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Cognitive Function Mediates the Relationship Between Visual Contrast Sensitivity and Functional Outcome in Schizophrenia

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Abstract

Background: Individuals with schizophrenia exhibit deficits in visual contrast processing, though less is known about how these deficits impact neurocognition and functional outcomes. This study investigated effects of contrast sensitivity (CS) on cognition and capacity for independent living in schizophrenia.

Methods: Participants were 58 patients with schizophrenia ($n = 49$) and schizoaffective disorder ($n = 9$). Patients completed a psychophysical paradigm to obtain CS with stimuli consisting of grating patterns of low (0.5 and 1 cycles/degree) and high spatial frequencies (4, 7, 21 cycles/degree). Patients completed the MATRICS Consensus Cognitive Battery and Wechsler Adult Intelligence Scales, Third Edition to assess cognition, and the problem-solving factor of the Independent Living Scales to assess functional capacity. We computed bivariate correlation coefficients for all pairs of variables and tested mediation models with CS to low (CS–LSF) and high spatial frequencies (CS–HSF) as predictors, cognitive measures as mediators, and capacity for independent living as an outcome.

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Declarations of Interest
None.

Results: Cognition mediated the relationship between CS and independent living with CS–LSF a stronger predictor than CS–HSF. Mediation effects were strongest for perceptual organization and memory-related domains. In an expanded *moderated mediation* model, CS–HSF was found to be a significant predictor of independent living through perceptual organization as a mediator and CS–LSF as a moderator of this relationship.

Conclusion: CS relates to functional capacity in schizophrenia through neurocognition. These relationships may inform novel visual remediation interventions.

Keywords

vision; cognition; visual pathways; visual perception; independent living; mediation analysis

1. Introduction

Individuals with schizophrenia exhibit deficits in visual contrast processing compared to healthy controls in a number of psychophysical and neurophysiological studies (Butler et al., 2009; Butler and Javitt, 2005; Butler et al., 2007; Butler et al., 2001; Cadenhead et al., 2013; Calderone et al., 2013b; Cimmer et al., 2006; Fernandes et al., 2019; Keri et al., 2002; O'Donnell et al., 2006; Slaghuis, 1998, 2004; Zemon et al., 2021). Contrast, a basic property of visual perception, is fundamental for viewing the natural world and is involved in all visual input to the brain, leading to dynamic effects on cortical circuitry (Zemon and Gordon, 2006). Altered properties of visual cortical neurons associated with deficits in contrast processing in schizophrenia may lead to deficits in higher-level cortical processes, given that projections from visual cortex to these higher cortical areas are known to be involved in cognitive and behavioral functioning (e.g., attention, perceptual organization, working memory, and decision-making) (Butler and Javitt, 2005; Butler et al., 2008; Elston, 2003; Felleman and Van Essen, 1991; Javitt, 2009; Roelfsema and Lange, 2016; Silverstein and Keane, 2011).

Initial investigations of links between contrast processing deficits and higher-level cognitive and functional deficits in schizophrenia have been carried out through correlational analyses. Lower psychophysical contrast sensitivity (CS) (e.g., poorer ability to detect contrast) was associated with deficits in intelligence quotient (IQ), attention, working memory, reading, facial emotion recognition, and functional outcome in schizophrenia (Butler et al., 2009; Butler et al., 2005; Martinez et al., 2012; Revheim et al., 2006a; Revheim et al., 2014). Lower CS as measured by a contour integration task was associated with decreased independent functioning in schizophrenia (Keane et al., 2014). Electrophysiological assessments of contrast processes have shown similar findings, with smaller visual evoked potential responses to contrast modulation being related to poorer performance on a facial emotion recognition task (Butler et al., 2009), as well as on measures of functional outcome in people with schizophrenia (Butler et al., 2005).

Studies also show links between other visual functions and cognition, symptoms, and functional outcomes in schizophrenia. Motion perception and motion recognition have been associated with cognition (Brenner et al., 2002), and perceptual organization has been linked to disorganized symptoms (Silverstein and Keane, 2011). Green and colleagues utilized structural equation modeling and found significant pathways from visual masking performance to functional outcomes through factors such as social cognition, beliefs, and negative symptoms (Green et al., 2012; Rassovsky et al., 2011; Sergi et al., 2006). Given that neurocognition is well known to predict functional outcomes in schizophrenia (Brekke et al., 2007; Green et al., 2004; Nuechterlein et al., 2011), there may be a significant pathway from visual processing to functional status through neurocognition. While CS in schizophrenia has been well investigated (Zemon et al., 2021), its relationships to neurocognition and functional outcomes require more extensive exploration. These examinations may further our understanding of the neural origins of deficits in cognition and functional outcomes in schizophrenia, as well as provide insight into novel treatments that target low-level perceptual processing. For instance, visual remediation shows promise for improving CS as well as higher level cognitive and behavioral functioning (Butler et al., 2017; Silverstein et al., 2020).

CS to low spatial frequency (CS–LSF) and high spatial frequency (CS–HSF) stimuli have yielded differential contributions to object and face processing (Bar, 2003; Calderone et al., 2013a; Keane et al., 2014; Silverstein et al., 2014; Vakhrusheva et al., 2014), and are thought to be processed by different mechanisms. LSF (coarse) information appears to be processed preferentially by a *transient* mechanism, while HSF (fine detail) information appears to be processed preferentially by a *sustained* mechanism (Breitmeyer and Ganz, 1977; Legge, 1978; Merigan et al., 1991a; Merigan and Eskin, 1986; Merigan et al., 1991b; Zemon et al., 2021). A principal component analysis of CS to grating patterns presented across a range of spatial frequencies demonstrated that, indeed, CS–LSF and CS–HSF loaded onto separate principal components (Zemon et al., 2021).

The goal of the current study was to investigate pathways between CS–LSF, CS–HSF, cognitive abilities, and functional capacity in schizophrenia. The Problem Solving Factor of the Independent Living Scales (ILS-PB) was selected as a measure of functional capacity given that it is based on necessary cognitive skills for independent community living, and has been shown to be of value as a global measure of functional outcome in schizophrenia (Loeb, 1996; Revheim and Medalia, 2004a; Revheim and Medalia, 2004b; Revheim et al., 2006b). Here, it was hypothesized that cognitive abilities would mediate the relationships between CS–LSF/CS–HSF and capacity for independent living among individuals with schizophrenia. To our knowledge, this is the first study to assess the pathways from the low-level visual property of CS to functional capacity in schizophrenia.

2. Methods

2.1 Participants

Participants were 58 patients with schizophrenia ($n = 49$) and schizoaffective disorder ($n = 9$). This is a subsample of participants extracted from a larger dataset (Zemon et al., 2021) of patients who completed the CS task, cognitive measures, and Problem-Solving Factor of the Independent Living Scales (ILS-PB). Number of participants per analysis is noted when there are missing neurocognitive data. Participants were recruited from the Nathan Kline Institute for Psychiatric Research and all participants provided informed consent in accordance with the Declaration of Helsinki. Diagnoses were obtained using the Structured

Clinical Interview for DSM-IV (SCID) and available clinical information. Exclusion criteria included the following: (a) met criteria for alcohol or substance dependence within the last six months, or abuse within the last month (b) had a neurological or ophthalmological disorder, including head injury that resulted in loss of consciousness for ≥ 30 minutes or loss of consciousness with any neurological sequelae, that might affect visual acuity or CS performance. Participants had a corrected visual acuity of 0.2 logMAR or better at 4 m based on the Logarithmic Visual Acuity Chart (Precision Vision, La Salle, IL) with decimal equivalent values reported here. This study was approved by the Nathan Kline Institute for Psychiatric Research/Rockland County Psychiatric Center Institutional Review Board.

Table 1 displays demographic and clinical characteristics of the sample. Note that there were more males than females in this sample. Chlorpromazine equivalents were calculated using known conversion factors (Hyman et al., 1991; Jibson and Tandon, 1998; Peuskens and Link, 1997; Woods, 2003). Patients' mean total score on the PANSS (Kay et al., 1987) suggests a markedly ill Clinical Global Impressions classification (Leucht et al., 2005).

2.2 Measures and Procedures

2.2.1 Psychophysical CS task—A two-alternative spatial forced-choice paradigm was used to obtain contrast thresholds. Stimuli were displayed on a cathode ray tube monitor with 90 frames/s viewed at 190 cm. The stimulus display subtended 6 × 6 degrees of visual angle with space-average luminance of approximately 100 cd/m^2. Stimuli were horizontal sine-wave gratings at spatial frequencies of 0.5, 1, 4, and 7 cycles/degree (cpd), and a square-wave grating of 21 cpd (VENUS system, NeuroScientific Corp.). Stimuli were presented at durations of 33 and 500 ms. The 33 ms condition was designed to bias processing toward a transient mechanism (phasic response, enhancing CS–LSF), and the 500 ms condition was designed to bias processing toward a sustained mechanism (tonic response, enhancing CS–HSF), respectively (Legge, 1978).

Gratings of the various spatial frequencies were presented randomly to the left or right side of the display, and the participant indicated which side of the display contained the grating by raising the right or left hand. The experimenter recorded the observer's response. An up-down transformed response rule was applied to track contrast thresholds based on correct identification of the location of the stimulus on 70.7% of the trials. The tracking procedure was interleaved for the five spatial frequencies. Contrast threshold was estimated by taking the mean of 10 contrast reversals (five peaks and five troughs) in the tracking procedure. The reciprocal of contrast threshold for each spatial frequency was calculated to obtain CS. Greater CS indicates better performance. For additional details on this method, see (Zemon et al., 2021).

2.2.2 Cognitive measures—Patients completed The Measurement and Treatment Research to Improve Cognition in Schizophrenia (MATRICS) Consensus Cognitive Battery (MCCB) (Kern et al., 2008; Nuechterlein et al., 2008) and the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III) (Wechsler, 1997) to assess cognitive abilities. T-scores were obtained for each of the MCCB domains (Speed of processing, Attention/vigilance, Working memory, Verbal learning, Visual learning, and Reasoning and problem-solving) and normalized scores were obtained for the Perceptual Organization Index (POI), Processing Speed Index (PSI), and Working Memory Index (WMI) of the WAIS-III.

2.2.3 Functional capacity—

Patients completed the Problem-Solving Factor of the Independent Living Scales (ILS-PB) (Loeb, 1996) as a measure of functional capacity. The total ILS has five subscales including memory-orientation, managing money, managing home and transportation, health and safety, and social adjustment. Factor analysis yielded two constructs, a performance-information factor which reflects actual knowledge or skills to perform tasks and the ILS-PB. ILS-PB contains 33 items related to money, home management, health and safety issues, and social adjustment that measure the likelihood of successful independent community living by evaluating cognitive skills, such as abstract reasoning and judgment, required for daily activities (Loeb, 1996). This factor of the ILS was shown to be a highly predictive measure of cognitive determinants of community status, and reliably discriminates among various levels of care in schizophrenia (Revheim and Medalia, 2004a; Revheim and Medalia, 2004b). Standardized scores range from 20 to 63: scores ranging from 20 to 39 suggest maximum (full-time) supervision for daily living, scores ranging from 40 to 49 suggest moderate supervision, and scores ranging from 50 to 63 suggest minimum supervision, or independent living (Loeb, 1996).

2.3 Analyses

CS was converted to $\log_{10}$CS for analyses; logCS to low spatial frequencies and logCS to high spatial frequencies were considered separately in analyses. The arithmetic mean of logCS to 0.5 and 1 cpd gratings for both stimulus durations (33 ms and 500 ms) was taken as an LSF variable (CS–LSF) and the arithmetic mean of logCS to 4, 7, and 21 cpd gratings for both stimulus durations (33 ms and 500 ms) was taken as an HSF variable (CS–HSF). This is based on previous work demonstrating CS–LSF and CS–HSF as two distinct components (Zemon et al., 2021).

Zeroth-order Pearson correlations were computed among CS, individual cognitive domains/indices, and independent living scores.

Mediation analysis conducted in SPSS by means of Andrew Hayes' PROCESS macro v3.5 tested a mediating relationship with CS as the predictor, cognitive measures as the mediator, and ILS-PB as the outcome measure (Hayes' Model 4, simple mediation). Models were tested separately for CS–LSF and CS–HSF and separately for each cognitive measure. Fritz and MacKinnon (2007) conducted computer simulations to determine the sample size required for a specified mediation effect. To detect a medium size indirect effect, given an alpha level of .05 with desired power of .8, a sample size of 78 is needed using a percentile bootstrap method; for a large effect, a sample size of 36 is required. With a total sample of 58 we sought to identify large effects that would be meaningful for clinical relevance. *Moderated mediation* modeling (Hayes' Model 8) was applied in follow-up analyses to simple mediation modeling. Models were estimated using ordinary least squares (OLS) regression path analyses. Bootstrapping for *indirect effects* was set at 5,000 samples. For *moderated mediation* modeling, heteroscedasticity-consistent standard error (HC3) estimation was used, and percentile 95% confidence intervals were used for all models. For the 18 simple mediation models tested, R^2 values are reported along with unadjusted *p* values and adjusted *p* values based on controlling the false discovery rate as developed by Benjamini and Hochberg (Benjamini and Hochberg, 1995), calculated using an online tool (https://tools.carbocation.com/FDR). This type of adjustment is preferred because of the greatly inflated type II error that is associated with conventional adjustments for the familywise error rate (e.g., Bonferroni correction) (Greenland, 2021), but it is more conservative than the subsequently proposed adaptive false discovery rate controlling procedure (Benjamini et al., 2006). Number of participants varied per model given missing data; this sample was extracted from a larger dataset and thus some participants are missing neurocognitive data.

3. Results

3.1 Univariate descriptive statistics

The means and standard deviations of the variables are reported in Table 1. Age- and gender-corrected T scores are reported for MCCB domains (normative mean = 50; standard deviation = 10). On average, patients showed greatest impairment for processing speed and least impairment for reasoning/problem solving, consistent with previously reported data for patients with schizophrenia (Kern et al., 2011). The WAIS-III index scores indicate that patients scored in the low average range overall, though abilities ranged from extremely low to very superior. On the ILS-PB, patients' independent living scores ranged from 20 (maximum, full-time supervision) to 58 (minimum supervision or independent living), with the average being maximum to moderate supervision.

3.2 Correlations

Correlation coefficients of contrast sensitivity, ILS-PB, and neuropsychological measures, along with corresponding density plots and bivariate scatterplots are presented in Figure 1. CS–LSF correlated significantly with all cognitive domains with the exception of reasoning/problem solving. CS–HSF correlated significantly with attention/vigilance, processing speed index, and working memory index. Cognitive domains correlated significantly with ILS-PB scores, with the exception of attention/vigilance. CS–LSF and CS–HSF did not correlate significantly with ILS-PB. These relationships informed the mediation models.

3.3 Mediation Modeling

Mediation modeling was used to test the *indirect (mediation) effects* of each cognitive domain on the relationship between CS and independent living in patients. Figure 2 shows an example conceptual model for visual learning mediating the relationship between CS–LSF and ILS-PB in patients. Table 2 shows the *indirect effect (ab, product of path coefficients for the mediating pathway)* for all simple mediation models tested, along with each model's R^2 value and Benjamini-Hochberg-adjusted *p* value (Benjamini and Hochberg, 1995). There were significant mediation effects based on the percentile bootstrapped 95% confidence intervals for all cognitive domains of the WAIS and MCCB, with the exception of Attention/vigilance, on the relation between CS–LSF and ILS-PB. Not all of these mediation models, however, achieved Benjamini-Hochberg-adjusted (B-H) *p* values below a .05 criterion. The models that achieved significance in terms of both *indirect effects* and B-

H-adjusted *p* values were perceptual organization and working memory (WAIS and MCCB) given either CS–LSF or CS–HSF predictors, and also verbal learning for just CS–LSF. The *c* paths (*total effects* of CS–LSF and CS–HSF on ILS-PB in the absence of a mediator) and *c'* paths (*direct effects* of CS–LSF and CS–HSF on ILS-PB in the presence of a mediator) were not significant for any model, indicating dominance of the mediating pathway. We also tested the models using CS to a single spatial frequency of 0.5 cycles/degree instead of the CS–LSF composite variable, and similar results were obtained with identical conclusions.

In addition, we explored *moderated mediation* models with CS–HSF as the predictor, ILS-PB as the outcome, and CS–LSF as a moderator of paths *a* and *c'*, with perceptual organization and both working memory measures (the cognitive measures that yielded significant *indirect, mediation effects* on ILS-PB in the simple mediation models) as mediating variables. Only the model with perceptual organization as a mediator (Figure 3a) yielded a significant *conditional indirect effect* of CS–HSF on ILS-PB (*index of moderation* = 27.52 95% CI [7.42, 57.33]). The *indirect effect* of the relation between CS–HSF and ILS-PB through perceptual organization changes from negative to positive as CS–LSF increases; the slope of this function is the *index of moderation* (Figure 3b). The *indirect effect* was significant when CS–LSF was 1.76 (−1 *SD* below the mean value of 1.95). Pairwise comparisons among the three levels of *indirect effect* conditioned on the three levels of CS–LSF were all significant based on 95% confidence intervals. In this model, 32% of the variance in perceptual organization is explained by CS–LSF, CS–HSF, and the interaction CS–LSF × CS–HSF ($F(3,49) = 5.38$, $p = .003$). The overall model explains 25.0% of the variance in ILS-PB ($F(4,48) = 5.68$, $p < .001$).

4. Discussion

A number of basic visual deficits in schizophrenia have been linked to higher-level problems in cognition and functional outcomes (Brenner et al., 2002; Butler et al., 2009; Butler et al., 2005; Dias et al., 2011; Green et al., 2012; Martinez et al., 2012; Rassovsky et al., 2011; Sehatpour et al., 2010; Sergi et al., 2006). Contrast sensitivity deficits are well documented in this population (Butler and Javitt, 2005; Fernandes et al., 2019; Keri et al., 2002; Silverstein, 2016; Slaghuis, 1998; Zemon et al., 2021) and have been shown to be related positively to higher level functions such as facial processing/emotion recognition (Butler et al., 2009; Kim et al., 2015; Laprevote et al., 2010; Lee et al., 2011; McBain et al., 2010; Silverstein et al., 2010; Silverstein et al., 2014; Vakhrusheva et al., 2014), reading (Revheim et al., 2006a), visual learning (Dias et al., 2011), and object recognition (Calderone et al., 2013a; Laprevote et al., 2013).

The current study is the first to our knowledge to demonstrate that neurocognition mediates the relationship between CS and a measure of functional outcome in people with schizophrenia. Specifically, CS to low spatial frequencies (CS–LSF) was related to a measure of independent living through several neurocognitive domains tested. These findings support an effect of early visual processing on higher-level cognitive and functional outcomes in schizophrenia.

The indirect effects from CS to independent living skills through various cognitive abilities were stronger for CS–LSF compared to CS–HSF. Only the two measures of working memory and perceptual organization reached significance as mediators between CS–HSF and independent living, though other cognitive mediators (e.g., visual learning) demonstrated marginal effects. Previous studies showed CS deficits to both LSFs and HSFs in schizophrenia (Fernandes et al., 2019; Keri et al., 2002; Slaghuis, 1998; Zemon et al., 2021), however, the current results indicate that LSF information might be more critical for the cognitive functions investigated here.

The stronger mediating relationships involving CS–LSF compared to CS–HSF in the current study may be due, in part, to a need to process visual information rapidly during a number of cognitive tests. One theory of object recognition proposes that LSF information in an object is processed earlier than HSF information, and it reflects a ‘frame and fill’ process (Chen et al., 2006) consistent with a model proposed by Bar (Bar, 2003). CS–LSF was also found to moderate the mediating effect of perceptual organization in the relation between CS–HSF and ILS-PB. Thus, it appears that CS–LSF is the dominant visual factor and its explanatory power covers much of that explained by CS–HSF. The finding of a negative mediating effect of CS–HSF on ILS-PB through perceptual organization when CS–LSF is low, but a positive mediating effect when CS–LSF is high, might indicate that high spatial frequency information interferes with the relationship between perceptual organization and capacity for independent living when there is not sufficient low spatial frequency information to provide an adequate ‘frame’ for global perception. When this ‘frame’ is established with strong low spatial frequency information, the positive effect of high spatial frequency information might reflect details (‘fill’) added to the ‘frame’ with commensurate enhanced perceptual organization.

Perceptual organization and memory-related cognitive domains (i.e., working memory, verbal learning) demonstrated the strongest mediating effects in this study. On the MCCB, the memory-related domains include tests such as word recall and letter-number strings that need to be reordered. The finding of significance for a nonvisual task (i.e., verbal learning) may be surprising, however, visual processing involves about 50% of the neocortex (Van Essen, 2004) and deficits in visual processing can alter the dynamics of cortical processing globally (e.g., (Musacchia and Schroeder, 2009; Schroeder et al., 2008)). Specifically, changes in contrast of visual stimuli alter the temporal integration and gain control properties of visual cortical neurons and consequently influence those properties of neurons in higher cortical areas (Butler et al., 2008; Zemon and Gordon, 2006). The current findings are consistent with research suggesting that perceptual organization and working memory deficits are core features of schizophrenia (Green et al., 2009; Lee and Park, 2005; Silverstein, 2016; Silverstein and Keane, 2011) and may underlie other cognitive deficits (Goldman-Rakic, 1994; Javitt, 2009; Kim et al., 2006; Silverstein, 2016).

Cognitive remediation has been shown to improve cognition and functional outcomes in people with schizophrenia (Biagianti et al., 2016; Medalia et al., 2019; Revell et al., 2015; Wykes et al., 2011), and interventions that target low-level visual processes may also have benefits (Demmin et al., 2019). There is preliminary evidence that visual remediation improves CS and spatial frequency processing (Butler et al., 2017;

Silverstein et al., 2020). Other studies have shown that in patients with schizophrenia visual remediation improved visual motion discrimination (Norton et al., 2011), visual backward masking training improved performance on a visuospatial memory test (Surti and Wexler, 2012), and pairing visual remediation with cognitive remediation improved cognition and psychosocial functioning (Contreras et al., 2017). The pathways from early stages of visual processing to functional outcomes discovered in the current study provide support for further investigations into the effects of visual remediation interventions on these pathways.

Limitations of this study included a modest sample size with greater number of males than females. Sample size was larger for the WAIS measures than for the MCCB measures with the exception of the Attention/vigilance domain of the MCCB in which case it was the same size. Notably, the Attention/vigilance domain yielded the highest *p* values in the mediation modeling with both LSF and HSF CS measures. It should be noted, however, that small samples might yield spuriously large effect sizes (Button et al., 2013), and therefore, additional studies are required to replicate these findings. The sample consisted of patients with chronic illness, some of whom are receiving typical antipsychotics. Longer illness duration and typical antipsychotics have been associated with poorer CS (Almeida et al., 2019; Fernandes et al., 2019). Studies with a larger sample are recommended to investigate more complex models (e.g., parallel mediation) with greater power (Fritz and Mackinnon, 2007; Hayes, 2013) and yield higher precision of parameter estimates (i.e., narrower confidence intervals).

Future studies should consider other mediating/moderating factors in these models, such as negative symptoms and social cognition (Green et al., 2012; Rassovsky et al., 2011; Sergi et al., 2006), in the relationship between CS and functional outcomes in schizophrenia. This study chose the ILS-PB as a measure of functional capacity given that it relies strongly on cognitive skills (Loeb 1966; Revheim et al., 2006). Additional work should include another, frequently used measure of functional capacity, the University of California, San Diego (UCSD) Performance-Based Skills Assessment (UPSA) (Patterson et al., 2001), as well as measures of social and role functioning.

In conclusion, this study provides evidence that early visual processing deficits may be a precursor to cognitive and functional deficits in schizophrenia. These results are encouraging for the development of novel treatments for schizophrenia, such as remediation of contrast detection.

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Highlights

- Patients with schizophrenia (sz) show deficits in visual contrast detection.
- First study to assess pathways from contrast sensitivity to functioning in sz.
- Contrast sensitivity impacts cognition and functional outcomes in sz.
- Novel treatments such as remediation of contrast detection may be helpful.

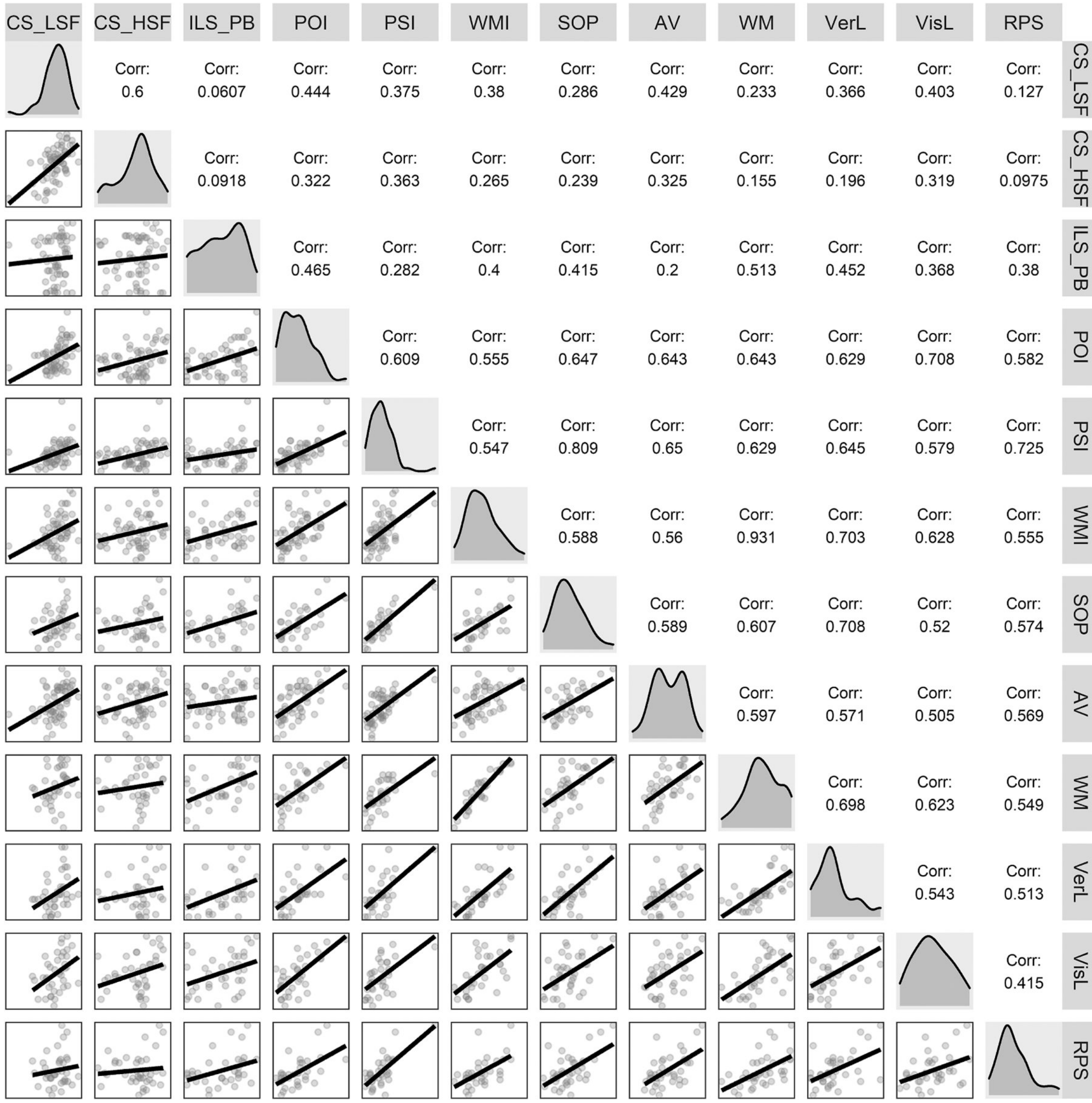


Figure 1.

Intercorrelations among contrast sensitivity, independent living, and neuropsychological measures (*n* per correlation coefficient ranges from 32 to 58 given missing data: CS–LSF ≡ mean log contrast sensitivity at low spatial frequencies (0.5 and 1 cycles/degree); CS–HSF ≡ mean log contrast sensitivity at high spatial frequencies (4, 7, 21 cycles/degree); ILS-PB ≡ Problem Solving Factor of the Independent Living Scales; POI ≡ Perceptual Organization Index; PSI ≡ Processing Speed Index; WMI ≡ Working Memory Index; SOP ≡ Speed of processing; AV ≡ Attention/Vigilance; WM ≡ Working memory; VerL ≡ Verbal learning; VisL ≡ Visual learning; RPS ≡ Reasoning and problem-solving.

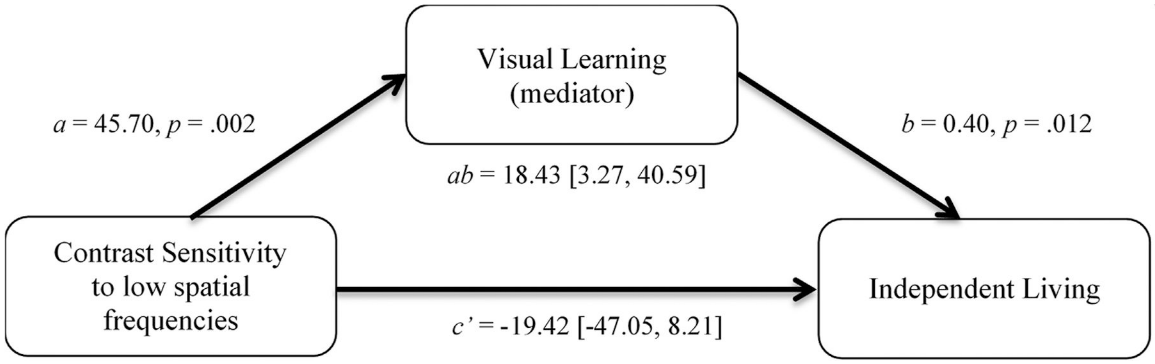
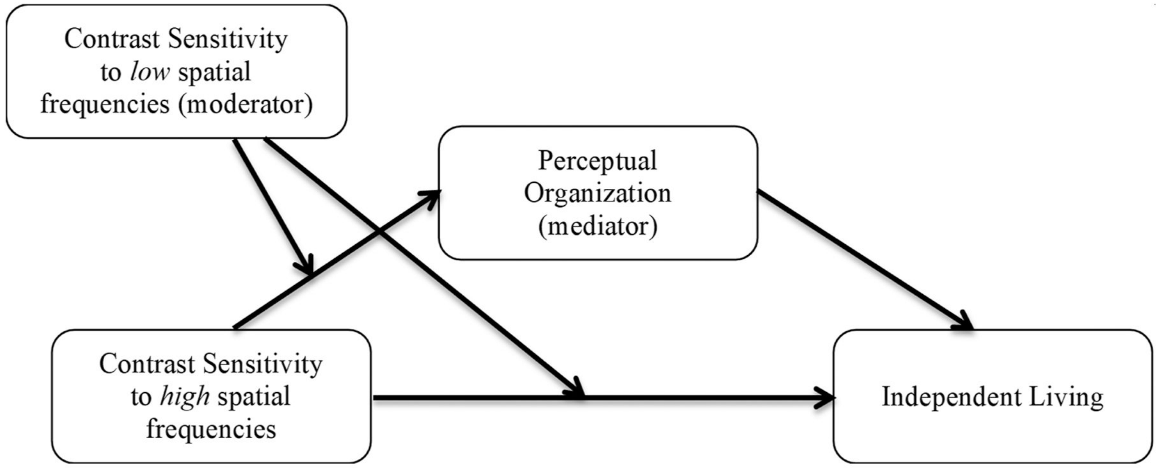


Figure 2.
Mediation model showing the *indirect effect* (*ab*, product of regression coefficients in the mediating pathway) of contrast sensitivity at low spatial frequencies (0.5 and 1 cycles/degree) on independent living (Problem-Solving Factor of the Independent Living Scales, ILS-PB) through visual learning in patients. There is no significant *direct effect (c')* of contrast sensitivity on independent living in the presence of the mediator, indicating dominance of the mediating pathway.



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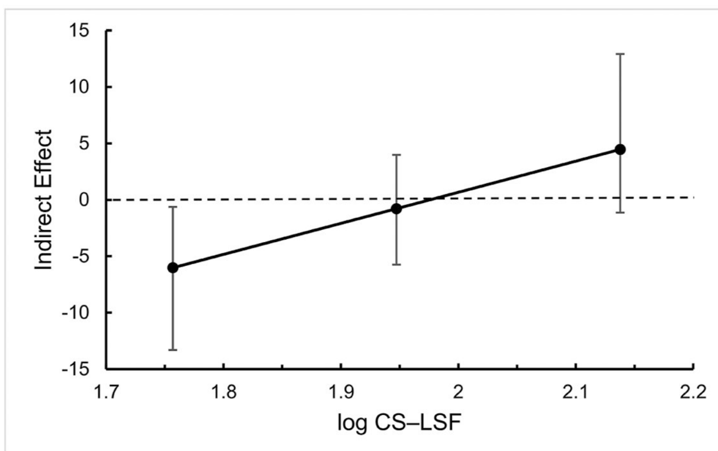

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Figure 3.

a) Moderated-mediation model showing a significant conditional *indirect effect* of CS–HSF on ILS-PB through the mediator, perceptual organization. As CS–LSF increases, there is an increasing *indirect effect* of the relation between CS–HSF and ILS-PB when the moderator CS–LSF is low. b) Plot of *indirect effect* of CS–HSF on ILS-PB through the mediator, perceptual organization, as a function of the moderator, CS–LSF.

Table 1.

Demographic and clinical characteristics of patients with schizophrenia and schizoaffective disorder (N = 58)

Age	38.9 ± 10.0
Gender (M/F)	46/12
Diagnosis	
Schizophrenia	49
Schizoaffective Disorder	9
Acuity	0.92 ± 0.20
Participant SES[a] *(n = 55)*	25.4 ± 12.1
Parent SES[a] (*n = 49)*	48.3 ± 25.4
PANSS[b] total score (*n = 54)*	73.0 ± 12.7
Positive Scale	19.8 ± 6.2
Negative Scale	17.9 ± 4.2
General Psychopathology Scale	35.3 ± 6.5
Duration of illness (years) (*n = 48)*	16.3 ± 9.1
Chlorpromazine daily equivalent, mg	876.6 ± 689.7
Antipsychotics	
Atypical	40
Typical	5
Combination	12
Not on antipsychotic	1
CS–LSF[c]	1.9 ± 0.2
CS–HSF[d]	1.4 ± 0.3
WAIS Perceptual Organization Index[e] *(n = 53)*	88.1 ± 16.6
WAIS Processing Speed Index[e] *(n = 55)*	79.4 ± 13.7
WAIS Working Memory Index (*n = 53)*	88.5 ± 13.6
MCCB Speed of processing[f] *(n = 35)*	25.7 ± 12.6
MCCB Attention/vigilance[f] *(n = 55)*	30.2 ± 11.3
MCCB Working memory[f] *(n= 35)*	30.9 ± 12.2
MCCB Visual learning[f] *(n = 35)*	33.0 ± 14.4
MCCB Verbal learning[f] *(n = 35)*	32.4 ± 7.5
MCCB Reasoning and problem-solving[f] *(n = 35)*	35.6 ± 9.4
ILS-PB[g]	38.6 ± 11.5

Values are $M \pm SD$ with the exception of gender and antipsychotics in which they are counts. Number of participants is noted given missing data.

[a] socioeconomic status measured by Hollingshead Four-Factor Index of Social Status (Hollingshead, 1975).

[b] Positive and Negative Syndrome Scale (Kay et al., 1987).

[c] mean log contrast sensitivity to low spatial frequencies (0.5 and 1 cycles/degree).

[d] mean log contrast sensitivity to high spatial frequencies (4, 7, 21 cycles/degree).

[e] Wechsler Adult Intelligence Scale-III.

[f] MATRICS Consensus Cognitive Battery (MCCB) domains.

[g] Problem-solving factor of the Independent Living Scales.

Table 2.

Indirect (mediation) effects of cognitive functions on the relations between CS at low and high spatial frequencies and independent living in patients with schizophrenia and schizoaffective disorder

Cognitive Measure	*n*	CS-LSF[a] *Indirect Effect ab* [95% CI]	R^2	*p*	*B-H p* value	CS–HSF[b] *Indirect Effect ab* [95% CI]	R^2	*p*	*B-H p* value
WAIS-III[c]									
Perceptual Organization Index	53	13.87 [4.91, 29.23]	.235	.001	.018	4.61 [0.55, 9.58]	.217	.002	.013
Processing Speed Index	55	7.38 [0.60, 18.81]	.086	.097	.116	3.52 [−0.09, 8.24]	.079	.116	.131
Working Memory Index	53	12.80 [4.13, 26.66]	.193	.005	.018	4.22 [0.43, 9.66]	.161	.013	.029
MCCB[d]									
Visual learning	35	18.43 [3.27, 40.59]	.187	.036	.059	5.24 [−0.10, 13.76]	.177	.044	.066
Speed of processing	35	12.91 [1.63, 28.31]	.203	.027	.053	3.72 [−2.04, 12.69]	.201	.027	.049
Attention/vigilance	55	5.97 [−3.30, 18.41]	.041	.341	.361	2.48 [−1.11, 8.86]	.041	.341	.341
Reasoning & problem-solving	35	8.97 [0.55, 20.57]	.161	.060	.077	3.14 [−2.34, 9.92]	.169	.052	.072
Verbal learning	35	19.07 [7.93, 34.73]	.264	.007	.021	4.61 [−0.14, 11.62]	.242	.012	.031
Working memory	35	18.31 [5.56, 38.44]	.321	.002	.019	5.73 [0.92, 12.57]	.312	.003	.014

The outcome measure was the Problem-solving factor of the Independent Living Scales (ILS-PB).

[a] mean log contrast sensitivity at low spatial frequencies (0.5 and 1 cycles/degree), CS–HSF.

[b] mean log contrast sensitivity at high spatial frequencies (4, 7, and 21 cycles/degree), CS–HSF.

[c] Wechsler Adult Intelligence Scale-III indices.

[d] MATRICS Consensus Cognitive Battery (MCCB) domains.

ab ≡ indirect (mediation) effect.

95% CI ≡ 95% confidence interval (percentile) based on 5,000 bootstrapped samples.

B-H p value ≡ Benjamini-Hochberg-adjusted *p* value based on false discovery rate control.

R^2, *p (unadjusted),* and *B-H p* value for mediation model.