematic reviews of the perceptual organization literature in schizophrenia spectrum disorders. However, the present manuscript differs from these papers in important ways: (1) the aforementioned reviews did not perform meta-analyses to quantify the strength and heterogeneity of evidence, (2) the reviews were focused on the construct of perceptual organization which only partially overlaps with our construct of interest, visuospatial context, and (3) the reviews were published more than a decade ago and do not provide an account of more recent literature. Finally, Chen performed a review of atypical motion processing in SCZ; however, there was again only partial overlap with our construct of interest, the report was published more than a decade ago, and the report did not quantify evidence via meta-analysis.[11]

To date, a wide variety of paradigms have been used to assess the atypical use of visuospatial context in psychotic psychopathology with respect to perception of size, contrast, contours, lightness, orientation, and motion (see figure 1). Some of these studies observed reduced susceptibility to visuospatial context,[12,13] but others found no group differences[5] and still others observed *greater* sensitivity to visuospatial context.[14,15] These discrepancies in the literature are likely due to heterogeneity between studies with respect to tasks, clinical groupings, sample sizes, exclusion criteria, and statistical/analytical decisions. Given the potential importance of the study of visuospatial context for elucidating etiology and identifying intervention targets of psychotic disorders, there is a pressing need for a systematic consolidation and quantification of the current state of published evidence.

Materials and Methods

A systematic review was conducted following the PRISMA guidelines.[16] The review protocol was preregistered with Prospero (https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=367238). OVID was used to simultaneously search the following databases on March 1, 2023: Ovid MEDLINE(R) ALL, Embase Classic+Embase, and APA PsycInfo. A flow diagram[16] describing the original search process can be found in supplementary figure 1. The original search words were: (schizo* OR bipolar OR psychosis OR psychoti*) AND (vis* context OR size illusion OR brightness induction OR surround contrast illusion OR tilt illusion OR ebbinghaus OR size perception OR simultaneous color contrast OR collinear flankers OR center-surround OR surround suppression). During peer review, an anonymous reviewer suggested additional keywords with the aim of including eligible studies that were missed by the original search. Thus, a revised search was conducted on January 12, 2024 that contained the original search terms as well as the following additional terms: visual illusions, collinear facilitation, spatial vision, lateral interactions, perceptual organization, perceptual grouping, visual binding, visual integration, feature binding, and Gestalt perception. All other features of the search strategy were identical to the original search. A second flow diagram further describing the revised search can be found in supplementary figure 2.

Duplicates were removed using the find_duplicates function from revtools.[17] Next, custom R code (https://github.com/vpokorny123/VisContextMetaAnalysis/) was used to automatically filter poster abstracts, review articles, and dissertations. The remaining studies were then reviewed by authors V.P., S.K., and C.T. Inclusion criteria for a given study were as follows: peer-reviewed, original study (ie, not a review or theoretical paper), English language, human subjects, and the sample includes individuals with clinical or subclinical (eg, schizotypal traits, clinical high risk, etc.) psychotic psychopathology. Studies were excluded if (1) visuospatial context was not manipulated, (2) the study lacked a nonpsychotic comparison control group *and* reported no dimensional measures of psychotic psychopathology, (3) a significant portion (>50%) of the primary data was published in another report, (4) the article could not be retrieved, or (5) insufficient information was provided to judge eligibility. With respect to the first exclusion criterion (ie, criterion A), a visuospatial context manipulation was defined as the modulation of perception of a target stimulus via manipulation of a spatially distinct, but temporally concomitant, stimulus. This definition excluded a number of popular paradigms such as the Jittered Orientation Visual Integration (JOVI) paradigm and illusory contour paradigms (eg, Kanizsa shapes) because these tasks lack clear spatial separation between target and context. This criterion also excluded tasks that manipulated *temporal* context such as backwards masking and working memory paradigms. Finally, we did not include paradigms where the primary dependent variable was reaction time because atypical motor responding is confounded with atypical visual perception. This excluded popular paradigms such as Eriksen flanker tasks, Stroop tasks, and visual search tasks.

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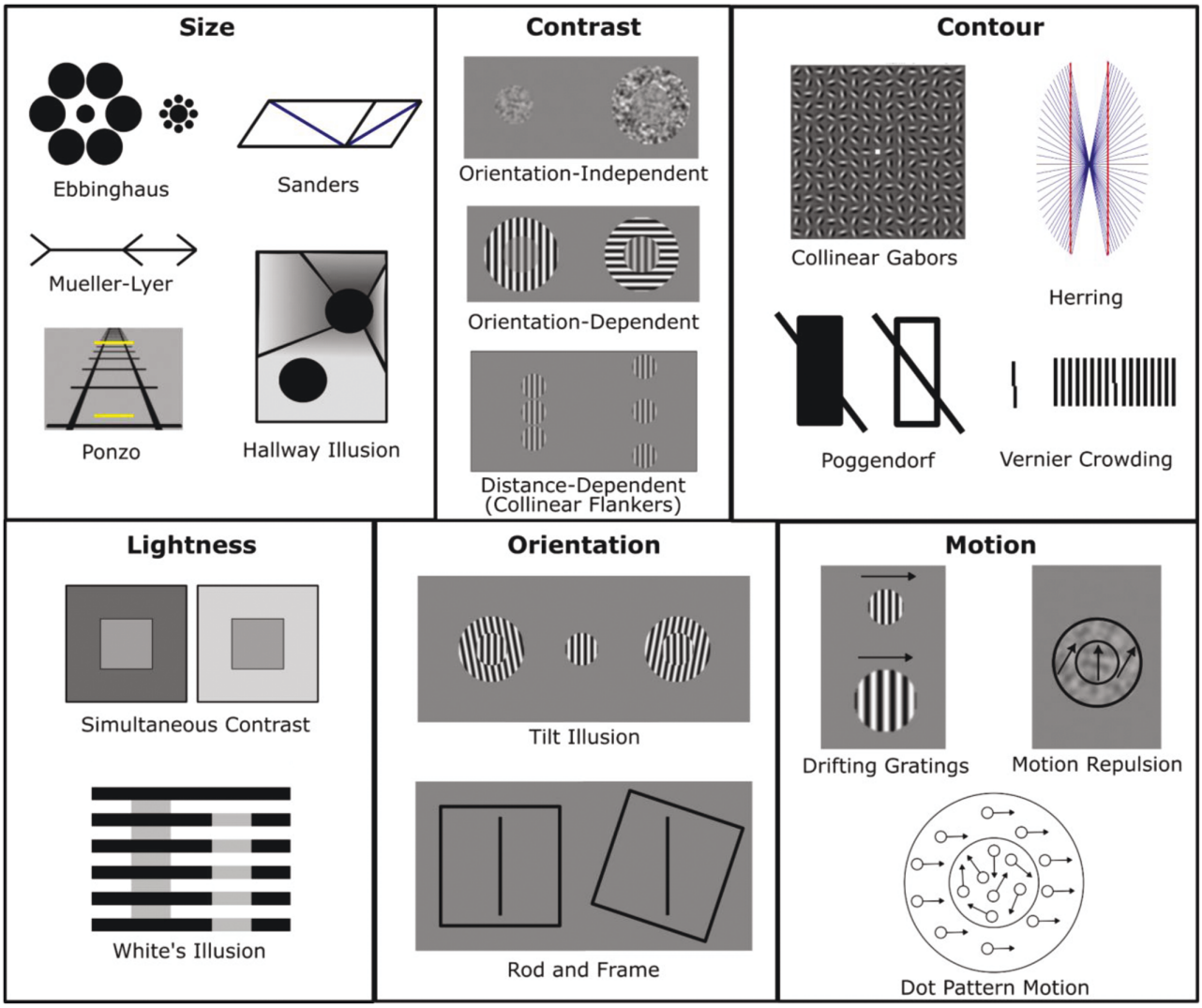

Fig. 1. Visuospatial context paradigm examples. All paradigms depicted are either public domain or generated by the authors of this manuscript. Due to space and copyright constraints, some paradigms from the articles we reviewed are not depicted here; however, in general, all paradigms we reviewed shared notable similarities with the examples shown above.

To assess for agreement between raters an initial subset of 50 studies was selected at random for which the 3 raters made independent binary include/exclude decisions. Interrater reliability was then assessed using Fleiss' kappa via the R package "irr."[18] Once kappa was calculated, the 3 reviewers convened to make final consensus decisions on the articles. This process was repeated in rounds with differing numbers of articles per round (second round = 50, third round = 100, and fourth round = 111). Further information on interrater reliability can be found in supplementary materials.

Data Extraction

After inclusion decisions were made, V.P., S.W., and C.O. independently extracted data from the included studies for meta-analysis. The primary variables of interest were behavioral and neurophysiological measurements including, but not limited to, those derived from functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG). Secondary variables of interest included visual acuity, clinical groupings, gender, and target stimulus placement (ie, foveal or peripheral). For studies of SCZ, we also collected information regarding medication status, inpatient vs outpatient status, and chronic vs first-episode status. When coding visual acuity, we assumed that vision described as "normal" referred to a Snellen score of 20/20, unless otherwise indicated. For group analyses, means, SDs, and sample sizes of groups were extracted as well as any relevant group comparison statistics.

Meta-analytic Approach

Effect sizes were aggregated using a multilevel random effects model via the metafor package in R.[19] Effect sizes

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were pooled both across and within perceptual domains (eg, size, contrast, motion) in separate models. In addition to pooling within perceptual domains, we performed a more fine-grained analysis in which we pooled by paradigm type. To reduce the number of comparisons, we only performed paradigm-specific meta-analyses if there were 5 or more studies with extractable effect sizes for a given paradigm. When multiple relevant effect sizes were reported for a study, effect sizes were nested within the study prior to pooling between studies assuming a modest within-study correlation of 0.6. Sensitivity analyses assuming different within-study correlation values did not greatly affect the overall pooled effect sizes. Additionally, we conducted a mixed-effect version of the classical Egger test to quantify evidence of publication bias using the regtest function from the metafor package. R code for all analyses can be found at github.com/vpokorny123/VisContextMetaAnalysis/.

Results

Among the 54 eligible studies (46 from the original search and 8 from the revised search), we observed a breadth of visuospatial context paradigms: 20 size paradigms,[2–4,20–36] 16 contrast paradigms,[1,6,7,37–49] 2 orientation paradigms,[50,51] 2 motion paradigms,[14,15] 4 contour paradigms,[12,13,52,53] 1 lightness perception paradigm,[54] and 9 articles reporting on multiple paradigms within the same study.[34,55–62]

Comparisons of SCZ and CON: Overview

Forty-two out of the 54 studies reported on group differences between SCZ and CON. Of these 42 studies, we were able to extract effect sizes from 31 (see figure 2 and supplementary table 1). When pooling across all studies, the overall effect size did not significantly differ from zero (Hedges' $g = 0.25$, 95% CI [−0.04, 0.54]) suggesting weak evidence for a general visuospatial context deficit that spans perceptual domains (eg, size, contrast, orientation) and paradigm types (eg, Muller-Lyer illusion, contrast-contrast illusion, tilt illusion). We observed a large degree of between-study heterogeneity ($I^2 = 91.2\%$, 95% CI [86.8-95.91]) and little evidence of publication bias ($b = 0.8$, $t(30) = -1.24$, $P = .22$).

SCZ vs CON: Size Perception

When restricting the meta-analysis to size illusions only, the pooled effect size did not significantly differ from zero: Hedges' $g = -0.39$, 95% CI [−1.00, 0.22] (see supplementary figure 3). Thus, we observed little to no evidence of atypical use of visuospatial context across a variety of size illusions. We did, however, observe some evidence of publication bias (Egger's regression test: $b = 1.41$, $t(7) = -3.26$, $P = .01$). The 2 studies with the smallest sample sizes[21,24] reported the most extreme effect sizes. We also observed substantial heterogeneity across different size illusions. In particular, Muller-Lyer illusion studies found SCZ to be *more* sensitive to visuospatial context ($n = 5$; Hedges' $g = -0.60$, 95% CI [−1.17, −0.03]; see supplementary figure 4) while the other studies reported primarily null results.

SCZ vs CON: Contrast Perception

We identified 2 primary classes of contrast paradigms: orientation-independent and orientation-dependent (though note there was also 1 distance-dependent contrast paradigm[46]). Because both the orientation and contrast of a surround jointly influence the perceived contrast of the center, some paradigms only manipulated surrounding contrast[7] while others manipulated both contrast and orientation,[6] and 1 study matched the center-surround contrast, only manipulating orientation.[45]

Pooling across all contrast paradigm types (see figure 3), the overall effect size significantly differed from zero: Hedges' $g = 0.72$, 95% CI [0.42, 1.02]. Encouragingly, all effect sizes were in the expected direction with SCZ being less susceptible to visuospatial context. However, the funnel plot and Egger's regression test results ($b = -0.58$, $t(14) = 3.32$, $P = .01$) suggested an asymmetry in the relationship between study precision and effect size. In particular, 4 reports[6,7,39,41] observed large effect sizes (Hedges' $g > 1$) while 2 studies with substantially larger sample sizes[1,37] from the Cognitive Neuroscience Test Reliability and Clinical applications for Schizophrenia (CNTRACS) consortium observed smaller effect sizes. This may be indicative of publication bias: studies with smaller sample sizes are capable of producing larger spurious effect sizes by chance (even when the true effect size is zero). Thus, if studies with small sample sizes are only published when statistically significant effects are observed then the pooled effect size will be inflated. However, we also note that the samples from the CNTRACS studies consisted of stable outpatients with less severe symptoms than other studies[7] which may also explain the discrepancy in effect size magnitude.

When restricting the meta-analysis to orientation-independent contrast illusions, the pooled effect size significantly differed from zero: Hedges' $g = 0.60$, 95% CI [0.2, 1.00]. Similarly, the pooled effect size for orientation-*dependent* contrast paradigms also differed from zero: Hedges' $g = 0.84$, 95% CI [0.39, 1.29] (see supplementary figures 5 and 6). For both categories, we observed marginal evidence of an association between study precision and effect size (Orientation-Independent: $b = -0.36$, $t(8) = 2$, $P = .08$; Orientation-Dependent: $b = -1.24$. $t(7) = 2.27$, $P = .06$). Interestingly, the study that reported one of the smallest orientation-dependent contrast effect sizes[42] was the only study to match participants for visual acuity. The other study reporting a much smaller orientation-dependent effect,[45] found that visual acuity moderated the association between group membership

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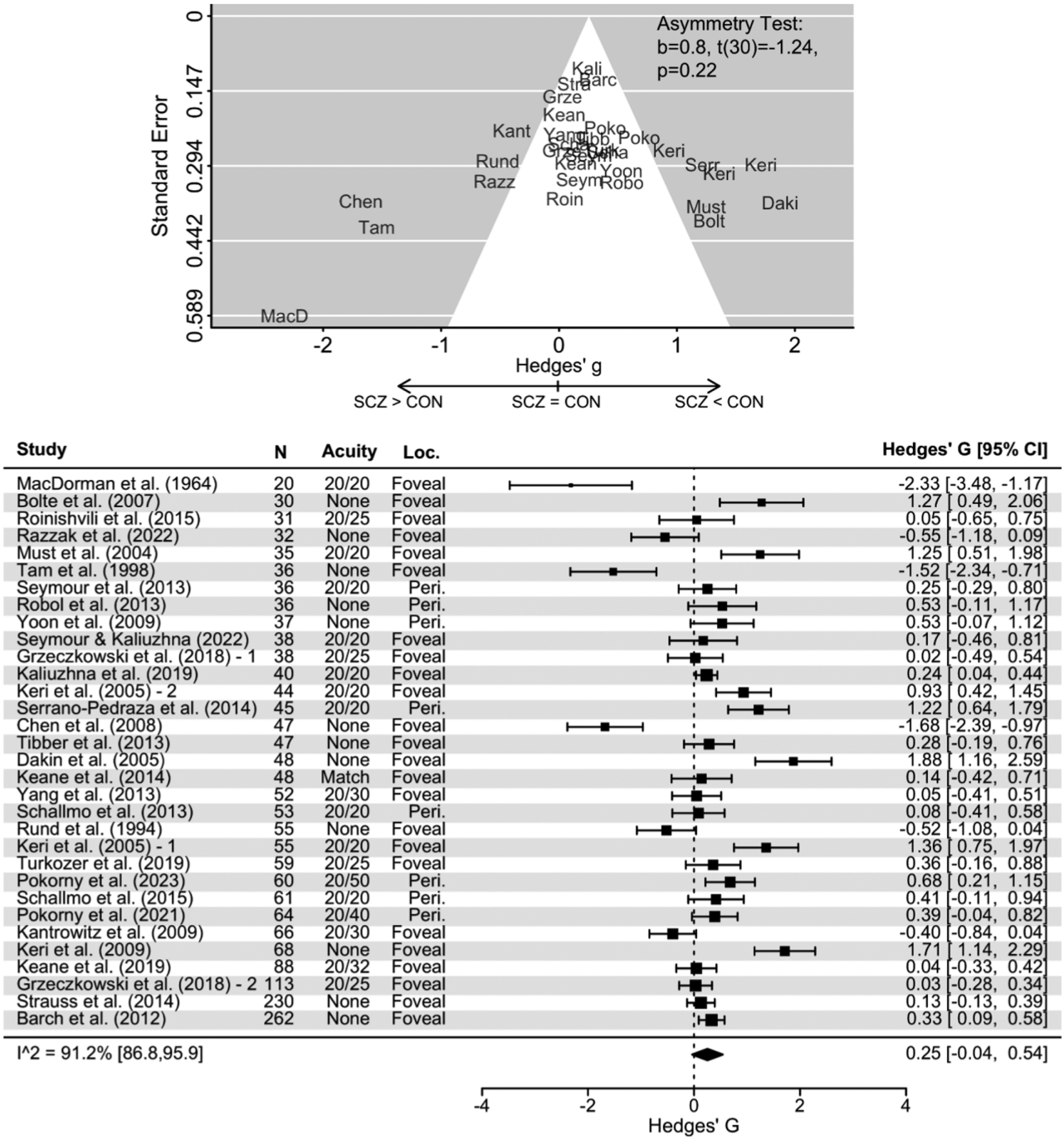

Fig. 2. Comparison of SCZ and CON across all studies. Top: Funnel plot with the first 4 letters of the first author's last name indicating each data point. Positive effect sizes indicate that SCZ was less susceptible to visuospatial context than CON. Negative effect sizes indicate that SCZ was more susceptible to visuospatial context. "Asymmetry Test" refers to a mixed-effect version of the classical Egger test with standard error as the predictor variable and effect size as the outcome variable. Bottom: I^2 is the percentage of variance attributable to between-study differences. The "*N*" column indicates the total number of participants in each study. The "Acuity" column indicates the minimum acuity threshold for inclusion in each study. The "Loc." column indicates whether the target stimulus was presented foveally or peripherally. Studies are sorted by sample size. *Note*: SCZ, schizophrenia.

and strength of orientation-dependent suppression. Thus, visual acuity may partially explain the discrepancy in effect size magnitude between orientation-dependent contrast studies. With respect to paradigm-specific analyses, the pooled effect sizes for both the oriented contrast-contrast illusion (n = 5; Hedges' g = 0.61, 95% CI [0.18, 1.05]) and the collinear flankers contrast illusion (n = 6; Hedges' g = 0.88, 95% CI [0.15, 1.61]) differed significantly from zero (see supplementary figures 7 and 8).

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SCZ vs CON: Orientation Perception

When restricting the meta-analysis to the orientation perception domain, the pooled effect size did not differ significantly from zero: Hedges' $g = 0.08$, 95% CI [−0.38, 0.54] (see supplementary figure 9). Only 1 study[59] out of 6 reported a significant difference between SCZ and CON. This study had a smaller sample size and used an unconventional paradigm in which the perceived orientation of a central Gabor was modulated by 2 flanking Gabors. All of the other studies, except for a single rod-and-frame paradigm,[51] used a tilt illusion design in which a central grating was completely encompassed by a larger surround grating. We did not observe strong evidence for a relationship between study precision and effect size ($b = -1.15$, $t(5) = 1.41$, $P = .22$). With respect to paradigm-specific analyses, the pooled effect size for tilt illusions did not significantly differ from zero: Hedges' $g = 0.02$, 95% CI [−0.34, 0.38] (see supplementary figure 10).

SCZ vs CON: Lightness

When restricting the meta-analysis to the 4 lightness perception studies, the pooled effect size did not differ significantly from zero: Hedges' $g = 0.19$, 95% CI [−0.03, 0.41] (see supplementary figure 11). Pooling across the 3 effect sizes reported by Kaliuzhna et al revealed a small effect size of .24 for which the 95% CIs slightly excluded zero; however, the effect sizes individually were not statistically significant.[54] Interestingly, Grzeczkowski et al reported on a wide variety of illusion paradigms and only found a significant difference between SCZ and CON for a lightness illusion.[60] Note, this lightness illusion is referred to in the original paper as a "simultaneous contrast illusion," but we have categorized it as a lightness illusion because the subjects were asked to perceive the relative lightness, not the relative contrast, of the target stimuli. We did not observe evidence for a relationship between study precision and effect size ($b = 0.37$, $t(3) = -1.06$, $P = .37$).

SCZ vs CON: Contour Perception

For the contour perception domain, the pooled effect size did not differ significantly from zero: Hedges' $g = 0.21$, 95% CI [−0.12, 0.55] (see supplementary figure 12). All estimated effect sizes were positive, but small. Only Pokorny et al observed a behavioral effect that significantly differed from zero.[12] Notably, 3 studies found larger group differences for parallel flanking context conditions compared with orthogonal.[12,13,59] It is possible that the effect of facilitation by orthogonal context is not as strong as the effect of suppression by parallel context which may explain why we did not observe strong differences in the effect of orthogonal context. Our analyses pooled across parallel and orthogonal conditions which may have attenuated the pooled effect sizes if true group differences are indeed stronger for parallel context only. We did not observe evidence for a relationship between study precision and effect size ($b = 0.46$, $t(3) = -0.37$, $P = .73$).

SCZ vs CON: Motion Perception

We were only able to extract effect size estimates for 2 motion paradigms. This suggests the effect of visuospatial context on motion perception is relatively understudied in SCZ. We chose not to proceed with the pooling of effect sizes due to the small number of studies. A qualitative description of these studies can be found in the supplementary materials.

Group Differences Between BP and CON

Only 7 studies reported differences between people with bipolar disorder (BP) and CON (see supplementary table 2). Given the small number of studies, we chose to forego domain- and paradigm-specific meta-analyses, but we did conduct a meta-analysis pooling across all studies (see supplementary figure 13). The pooled effect size was small, but the 95% CI slightly excluded zero: Hedges' $g = 0.25$, 95% CI [0.02, 0.49]. Thus, the pooled effect size differed from zero; however, only 1 study[61] of the 7 reported a significant difference between BP and CON. Also notably, the estimated between-study heterogeneity was zero (95% CI [0, 68.4]). This low heterogeneity estimate may be due in part to the small number of studies which is known to bias I^2 downward when the true heterogeneity is large.[63] Interestingly, 6 out of the 7 studies included both SCZ and BP groups and in all 6 of these studies the SCZ groups deviated more from the CON than BP. Thus, our pattern of results suggests that the bipolar effect sizes tended to be less extreme, but more consistent than the SCZ effect size.

Subclinical Samples

Atypical use of visuospatial context is thought to be found, not only within clinical populations, but also in individuals exhibiting subclinical or "normative" psychotic traits (eg, schizotypy, clinical high risk, etc.). We identified a total of 11 studies that investigated the atypical use of visuospatial context in such subclinical samples (see supplementary table 3). We chose not to meta-analyze this subset of studies due to the large heterogeneity in (1) populations of interest, (2) study designs, and (3) individual difference variables selected. A qualitative description of these studies can be found in the supplementary materials.

Discussion

Summary

The present meta-analysis attempted to quantify, summarize, and reconcile the findings of 54 studies related to the atypical use of visuospatial context in psychotic

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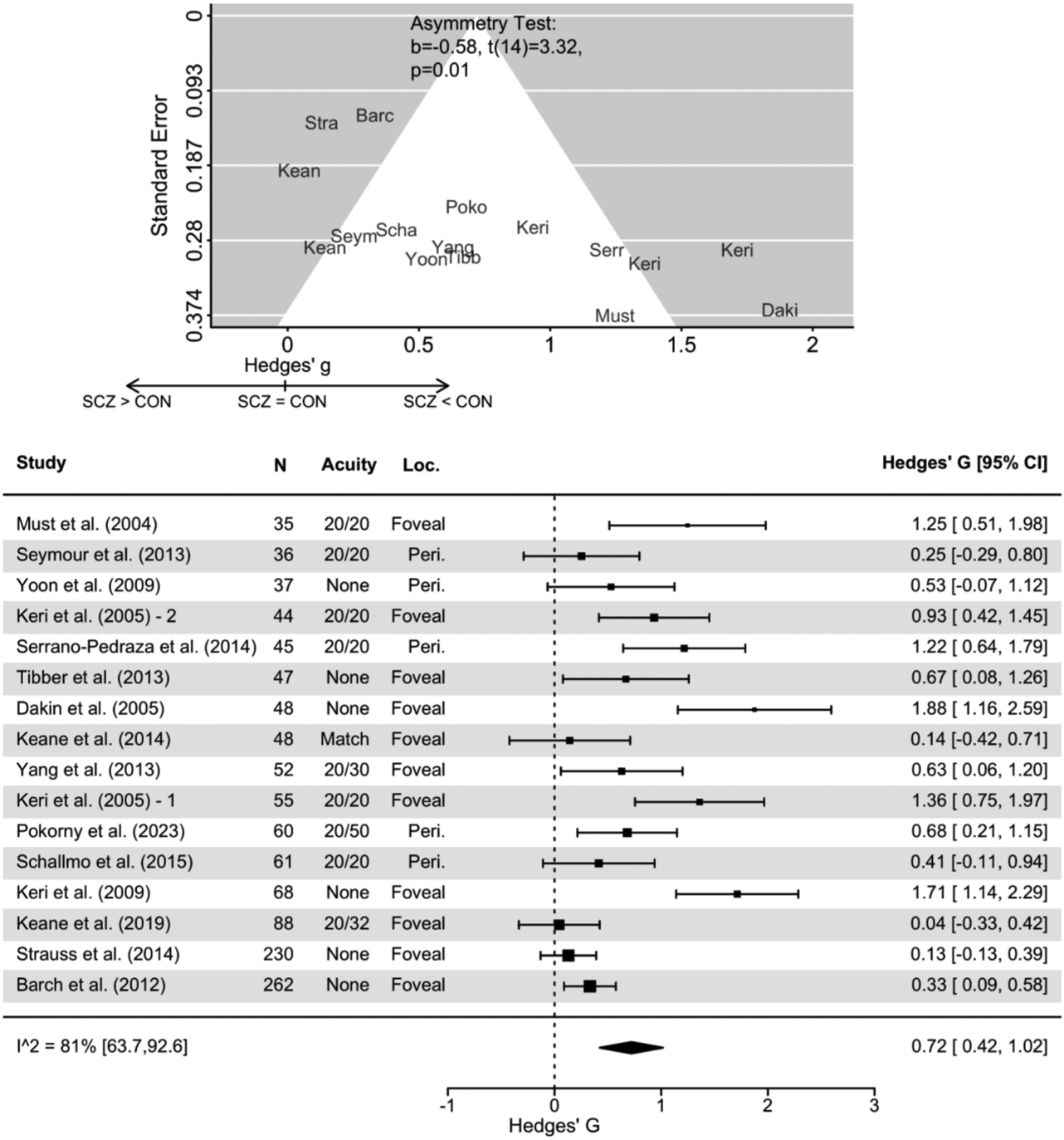

Fig. 3. Comparison of SCZ and CON: contrast studies. *Note*: CON, control; SCZ, schizophrenia.

psychopathology, spanning over 50 years of research on the subject. We observed weak evidence of a general visuospatial context difference in SCZ. This result aligns with the recent findings of multi-paradigm studies[57,58,60] in which SCZ did not differ from CON when pooling across a variety of paradigm types. We instead observed the strongest evidence for atypical use of visuospatial context for contrast perception, though publication bias may have inflated the observed pooled effect size estimate. With respect to bipolar disorder, we observed generally weaker, but more consistent effect sizes relative to SCZ. In terms of subclinical samples, we observed a large degree of heterogeneity with respect to populations of interest, measures, and study designs in the published literature.

Possible Neural Correlates of Atypical Use of Visuospatial Context

Visuospatial context paradigms are valuable because they are well studied in both animal and human models which

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allows psychosis researchers to make inferences about possible altered neural mechanisms. In the following section, we discuss the neural mechanisms implicated by the observed pattern of results (see figure 3).

We observed little evidence of atypical lightness perception in psychotic psychopathology. Salmela et al argued that lightness paradigms tap lower-level, pre-cortical (eg, retinal, thalamic, etc.) neural mechanisms.[61,65] It is therefore tempting to interpret our results as suggestive of intact pre-cortical processing; however, as White's illusion[66] famously shows, top-down grouping mechanisms can lead to lightness percepts that are opposite of what would be predicted based purely on lateral inhibition. Thus, as with most perceptual processes, there appears to be a rich interplay between bottom-up and top-down processing such that it is unlikely that all, or even most, lightness paradigms tap purely pre-cortical processes. Furthermore, there is increasing evidence of altered retinal mechanisms in SCZ, as measured by electroretinogram and optical coherence tomography[67] such that pre-cortical processes are likely altered in SCZ despite the little evidence we observed for atypical lightness perception.

We observed the strongest evidence of atypical orientation-independent and orientation-dependent contrast perception in SCZ. Both illusion types are thought to be mediated by local horizontal connections in V1 and feedback from higher cortical areas[68]; however, orientation-dependent contrast illusions more specifically tap "like-to-like" surround suppression in which neuronal firing is inhibited for neurons that are tuned to the same orientation, but sample different spatial locations.[68,69] Our results, therefore, are suggestive of generally weakened inhibition in V1 (either from local and/or feedback connections) with possibly a more specific alteration in like-to-like horizontal inhibitory connections. However, this latter point is complicated by the scant evidence of altered use of visuospatial context for orientation illusions. The repulsion effect elicited by most orientation illusions is well explained by the same "like-to-like" horizontal inhibitory connections that presumably mediate the orientation-dependent contrast suppression effect.[70] Thus, one might predict altered tilt illusion performance in psychotic psychopathology if these orientation-specific horizontal inhibitory connections were altered. One hypothesis that reconciles this pattern of results is that horizontal connections are intact in SCZ, but the feedback mechanisms recruited for contrast perception are altered. Though many studies of contextual modulation of contrast focus on V1 mechanisms, such modulation is known to occur as early as the retina.[71,72] Furthermore, contrast sensitivity has been linked to retinal dopamine functioning in studies of Parkinson's disease[73,74] and dopamine-blocking medications.[75] Thus, it is possible that altered retinal mechanisms, perhaps due to altered dopaminergic functioning, contribute to weakened effects of visuospatial context on contrast perception in SCZ.

We observed little evidence of atypical use of visuospatial context during size perception in SCZ. However, there is some evidence that size illusion susceptibility is moderated by clinical state and stage of illness which may explain the heterogeneity in effect sizes that we observed.[29] Size illusions are generally thought to arise from the adaptive need to account for distance cues when inferring object size from 2-dimensional retinal inputs.[76] The neural mechanisms by which the brain accomplishes this task are, to the best of our knowledge, not known; however, fMRI studies have shown the spatial extent of V1 activation varies as a function of perceived size.[77,78] Though it is possible that V1 locally computes size estimates from pre-cortical inputs, it is more likely that changes in V1 activation are caused by feedback from higher-level brain areas. Specifically, the lateral occipital complex (LOC) appears to play an important role in size perception.[79,80] Additionally, different size illusion paradigms may recruit different feedback mechanisms which may explain the substantial heterogeneity we observed across size paradigms.

In V1, perception of contours is thought to rely on excitatory (red arrows in figure 3), rather than inhibitory, lateral connections that support the integration of similarly oriented elements. Contextual effects on contour detection are hypothesized to be mediated by a mixture of inhibitory and excitatory connections in which contextual stimuli that are oriented parallel to the target contour are suppressive while orthogonally oriented stimuli are facilitative.[81] Three of the contour studies reviewed[12,13,59] found that people with SCZ were less affected by parallel flanking context which suggests a specific alteration in inhibitory lateral connections in V1. However, the evidence for this hypothesis is preliminary with 2 of the 3 studies coming from the same group of investigators. The LOC is also known to play an important role in shape/object recognition[79] such that local contours detected in V1 are likely pooled into global shape percepts in LOC. Furthermore, Silverstein et al found that BOLD activation in SCZ during contour integration did not differ from controls at V1, but did differ at V2, V3, and V4.[64] This suggests that visual areas as early as V2 play a role in the successful detection of contours. Finally, visual acuity is an important moderating factor to consider because contour integration performance has been associated with visual acuity, even for subjects with 20/20 vision or better.[82]

Finally, with respect to motion illusions, V1 neurons are known to be direction selective. The activation of these direction-selective V1 neurons is thought to be aggregated into an "optical flow field" represented by middle temporal (hMT+/V5) neurons.[83] V1 lesion and scotoma studies also provide evidence for a koniocellular pathway from lateral geniculate nucleus to hMT+ that may be responsible for residual vision or "blindsight."[84] If atypical illusory motion perception were associated with psychotic psychopathology, this could provide evidence for alterations of the neural mechanisms that pool

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local features to support motion estimates. However, the current evidence is too sparse and inconsistent for any meaningful inferences to be made.

Between-Study Heterogeneity

We observed a large degree of between-study heterogeneity. Much of this heterogeneity can be attributed to sampling heterogeneity and methodological heterogeneity. Some common sources of sampling heterogeneity included differential sampling of inpatients vs outpatient populations, chronic vs first-episode populations, adolescent vs adult populations, and medicated vs unmedicated populations. Demographic factors also likely contributed to sampling heterogeneity such as geographic location, socioeconomic status, acculturation, race, sex, gender, and education. We also observed a large degree of methodological heterogeneity in terms of differing laboratory environments, analytical decisions (eg, removal of outliers, exclusion of individuals with low acuity), response instructions, stimuli characteristics, number of trials, duration of trials, etc. Although this heterogeneity can make aggregation of effect sizes across studies difficult, it can also provide important clues as to which moderating factors might be important drivers of effects. For example, it has been proposed that the stage of illness is an important moderator of the degree to which SCZ is associated with reduced use of visuospatial context.[29] Such an effect provides important insights into the causal nature of altered perceptual mechanisms: if alterations are not observed in first-episode or high-risk subjects, this would suggest that these alterations are markers of disease progression rather than risk factors. In this way, between-study heterogeneity in sample characteristics can be valuable for identifying clinically informative moderators of visuospatial context effects.

The I^2 statistic was the largest for the meta-analysis that pooled across all effect sizes (see figure 2) and was reduced for subgroup analyses. This may reflect that the heterogeneity was reduced when grouping effect sizes by perceptual domain and paradigm type; however, the I^2 statistic is biased downward for meta-analyses with small numbers of studies when the true heterogeneity is large.[63] Thus, we cannot rule out that this observed reduction in I^2 was primarily driven by this bias. For this reason, I^2 alone could not be used for adjudicating whether a given grouping of effect sizes was appropriate and interpretable. Instead, we used a priori domain knowledge regarding visual perception and putative neural mechanisms to arrive at theoretically motivated groupings. Whether these groupings carve nature at its joints is an empirical question that future work would do well to address.

Limitations

The goal of the present review and meta-analysis was to summarize and quantify the published literature. Thus, it is possible that the estimated effect sizes are more sensitive to publication bias than a review that included unpublished reports. Indeed, some publication bias was apparent from the inspection of funnel plots and asymmetry tests for contrast perception studies (see figure 4). However, restricting our review to only peer-reviewed studies provided an overview of the published visuospatial context literature available to researchers. Encouragingly, the present review also included multiple peer-reviewed articles that reported primarily null findings.[54,57,60]

Some studies did not report sufficient data for the extraction of effect sizes. We went to great lengths to extract effect sizes even when the necessary information was not directly reported. Our estimates are likely imperfect reflections of the actual data, but we argue are preferable to outright omission. Despite efforts to minimize the omission of studies, we were unable to extract effect sizes for 11 studies. These omissions may bias the pooled effect size estimates if there is a relationship between "missingness" and the magnitude of effect sizes. For example, if studies reporting null results generally tended to be the ones for which we could not extract effect sizes, then the omission of these studies would lead to inflated effect size estimates. In our case, however, 5 of the omitted studies reported significant differences such that, if anything, our pooled effect sizes may have been biased toward zero. Also, the majority of the missing effect sizes were studies of size perception such that the pooled effect for size perception studies may be more biased toward zero than other perceptual domains. A long-term solution to this problem is for research training programs, peer-reviewers, journal editors, and funding bodies to emphasize the importance of reporting effect sizes (or at least the relevant data necessary for computing effect sizes). Alternatively, many of these problems could be alleviated by making study data publicly available.

One of the more promising findings was the difference between SCZ and CON across contrast perception tasks; however, the funnel plot and corresponding asymmetry test depicted in figure 4 suggest a relationship between effect size and study precision. This apparent asymmetry is largely driven by 2 large studies from CNTRACS that reported unexpectedly weak effect sizes. It is possible this discrepancy is due to differences in testing environments/procedures and sample characteristics. In particular, the CNTRACS sample exclusively consisted of stable outpatients while other studies such as Dakin et al recruited from inpatient populations.[7] However, publication bias is also a key factor because studies with smaller sample sizes can produce larger spurious effect sizes by chance. The larger CNTRACS studies have superior precision and, therefore, are more likely to produce effect size estimates that deviate less from the true effect size. On the other hand, 3 independent multi-domain studies[5,58,61] found that contrast paradigms significantly differentiated between

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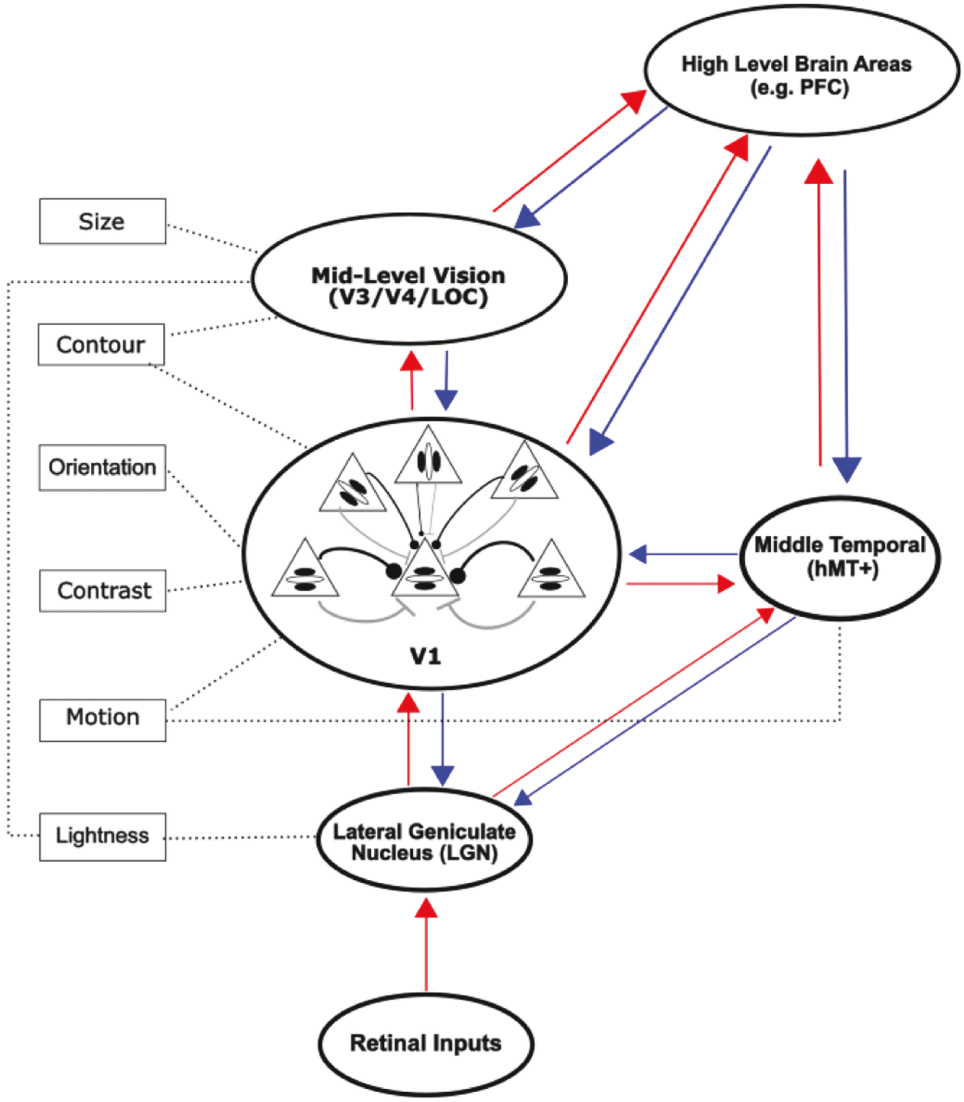

Fig. 4. Neural mechanisms related to visuospatial context domains. Boxes correspond to visuospatial context perceptual domains. Circles represent brain regions. Dotted lines connect domains to implicated brain regions/circuits. Arrows between circles correspond to feedforward and feedback connections. Within V1, triangles represent V1 neurons and cartoon Gabors represent receptive fields. Horizontal excitation and inhibition between V1 neurons are represented by gray and black lines, respectively. Neurons with similar orientation tuning provide stronger modulation (thicker gray and black lines), while neurons with different orientation tuning provide weaker modulation (thinner lines). Some lightness illusions can be explained via mechanisms as early as LGN; however, other lightness paradigms likely tap feedback mechanisms from higher-level brain regions. Motion detection occurs as early as V1, but hMT+ also plays an important role in motion perception. Contrast illusions can be explained by mechanisms as early as V1, but likely rely on feedback from higher-level brain regions as well. The same V1-intrinsic mechanisms (horizontal connections) that can explain contrast illusions can also explain orientation illusions. Local contours are detected by facilitatory connections (gray lines) between V1 neurons with similar orientation preferences that sample adjacent spatial locations; however, perception of more global contours likely relies on shape perception mechanisms in the lateral occipital complex (LOC), but may begin as early as V2.[64] Size perception has also been linked to the LOC. V1 activation has been shown to correspond to perceived size, but we argue that these findings are due to feedback from higher-level brain regions such as the LOC. *Note*: LGN, lateral geniculate nucleus.

psychotic psychopathology groups and controls. If effects were purely driven by publication bias then there would be an equal probability of type-1 error across all domains.

Furthermore, though we found differences in the use of visuospatial context between SCZ and controls for contrast-contrast illusions, a variety of confounding variables may be, at least partially, responsible for the effect. First, SCZ is thought to be associated with reduced visual acuity[85–87] and contrast sensitivity[88] which may influence the degree of suppression of perceived contrast. Additionally, in the case of contrast sensitivity, there is also evidence for *greater* contrast sensitivity in unmedicated first-episode psychosis such

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that the stage of illness likely moderates associations between contrast sensitivity and SCZ.[89] Other possible confounding variables include attentional lapses, generally reduced cognitive functioning, and atypical eye movements.[90,91] In particular, attentional lapses are problematic because they may lead to random responses. Random responses can falsely suggest reduced use of visuospatial context because condition effects are weakened. In fact, a completely random response pattern could be interpreted as complete imperviousness to visuospatial context. Indeed, Barch et al observed a reduction in effect size when excluding subjects who performed poorly on catch trials.[1] However, we also note that greater attentional lapse rates could be associated with greater illness severity such that excluding based on attentional lapses may inadvertently exclude individuals with higher perceptual dysfunction. Furthermore, Dakin et al collected full psychometric functions for each individual which allowed for direct estimation of random response rates. Interestingly, the error rates did not differ between groups while the bias estimates (ie, the degree to which visuospatial context influenced responses) did differ between groups.[7] Thus, further work is needed to clarify the causal pathways between reduced use of visuospatial context, psychosis, and myriad atypical cognitive and physiological correlates of the disorder.

Finally, though disaggregating effect sizes by perceptual domain and paradigm type improved the interpretability of pooled effect sizes, it also substantially reduced the number of studies included in a given analysis. This means that the pooled effect sizes for these analyses will be more sensitive to outliers and the standard error of the pooled effect sizes will be larger. Furthermore, it is more difficult to assess for publication bias due to the sparsity of the funnel plots and the low power of Egger-style regression tests.

Conclusion

The present meta-analysis attempted to answer the question: "Do people with psychotic psychopathology make less use of visuospatial context?" The available evidence suggests: "It depends." SCZ does not appear to be strongly associated with generally reduced use of visuospatial context when pooling across all of the available, published evidence. This finding is valuable and surprising because altered context processing is thought to be a core feature of SCZ.[92] Indeed, SCZ has been associated with not only atypical use of visuospatial context, but atypical use of temporal context (eg, working memory tasks, backward masking tasks, visual priming tasks, etc.), social context, and emotional context, among others. It is therefore tempting to conclude (and has been concluded by others) that there is a general context processing deficit in psychosis.[92–94] However, our results suggest that atypical context processing may be specific to certain domains and paradigms. Even within the more restricted scope of the present meta-analysis, we found large amounts of heterogeneity between studies, and little evidence of a general context processing deficit. SCZ did appear to be associated with a meaningful and replicable decreased use of visuospatial context with respect to contrast perception. This finding is exciting because the neural mechanisms of contextual modulation of perceived contrast are well studied in both human and nonhuman models.

An alternative explanation for our pattern of results is that a general reduction in the use of visuospatial context does exist in SCZ, but a variety of factors such as clinical state, symptom type/severity, and stage of illness moderate this reduction. Specifically, Silverstein et al found that size illusion susceptibility was weaker for SCZ at admission relative to discharge.[29] Furthermore, Parnas et al found that individuals in the prodromal stage of SCZ were significantly less susceptible to illusions than individuals with chronic SCZ.[95] Thus, clinical state and disease progression, in particular, may be important moderating factors to consider. We were unable to systematically quantify such moderating factors due to the large heterogeneity between studies with respect to whether and how these factors were assessed in each study. Future meta-analyses may identify specific factors that drive generally reduced use of visuospatial context. In particular, understanding the moderating role of illness stage will be crucial for determining whether atypical use of visuospatial context is a marker of disease progression or represents a predisposing risk factor. Such work will inform the degree to which these behavioral and neural markers are useful for predicting psychosis onset, determining illness trajectory, and measuring treatment outcomes. Thus, we are optimistic that future work refining and isolating the altered neural mechanisms of visuospatial context may lead to improved understanding of etiology, and improved diagnosis and treatment of psychotic psychopathology.

Supplementary Material

Supplementary material is available at https://academic.oup.com/schizophreniabulletin/.

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