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Original Article

Cite this article: Moran EK, Gold JM, Carter CS, MacDonald III AW, Ragland JD, Silverstein SM, Luck SJ, Barch DM (2020). Both unmedicated and medicated individuals with schizophrenia show impairments across a wide array of cognitive and reinforcement learning tasks. *Psychological Medicine* 1–11. <https://doi.org/10.1017/S003329172000286X>

Received: 8 November 2019

Revised: 26 May 2020

Accepted: 20 July 2020

Key words:

Antipsychotic medications; cognition; reinforcement learning; schizophrenia

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Both unmedicated and medicated individuals with schizophrenia show impairments across a wide array of cognitive and reinforcement learning tasks

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Abstract

Background. Schizophrenia is a disorder characterized by pervasive deficits in cognitive functioning. However, few well-powered studies have examined the degree to which cognitive performance is impaired even among individuals with schizophrenia not currently on antipsychotic medications using a wide range of cognitive and reinforcement learning measures derived from cognitive neuroscience. Such research is particularly needed in the domain of reinforcement learning, given the central role of dopamine in reinforcement learning, and the potential impact of antipsychotic medications on dopamine function.

Methods. The present study sought to fill this gap by examining healthy controls ($N = 75$), unmedicated ($N = 48$) and medicated ($N = 148$) individuals with schizophrenia. Participants were recruited across five sites as part of the CNTRaCS Consortium to complete tasks assessing processing speed, cognitive control, working memory, verbal learning, relational encoding and retrieval, visual integration and reinforcement learning.

Results. Individuals with schizophrenia who were not taking antipsychotic medications, as well as those taking antipsychotic medications, showed pervasive deficits across cognitive domains including reinforcement learning, processing speed, cognitive control, working memory, verbal learning and relational encoding and retrieval. Further, we found that chlorpromazine equivalency rates were significantly related to processing speed and working memory, while there were no significant relationships between anticholinergic load and performance on other tasks.

Conclusions. These findings add to a body of literature suggesting that cognitive deficits are an enduring aspect of schizophrenia, present in those off antipsychotic medications as well as those taking antipsychotic medications.

Impairments in cognitive functioning are a core feature of schizophrenia with deficits seen throughout the course of illness including at the first episode (Barch et al. 2001; Bilder et al. 2000; Mesholam-Gately, Giuliano, Goff, Faraone, & Seidman, 2009; Saykin et al. 1994) and in adults with chronic schizophrenia (Barch & Ceaser, 2012; Fioravanti, Carlone, Vitale, Cinti, & Clare, 2005; Green, Kern, Braff, & Mintz, 2000; Nuechterlein et al. 2004). Impairments are consistently reported in a broad range of cognitive domains including processing speed, verbal learning, working memory, cognitive control, visual integration and reinforcement learning (Butler, Silverstein, & Dakin, 2008; Dickinson, Ramsey, & Gold, 2007; Gold et al. 2012; Lee & Park, 2005; Lesh, Niendam, Minzenberg, & Carter, 2011; Macdonald & Carter, 2003; Minzenberg, Laird, Thelen, Carter, & Glahn, 2009; Silverstein, Kovács, Corry, & Valone, 2000). The relationship between antipsychotic medications and cognitive functioning has been examined (Goldberg et al. 2007; Harvey & Keefe, 2001; Keefe et al. 2007a; Mishara & Goldberg, 2004) with research suggesting that medications currently and commonly prescribed to individuals with schizophrenia have either minimally beneficial (Goldberg et al. 2007; Keefe et al. 2007b; Lesh et al. 2015; Meltzer & McGurk, 1999; Spagna et al. 2015) or potentially even slightly deleterious effects on cognitive performance (Élie et al. 2010; Hori et al. 2006; Spohn & Strauss, 1989; Uchida et al. 2009). However, limited work has examined reinforcement learning and visual integration in those off medications. Moreover, limited work has examined the degree to which cognitive impairments are present

among unmedicated individuals with chronic schizophrenia using cognitive tasks derived from cognitive neuroscience. The current study, conducted as part of the Cognitive Neuroscience Test Reliability and Clinical applications for Serious mental illness (CNTRaCS) Consortium, examined whether pervasive deficits in cognitive functioning are seen in individuals off as well as on medications across a wide range of cognitive domains.

A number of studies have confirmed the presence of impairments among individuals not taking medications on measures of memory, processing speed and cognitive control (Barch, Carter, MacDonald, Braver, & Cohen, 2003; Braff & Saccuzzo, 1982; Cadenhead *et al.* 1997). However, there is limited work examining individuals with schizophrenia off medications in other cognitive domains impaired in schizophrenia, such as reinforcement learning. For example, research has shown impairments in the ability to learn from reward in medicated schizophrenia patients (Barch *et al.* 2017; Cicero, Martin, Becker, & Kerns, 2014; Culbreth, Westbrook, Xu, Barch, & Waltz, 2017; Dowd, Frank, Collins, Gold, & Barch, 2016; Gold *et al.* 2012; Murray *et al.* 2008; Strauss *et al.* 2011; Waltz, Frank, Robinson, & Gold, 2007), however, less is known about reinforcement learning in unmedicated patients. Reinforcement learning is thought to be critically dependent on the subcortical dopamine system (Maia, 2009; Montague, Dayan, & Sejnowski, 1996; Schultz, 2007, 2016a, 2016b), which is modulated by many, if not all, of the medications used to treat psychosis (Amato, Vernon, & Papaleo, 2018). There are some hints in the literature that reinforcement learning is disrupted even among unmedicated individuals with schizophrenia (Juckel *et al.* 2006; Reinen *et al.* 2016; Schlagenhauf *et al.* 2014; Stoy *et al.* 2012), though sample sizes have been small. Thus, additional work is needed in larger samples to assess whether deficits in reinforcement learning are present amongst unmedicated individuals with schizophrenia, and if so, whether the magnitude of such deficits differs from those seen among medicated individuals with schizophrenia.

Visual integration is another domain of cognitive functioning that has consistently shown deficits in individuals with schizophrenia (Butler *et al.* 2013; Butler, Silverstein, & Dakin, 2008; Silverstein *et al.* 2010, 2009, 2015, 2011) demonstrating impairments in their ability to integrate visual stimulus elements into a unified visual representation. While the bulk of studies have included medicated individuals with schizophrenia, two studies examining unmedicated patients suggest that these impairments are evident in unmedicated patients as well (Frith, Stevens, Johnstone, Owens, & Crow, 1983; Keri, Kiss, Kelemen, Benedek, & Janka, 2005). Moreover, studies examining the relationship between visual integration and chlorpromazine equivalence suggest that medication is independent of performance (Knight, 1992; Silverstein *et al.* 2010, 2009; Spencer *et al.* 2004). However, these studies have relatively small sample sizes and thus additional work is needed to confirm the presence of impairments in visual integration among unmedicated individuals with schizophrenia.

In addition to examining those individuals off medications, type of medication has also been examined. Treatment of schizophrenia often involves medications associated with a high anticholinergic burden. Anticholinergic medications can adversely affect learning and memory by blocking the muscarinic M1 acetylcholine receptors (Everitt & Robbins, 1997; Seeger *et al.* 2004; Tzavara *et al.* 2003). Indeed research in aging and dementia populations taking anticholinergic medications supports this decrement in memory (Boustani, Campbell, Munger, Maidment, &

Fox, 2008; Fox *et al.* 2011). Studies in schizophrenia suggest a similar pattern, wherein memory and attention deficits appear to worsen as anticholinergic burden increases (Calev, 1984; Eum *et al.* 2017; Hitri, Craft, Fallon, Sethi, & Sinha, 1987; Minzenberg, Poole, Benton, & Vinogradov, 2004; Perlick, Stastny, Katz, Mayer, & Mattis, 1986; Strauss, Reynolds, Jayaram, & Tune, 1990; Tracy, Monaco, Giovannetti, Abraham, & Josiassen, 2001). In a double-blind study, Baker, Cheng, and Amara (1983) found evidence that patients taken off anticholinergic medications for 2 weeks showed greater memory performance relative to those who remained on their original medication regimen, though memory performance was reduced relative to controls even among those not taking anticholinergics. Further, Vinogradov *et al.* (2009) found that serum anticholinergic levels were associated with poorer performance on working memory and verbal learning and that anticholinergic serum level was associated with a lower response to cognitive remediation training. Thus, across studies, findings suggest that anticholinergic burden is associated with impaired memory, learning and attention and that medication withdrawal may result in improvements relative to those maintaining their original medication regime. Importantly, the bulk of these studies were limited to learning and attention batteries focused on neuropsychological tests. To our knowledge, there have been no studies examining relationships between anticholinergic status and reinforcement learning. Further, limited studies have examined this relationship across a battery of cognitive tasks developed from cognitive neuroscience.

The current study had several goals. The primary goal was to examine whether individuals with schizophrenia off medications, as well as those on anti-psychotic medications showed impairments relative to healthy controls across a wide array of cognitive domains in which people with schizophrenia have consistently demonstrated impairment, using behavioral tasks derived from the cognitive neuroscience literature. These domains included: reinforcement learning, visual integration, processing speed, verbal learning, working memory, cognitive control, visual integration and relational encoding and retrieval. As a secondary goal, we also examined associations between cognitive performance and anticholinergic burden.

Method

Participants

Participants were recruited across five sites as part of the CNTRaCS Consortium: Maryland Psychiatric Research Center, University of Maryland; University of California, Davis; Rutgers University; University of Minnesota, Twin Cities; and Washington University in St Louis. All participants provided written informed consent to the protocol approved by the local Institutional Review Board.

Participants included 148 medicated individuals with schizophrenia or schizoaffective disorder, 48 unmedicated individuals with schizophrenia or schizoaffective disorder (SZ) and 75 control participants (CON). Exclusion criteria included: (1) history of significant head trauma or neurological disease (2) history of the pervasive developmental disorder (3) diagnosis of substance dependence or abuse in the last 6 months (4) score below 6 on the Wechsler Test of Adult Reading [WTAR; (Wechsler, 2001)] (5) failing a drug or alcohol screen administered the day of testing. Additional criteria for the medicated SZ group included no medication changes in the month prior to study participation. The

unmedicated group was recruited from the community and consisted of people meeting inclusion criteria for the patient group. In addition, unmedicated participants were not required to be medication naïve, rather they self-reported that they had not taken medication for at least 1 month prior to their participation in the study. Additional criteria for CON included: (1) no personal or 1st degree relative with a history of schizophrenia, schizoaffective, or bipolar disorder; (2) no current major depression or dysthymia; and (3) no current psychotropic medication.

Diagnostic status was confirmed using the Structured Clinical Interview for DSM-IV-TR SCID conducted by masters-level clinicians. Individuals with SZ were also assessed for general psychiatric symptoms using the Brief Psychiatric Rating Scale (Overall & Gorham, 1962). Negative symptoms were assessed using the Clinical Assessment Interview for Negative Symptoms (CAINS) (Kring, Gur, Blanchard, Horan, & Reise, 2013) which includes a Motivation and Pleasure (MAP) and Expression (EXP) subscale, with higher scores indicating greater impairment. To assess functioning, participants completed the UCSD-Performance-Based Skills Assessment (UPSA) (Harvey, Velligan, & Bellack, 2007) and the Specific Levels of Functioning Scale (SLOF) (Schneider & Struening, 1983) which includes both a self-report and informant report of those close to the participant. Only a subset of participants had informant data collected (Medicated = 100; Unmedicated = 21).

Chlorpromazine equivalency doses were calculated for each participant taking medications using published conversion formulas (Woods, 2003). Anticholinergic load was based on Minzenberg et al. (2004) which includes two scales indexing anticholinergic load: a pharmacological index established from *in vitro* acetylcholine receptor bindings studies and a clinical index based on expert clinicians' ratings of anticholinergic side effects of medications. Both pharmacological and clinical index were calculated for each participant. Only findings based on the Clinical Index are reported in the current study; however, the two indices were highly correlated ($r = 0.81$, $p < 0.001$) and the same pattern of findings was observed using either index.

Procedure

As shown in Table 1, participants completed nine tasks measuring a broad range of cognitive functioning. Each task has been described in detail in earlier reports (Barch et al. 2017; Brandt, 1991; Gold, Carpenter, Randolph, Goldberg, & Weinberger, 1997; Henderson et al. 2012; Keefe et al. 2004; Pizzagalli, Jahn, & O'Shea, 2005; Ragland et al. 2012; Silverstein et al. 2009) and all tasks are described in Table 1. Tasks were administered in a fixed order across participants as presented in Table 1. As the overarching study assessed test-retest reliability, participants completed the same task on multiple visits, with parallel forms used for memory testing. The current study focused all analyses on participants' first session data.

Data analysis

Primary ANCOVA analyses included group (CON, Unmedicated, Medicated) as a between-subject factor, with age and WTAR score entered as covariates, using post-hoc contrasts for pairwise comparisons. We then conducted analyses in a subset of the groups matched for age, to confirm that age was not confounding the results. Next, we conducted partial correlation analyses examining the relationship between task performance, chlorpromazine equivalency and anticholinergic load, while entering symptom

variables of interest (positive symptoms, negative symptoms and disorganization symptoms) as covariates. Follow-up analyses were conducted within the patient groups (Unmedicated, Medicated) to examine the potential role of BPRS positive symptoms, disorganization symptoms and negative symptoms. False discovery rate correction was used to correct for multiple comparisons (Benjamini & Hochberg, 1995).

Results

Demographic information

As shown in Table 2, the unmedicated group was significantly younger than the medicated and CON groups ($F_{(2,271)} = 4.22$, $p < 0.05$), while the medicated group had a lower WTAR score ($F_{(2,271)} = 17.09$, $p < 0.001$). Age and WTAR were included as covariates in analyses to account for between-group differences. In regard to symptom variables (Table 2), the unmedicated group reported more positive symptoms relative to the medicated group; however, they also displayed less emotional blunting. There were no significant differences between medicated and unmedicated patients in functioning as reported on the SLOF or UPSA.

Implicit and explicit reinforcement learning

IPILT

As shown in Table 3, we analyzed the IPILT using a repeated-measures ANOVA with Block as a within-subject factor and Group (CON, unmedicated, medicated) as a between-subject factor. When looking at positivity bias we saw the main effect of Block showing greater bias towards positive response across later blocks. There was no Group or Block \times Group interaction. When looking at negative biases on the IPILT-N, we found no Block, Group or Block \times Group interaction.

EPILT

We conducted a repeated-measures ANOVA with Block (4); Condition (Reward, Loss) and Probability (90/10 *v.* 80/20) as within-subject factors and group (control, unmedicated, medicated) as a between-subjects factor. As shown in Fig. 1, we found significant main effects of Block and Probability with better performance across blocks and in the 90% probability condition. A main effect of Group showed that controls performed better than both the unmedicated and medicated patient groups. These main effects were qualified by interactions between Group, Block and Condition (Table 3). Follow-up analyses indicated that controls performed significantly better across later blocks, which was most pronounced in the Reward conditions wherein the magnitude of difference between the two patient groups and controls was larger (see Fig. 1). There were no significant differences between the medicated and unmedicated groups.

Visual integration

We conducted a repeated-measures ANOVA on accuracy with orientational jitter level as a within-subject factor and Group (CON, unmedicated, medicated) as a between subject factor (Table 3). We found the main effect of Group wherein medicated patients performed more poorly relative to controls and unmedicated patients ($ps < 0.05$), while we saw a trend of unmedicated patients performing more poorly than controls ($p = 0.06$). There

Table 1. Task Description in order of administration

Task Name	Reference	Domain	Brief Description	Dependent Variable
Implicit Probabilistic Incentive Learning Task (I-PILT)	Pizzagalli et al. (2005)	Reinforcement Learning	Participants are asked to make a judgment regarding the length of a line and are implicitly biased towards the selection of a particular stimulus via increased probability for reward or punishment	Response bias = $\frac{1}{2} \log \left(\frac{RICH_{correct} \times LEAN_{incorrect}}{RICH_{incorrect} \times LEAN_{correct}} \right)$
Relational and Item-Specific Encoding (RiSE)	Ragland et al. (2012)	Episodic Memory	Participants are asked to encode visual stimuli presented either in pairs to encode them relationally or individual to encode single items. Item and associative recognition tests following encoding are assessed for the dependent measure.	Recognition (Hits – False Alarm Rate) for both Relational and Item-Specific Encoding
Explicit Picture Incentive Learning Task (E-PILT)	Gold et al. (2012)	Reinforcement Learning	Participants are presented with various picture stimuli that are reinforced at different contingencies (80% or 90%) and asked to learn which images are associated with gain or avoiding loss.	Percentage of pictures accurately selected that were associated with receiving a reward or avoiding loss in the 80% and 90% reinforcement conditions.
Running Span (O-Span)	Broadway & Engel (2010)	Working Memory	Participants are presented with a string of letters and are asked to recall the last X letters.	# of items correctly remembered in their correct position
Hopkins Verbal Learning Test (HVLT)	Brandt (1991)	Episodic Memory	Participants are read a list of words and asked to repeat those words across three trials.	Total number of correct words recalled across all 3 trials.
BACS Symbol Coding	Keefe et al. (2004)	Processing Speed	Participants are asked to quickly write the symbol associated with a given number within 90 s.	T-Score
Letter Number Sequencing (LNS)	Gold et al. (1997)	Working Memory	Participants listen to a string of intermixed letters and numbers and then are asked to restate the sequence in numeric and alphabetical order.	T-Score
Dot Probe Expectancy Task (DPX)	Henderson et al. (2012)	Cognitive Control	Individuals are asked to discriminate target from non-target dot patterns given a simple rule.	d'-context (AX hits v. BX false alarms)
Jittered Orientation Visual Integration Task (JOVI)	Silverstein et al. (2011)	Visual Integration	Participants are presented with visual stimuli jittered by varying degrees and asked to identify whether the stimulus is pointing to the left or right.	Accuracy

was no Jitter Level \times Group interaction, which is consistent with prior studies (Silverstein et al. 2009, 2015, 2012).

Processing speed

As shown in Table 3 and Fig. 2, an ANOVA with BACS Symbol Coding score as the dependent variable indicated a main effect of Group (CON, medicated, unmedicated) demonstrating higher scores among the controls, followed by the unmedicated SZ group, and the medicated group (all pairwise comparisons significant $p < 0.05$).

Cognitive control

An ANOVA with d-prime (d') on the DPX task as the dependent variable (Table 3) indicated a main effect of Group. Post-hoc analyses indicated that both the unmedicated and medicated groups had significantly lower d' scores relative to controls ($p < 0.001$).

There was no significant difference between the medicated and unmedicated groups ($p = 0.78$).

Working memory

An ANOVA with LNS total score as the dependent variable indicated a main effect of Group (Table 3). Follow-up analyses showed that CON scored significantly higher than both patient groups ($ps < 0.001$), with no significant differences between the medicated and unmedicated groups ($p = 0.13$). Examining Run Span Score revealed a significant effect of Group with controls performing significantly better than both patient groups ($ps < 0.05$). The unmedicated group performed significantly better than the medicated group ($p < 0.05$).

Episodic memory

For the HVLT (Table 3), we found a significant main effect of Group (CON, unmedicated, medicated) with controls

Table 2. Subject Demographics

Demographics	Control (N = 75)	Medicated (N = 148)	Unmedicated (N = 48)	Statistic
Gender (% Women)	43%	43%	42%	$\chi^2 = 0.04$
Age	35.86 (14.42)	37.93 (10.38)	32.54 (11.06)	$F = 3.92^*$ (Med > Unmed)
WTAR Total	39.08 (8.63)	30.17 (10.92)	35.25 (11.69)	$F = 18.12^{**}$ (CON, Unmed > Med)
Personal Years Education	14.81 (2.27)	12.93 (2.30)	13.54 (2.25)	$F = 16.63^{**}$ (CON > Med, Unmed)
Parental Years Education	13.67 (3.32)	13.18 (3.40)	13.78 (3.20)	$F = 1.11$
BPRS Positive Symptoms	–	7.74 (4.16)	10.38 (4.77)	$t = 3.68^{**}$ (Unmed > Med)
BPRS Disorganization	–	5.49 (1.98)	6.71 (3.77)	$t = -2.49^{**}$ (Unmed > Med)
CAINS-MAP	–	12.00 (6.43)	13.23 (8.06)	$t = 1.15$
CAINS-EXP	–	3.84 (2.92)	2.68 (3.01)	$t = 2.31^*$ (Med > Unmed)
CPZ	–	432.79 (28.85)	–	–
SLOF Total	–	4.23 (0.48)	4.23 (0.47)	$t = -0.09$
SLOF-Informant Total	–	4.19 (0.48)	4.14 (0.62)	$t = 0.71$
UPSA – Financial	–	39.60 (8.57)	40.69 (7.37)	$t = -0.75$
UPSA – Communication	–	36.50 (8.25)	35.56 (7.89)	$t = 0.68$

CON, Control; Unmed, Unmedicated; Med, Medicated; * $p < 0.05$; ** $p < 0.01$.

outperforming both patient groups ($ps < 0.05$). The unmedicated patients performed significantly better than the medicated group ($p < 0.001$).

For the RISE (Table 3), we conducted a repeated-measures ANOVA with encoding condition (Item-Specific Recognition Accuracy, Relational Recognition Accuracy) as a within subject variable and Group as a between subject variable. There was a main effect of condition with participants showing lower performance on the relational recognition task relative to the item recognition task. A significant effect of Group with both medicated and unmedicated groups showed impairments in both conditions relative to controls ($ps < 0.05$). There were no significant differences between the medicated and unmedicated groups ($p > 0.20$).

Analyses in age-matched group

Given that age is known to be related to performance across cognitive domains, we examined whether our findings relating to group differences in unmedicated, medicated and control participants remained when looking at subsets of the participants' groups matched for age. We created groups matched on age by sequentially removing older participants in the control and medicated SZ groups until there was less than 1-year difference between groups ($F_{(2,194)} = 0.16$, $p = 85$). As shown in online Supplementary Table S1, the patient groups still had a lower WTAR score ($F_{(2,194)} = 6.82$, $p < 0.005$) than controls, however, there was no significant difference between the patients' groups ($p = 0.61$).

When examining the age matched group (CON, unmedicated, medicated), we once again found that CON participants outperformed both the unmedicated and medicated groups across the majority of tasks including processing speed ($F_{(2,190)} = 15.06$, $p < 0.001$, $\eta_p^2 = 0.14$), cognitive control ($F_{(2,188)} = 6.95$, $p < 0.005$, $\eta_p^2 = 0.07$), letter number sequencing ($F_{(2,190)} = 12.41$, $p < 0.001$, $\eta_p^2 = 0.12$), original running span ($F_{(2,192)} = 6.69$, $p < 0.05$, $\eta_p^2 = 0.07$), verbal learning ($F_{(2,191)} = 13.93$, $p < 0.001$, $\eta_p^2 = 0.13$), item-

specific encoding ($F_{(2,192)} = 4.91$, $p < 0.01$), relational encoding ($F_{(2,192)} = 7.46$, $p < 0.005$), visual integration ($F_{(2,191)} = 6.45$, $p < 0.005$, $\eta_p^2 = 0.07$) and explicit reinforcement learning ($F_{(2,191)} = 3.31$, $p < 0.05$, $\eta_p^2 = 0.04$). Similar to the analyses in the entire sample, there were no main effects of the group when examining implicit reinforcement learning. Age-matched medicated participants performed more poorly than unmedicated participants on the HVLTL ($p < 0.05$), item recognition ($p < 0.05$) and visual integration ($p < 0.05$).

Relationship between cognitive performance to chlorpromazine and anticholinergic load among medicated patients

When comparing CPZ dose and task measures (online Supplementary Table S2), we found significant relationships that survived multiple comparison correction between CPZ and processing speed ($r = -0.35$, $p < 0.01$), HVLTL ($r = -0.35$, $p < 0.01$), LNS ($r = -0.30$, $p < 0.01$) and running span ($r = -0.30$, $ps < 0.01$) suggesting that higher CPZ load was related to poorer performance across tasks.

As shown in Supplementary Table S2, we found that HVLTL was related to anticholinergic load such that greater anticholinergic load was associated with poorer verbal learning. However, this finding did not remain significant after correcting for multiple comparisons using FDR correction. Further, we conducted an exploratory stepwise analysis entering anticholinergic load in Step 1 and group in Step 2 to predict HVLTL, and while the first step was significant ($r = 0.26$, $r^2 = 0.067$, $p < 0.005$), when the group was entered into the model, group was significant ($p < 0.05$) while the anticholinergic load was a trend ($p = 0.08$).

Examining potential symptom effects within patient groups

Finally, we examined whether including positive symptoms, motivation and pleasure, and expressive deficits influenced differences between patient groups (unmedicated and medicated)

Table 3. Group differences between Controls, Unmedicated and Medicated participants

Task	F Value	p value	η_p^2	Direction of Findings
BACS Symbol Coding				
Group	16.94	<0.001	0.12	CON > Unmed > Med
Dot Probe Expectancy (DPX)				
Group	6.92	0.001	0.05	CON > Unmed, Med
Letter Number Sequencing (LNS)				
Group	5.70	0.004	0.04	CON > Unmed, Med
Original Running Span (O-Span)				
Group	6.43	0.002	0.05	CON > Unmed > Med
Hopkins Verbal Learning Test (HVLТ)				
Group	15.61	<0.001	0.11	CON > Unmed > Med
Jittered Orientation Visual Integration (JOVI)				
Jitter Level	12.77	0.001	0.05	
Group	7.35	0.001	0.06	CON > Med
Jitter × Group	0.50	0.89	0.004	–
Implicit Probabilistic Incentive Learning Task Negative (IPILT-N)				
Block	3.57	0.03	0.01	BL 3 > BL 2 > BL 1
Group	1.08	0.34	0.009	–
Block × Group	0.59	0.67	0.005	–
Implicit Probabilistic Incentive Learning Task Positive (IPILT-P)				
Block	0.13	0.72	0.001	–
Group	1.01	0.37	0.008	–
Block × Group	2.37	0.06	0.02	–
Explicit Probabilistic Incentive Learning Task (EPILT)				
Block	5.43	0.02	0.04	BL 4 > BL 3 > BL 2 > BL 1
Probability	3.77	0.05	0.02	90 > 80%
Condition	1.51	0.22	0.006	–
Group	4.59	0.01	0.05	CON > Unmed, Med
Block × Group	4.01	0.02	0.03	See Fig. 1
Probability × Group	1.16	0.32	0.01	–
Condition × Group	1.34	0.26	0.01	–
Block × Condition × Group	5.59	0.004	0.05	See Fig. 1
Relational and Item Specific Encoding (RISE)				
Encoding Condition	3.77	0.05	0.02	Item > Relational
Group	7.93	<0.001	0.06	CON > Unmed, Med
Condition × Group	0.88	0.42	0.007	–

CON, control; Unmed, unmedicated; Med, medicated; BL, block; Age and WTAR included as covariates in above models.

within each task. While symptom variables were related to some task performance metrics, the overall pattern of group differences remained the same when entering positive and negative symptoms into analyses.

Discussion

The goal of the current study was to examine unmedicated individuals with schizophrenia, as well as those on medications, relative to controls across a range of well-validated cognitive measures. We found that across all but two of the cognitive domains assessed, both unmedicated and medicated patients showed impairments in performance relative to healthy control participants. Further, across every measure other than implicit reinforcement learning, unmedicated patients showed impairments relative to controls, though this was a trend level for visual integration.

While the bulk of the literature examining cognitive deficits in schizophrenia has been conducted on medicated samples, current findings suggest that, regardless of medication status, adults with chronic schizophrenia show deficits in tasks assessing processing speed, cognitive control, working memory, relational encoding and retrieval, visual integration and explicit reinforcement learning relative to healthy controls. These findings of cognitive impairment in unmedicated patients are consistent with previous literature showing deficits in working memory, cognitive control and attention in a young at-risk sample (Wood et al. 2003), in first-episode samples (Hutton et al. 1998; Minzenberg et al. 2010; Nejad et al. 2011) and in recent-onset medication-naïve individuals with schizophrenia (Daban et al. 2005; Lussier & Stip, 2001). Our findings of impairments among unmedicated individuals on an explicit reinforcement learning task are notable, as there have been concerns that medications that block D2 receptors could be creating some of the impairments in this domain. The current findings are consistent with Reinen et al. (2016) who found blunted prediction error responses in unmedicated patients relative to controls, suggesting that medication is not driven by antipsychotic medication alone. While not in unmedicated samples, studies examining reinforcement learning in at-risk and first-episode patients (Chang, Waltz, Gold, Chan, & Chen, 2016; Murray et al. 2008; Waltz et al. 2017), who have presumably a shorter duration of exposure to antipsychotics than chronic samples, also show a pattern of reinforcement deficits relative to controls. However, in a sample of medicated patients Insel et al. (2014) found a relationship between dose and lose-shift patterns, suggesting that higher doses were related to a greater likelihood to shift choice following negative feedback and in neural response when learning from loss but was not related to learning from the reward. Thus, while our findings suggest that unmedicated patients show deficits in reinforcement learning relative to controls, it will be important for future work to look at the relationship between medication and pattern of responding to feedback.

Deficits in visual integration in both medicated and unmedicated groups are notable, as deficits in visual integration have been shown to be related to illness duration (Keane, Paterno, Kastner, & Silverstein, 2016) raising the possibility that medication may be linked to deficits; however, only a handful of previous studies have examined the relationship in unmedicated groups. The present findings suggest that unmedicated and medicated individuals show a deficit relative to controls. These findings are consistent with prior research that did not find a relationship in medicated patients between chlorpromazine equivalence and integration (Grove et al. 2018; Keane et al. 2016; Silverstein et al. 2009) and consistent with previous studies showing deficits in unmedicated patients relative to controls (Frith et al. 1983; Keri et al. 2005). Thus, our findings extend previous research suggesting that impairments in visual integration are an aspect of

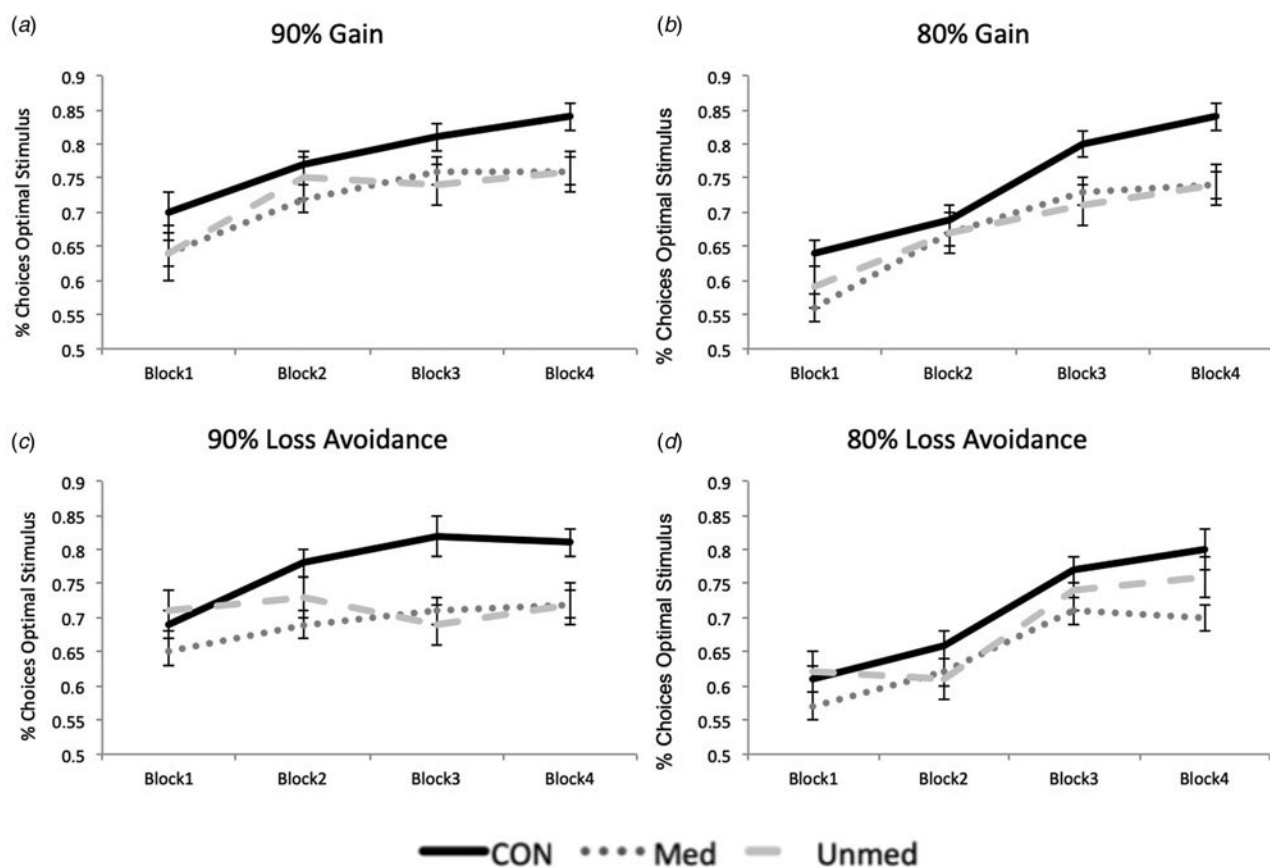


Fig. 1. CON, control; Med, medicated Schizophrenia; Unmed, unmedicated Schizophrenia. Panel A and B display performance on the explicit probabilistic incentive learning task (EPILT) by group in the 90 and 80% probability gain conditions by group. Panel C and D display performance on the 90 and 80% probability loss avoidance conditions.

schizophrenia present even among unmedicated individuals with schizophrenia.

Even though we found strong evidence for cognitive impairment among unmedicated individuals with schizophrenia, there were some differences between medicated and unmedicated individuals. Medicated patients had somewhat greater deficits on measures of processing speed, working memory, visual integration and verbal learning relative to unmedicated patients. These patient subgroup differences remained after controlling for symptom domains that differed between groups, including positive and negative symptoms. However, our primary goal was to examine deficits in unmediated individuals and the individuals with schizophrenia were not randomly assigned to medicated *v.* unmediated groups. While findings in relationship to differences between unmedicated and medicated patient groups are intriguing, it is important to consider a number of variables that may be driving these between group differences and which may also be leading to mixed findings within the literature. Similar to a number of other studies, in the present study we took a naturalistic approach to the investigation, recruiting people who had been off antipsychotic medications for at least 1 month. Given that antipsychotic medication adherence rates are poor with people going on and off medications frequently, our samples are likely representative of the population (Byerly, Nakonezny, & Lescouffair, 2007). However, because they were not randomly assigned to medication groups, there are a number of group differences which may be important in helping to explain

distinctions in cognitive functioning. For example, those taking medications were older, had lower WTAR scores and had more expressive negative symptom deficits. While our results held when controlling for estimated IQ, age and symptom variables, it is not possible to completely rule out an influence of these variables. It is also likely that other differences between these groups not captured in the current data may underlie these differential patterns of cognitive performance. For example, it may be the case that those taking antipsychotics in the current study may have had additional comorbid disorders that further impair functioning. While we saw no significant group differences on measures of functioning such as the UPSA or SLOF, there may be other categories of functioning not being fully captured. Nonetheless, the modest difference we saw between medicated and unmedicated individuals needs to be considered in light of the robust deficits we saw in all cognitive domains among unmedicated individuals, other than implicit reinforcement learning, which was not impaired in either medicated or unmedicated patients.

The present study had several limitations. First, as noted above, individuals with schizophrenia were not randomly assigned to medication groups, indeed the majority of studies in this area are not in randomized control trials. Instead, participants were under the care of their own mental health providers, thus medication type and dose varied between subjects. While this lends to the generalizability of findings, this also minimizes our ability to examine specific drug-related effects. Further, the lack of

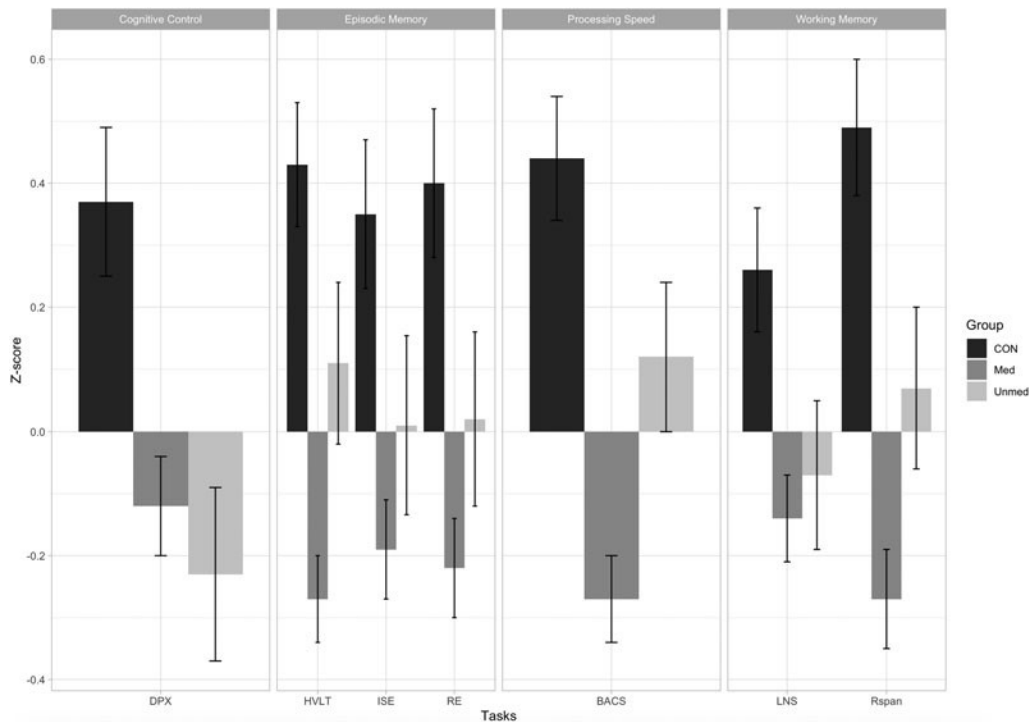


Fig. 2. CON, control; Med, medicated Schizophrenia; Unmed, unmedicated Schizophrenia; DPX, Dot Probe Expectancy; HVLTL, Hopkins Verbal Learning Test; ISE, Item-Specific Encoding; RE, Relational Encoding; BACS, BACS Symbol Coding; A-Span, Adaptive Running Span; LNS, Letter Number Sequencing; Rspan, Running Span. Performance on cognitive tasks assessing cognitive control, episodic memory, processing speed and working memory are presented. Scores were standardized to create z-scores for display purposes.

random assignment to the medication condition led to the medicated and unmedicated groups differing in age. While differences in age were unlikely to have led to null findings between patient groups, they could play a role across tasks in the present study (Braver & Barch, 2002; Hori *et al.* 2006; McKendrick, Weymouth, & Battista, 2010; Naveh-Benjamin, Hussain, Guez, & Bar-On, 2003; Roudaia, Bennett, & Sekuler, 2008). It will be important for future studies to design studies that address these limitations including randomization and better characterization in naturalistic studies to understand potential differences in the medicated and unmedicated samples that may be leading to differences in findings. Finally, individuals in the unmedicated group were not medication naïve; rather they were required to be off medications for at least 1 month prior to participation. Thus, it could be the case that medication naïve individuals with schizophrenia may show a different pattern of impairments *v.* those in the present study.

Taken together, the present findings show that individuals with schizophrenia, both unmedicated and medicated, have pervasive deficits across a range of cognitive domains including reinforcement learning, processing speed, cognitive control, working memory, verbal learning, and relational encoding and retrieval. In some domains these deficits appear to be more slightly more pronounced in medicated patients (though still clearly present in unmedicated individuals), particularly on tasks assessing processing speed and verbal learning. However, the fact that the unmedicated individuals showed cognitive impairments in all of the same domains impaired in medicated individuals, even if in some cases to a slightly lesser degree, adds to the body of literature suggesting that cognitive deficits are an enduring aspect of schizophrenia, present in those both on and off antipsychotic medications.

Supplementary material. The supplementary material for this article can be found at <https://doi.org/10.1017/S003329172000286X>

Acknowledgements. The authors would like to thank the participants in this study, who gave generously of their time and the many staff who helped complete this project. Funding for this study was provided by NIMH RO1s MH084840 (DMB), MH084826 (CSC), MH084821 (JMG), MH084861 (AWM) and MH084828 (SMS). Author EKM had full access to all study data and takes responsibility for the integrity of the data and accuracy of the data analysis. EKM performed the data analysis. All authors developed the study concept and design and aided in interpretation and provided critical revisions. All authors approved the final version of the paper for submission.

Conflict of interest. EKM has no conflicts to report. JMG has received grants from National Institutes of Health (NIH), receives royalty payments from Brief Assessment of Cognition in Schizophrenia, and has acted as a consultant to Acadia, Amgen, AstraZeneca, GlaxoSmithKline, Hoffman LaRoche, Merck, Pfizer and Solvay. CSC has received research grants from the National Institutes of Health (NIH), the Brain and Behavior Foundation, the Burroughs Wellcome foundation, GlaxoSmithKline and the Robert Wood Johnson Foundation and has been an external consultant for Lilly, Merck, Pfizer, Roche and Servier. SL has received research grants from the National Institutes of Health (NIH) and the National Science Foundation. AWM has received research grants from the National Institutes of Health (NIH) and the Brain & Behavior Research Foundation. JDR has received research grants from the National Institutes of Health (NIH), the Brain & Behavior Research Foundation, the EJLB Foundation, and the Robert Wood Johnson Foundation. SMS has received research grants from the National Institutes of Mental Health (NIMH), The Brain & Behavior Research Foundation, the van Ameringen Foundation, the Jacob and Valeria Langaloth Foundation, the New England Research Institutes, the New York State Office of Mental Health, the New Jersey Division of Mental Health and Addiction Services, The Lavelle Fund for the Blind, diaMentis, Inc., Janssen Pharmaceutica, AstraZeneca, and Pfizer. DMB has received grants from the Brain & Behavior Research Foundation and the National Institutes of Health (NIH).

References

- Amato, D., Vernon, A. C., & Papaleo, F. (2018). Dopamine, the antipsychotic molecule: A perspective on mechanisms underlying antipsychotic response variability. *Neuroscience & Biobehavioral Reviews*, 85, 146–159. <https://doi.org/10.1016/j.neubiorev.2017.09.027>
- Baker, L. A., Cheng, L. Y., & Amara, I. B. (1983). The withdrawal of benzotropine mesylate in chronic schizophrenic patients. *The British Journal of Psychiatry*, 143(6), 584–590. <https://doi.org/10.1192/bjp.143.6.584>
- Barch, D. M., Carter, C. S., Braver, T. S., Sabb, F. W., MacDonald, A., Noll, D. C., & Cohen, J. D. (2001). Selective deficits in prefrontal cortex function in medication-naïve patients with schizophrenia. *Archives of General Psychiatry*, 58(3), 280. <https://doi.org/10.1001/archpsyc.58.3.280>
- Barch, D. M., Carter, C. S., Gold, J. M., Johnson, S. L., Kring, A. M., MacDonald, III, A. W., ... Strauss, M. E. (2017). Explicit and implicit reinforcement learning across the psychosis spectrum. *Journal of Abnormal Psychology*, 126(5), 694–711. <https://doi.org/10.1037/abn0000259>
- Barch, D. M., Carter, C. S., MacDonald, A. W., Braver, T. S., & Cohen, J. D. (2003). Context-processing deficits in schizophrenia: Diagnostic specificity, 4-week course, and relationships to clinical symptoms. *Journal of Abnormal Psychology*, 112(1), 132–143. Retrieved from <https://insights.ovid.com/abnormal-psychology/jabnp/2003/02/000/context-processing-deficits-schizophrenia/13/00004468>
- Barch, D. M., & Ceaser, A. (2012). Cognition in schizophrenia: Core psychological and neural mechanisms. *Trends in Cognitive Sciences*, 16(1), 27–34. <https://doi.org/10.1016/J.TICS.2011.11.015>
- Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological)*, 57(1), 289–300. <https://doi.org/10.1111/j.2517-6161.1995.tb02031.x>
- Bilder, R. M., Goldman, R. S., Robinson, D., Reiter, G., Bell, L., Bates, J. A., ... Lieberman, J. A. (2000). Neuropsychology of first-episode schizophrenia: Initial characterization and clinical correlates. *American Journal of Psychiatry*, 157(4), 549–559. <https://doi.org/10.1176/appi.ajp.157.4.549>
- Boustani, M., Campbell, N., Munger, S., Maidment, I., & Fox, C. (2008). Impact of anticholinergics on the aging brain: A review and practical application. *Aging Health*, 4(3), 311–320. <https://doi.org/10.2217/1745509X.4.3.311>
- Braff, D. L., & Saccuzzo, D. P. (1982). Effect of antipsychotic medication on speed of information processing in schizophrenic patients. *American Journal of Psychiatry*, 139(9), 1127–1130. <https://doi.org/10.1176/ajp.139.9.1127>
- Brandt, J. (1991). The hopkins verbal learning test: Development of a new memory test with six equivalent forms. *Clinical Neuropsychologist*, 5(2), 125–142. <https://doi.org/10.1080/13854049108403297>
- Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and neuromodulation. *Neuroscience & Biobehavioral Reviews*, 26(7), 809–817. [https://doi.org/10.1016/S0149-7634\(02\)00067-2](https://doi.org/10.1016/S0149-7634(02)00067-2)
- Broadway, J. M., & Engle, R. W. (2010). Validating running memory span: Measurement of working memory capacity and links with fluid intelligence. *Behavior Research Methods*, 42, 563–570.
- Butler, P. D., Abeles, I. Y., Silverstein, S. M., Dias, E. C., Weiskopf, N. G., Calderone, D. J., & Sehatpour, P. (2013). An event-related potential examination of contour integration deficits in schizophrenia. *Frontiers in Psychology*, 4, 132. <https://doi.org/10.3389/fpsyg.2013.00132>
- Butler, P. D., Silverstein, S. M., & Dakin, S. C. (2008). Visual perception and its impairment in schizophrenia. *Biological Psychiatry*, 64(1), 40–47. <https://doi.org/10.1016/j.biopsych.2008.03.023>
- Byerly, M. J., Nakonezny, P. A., & Lescouffair, E. (2007). Antipsychotic medication adherence in schizophrenia. *Psychiatric Clinics of North America*, 30(3), 437–452. <https://doi.org/10.1016/J.PSC.2007.04.002>
- Cadenhead, K. S., Geyer, M. A., Butler, R. W., Perry, W., Sprock, J., & Braff, D. L. (1997). Information processing deficits of schizophrenia patients: Relationship to clinical ratings, gender and medication status. *Schizophrenia Research*, 28(1), 51–62. [https://doi.org/10.1016/S0920-9964\(97\)00085-6](https://doi.org/10.1016/S0920-9964(97)00085-6)
- Calev, A. (1984). Recall and recognition in mildly disturbed schizophrenics: The use of matched tasks. *Psychological Medicine*, 14(02), 425. <https://doi.org/10.1017/S0033291700003676>
- Chang, W. C., Waltz, J. A., Gold, J. M., Chan, T. C. W., & Chen, E. Y. H. (2016). Mild reinforcement learning deficits in patients with first-episode psychosis. *Schizophrenia Bulletin*, 42(6), 1476–1485. <https://doi.org/10.1093/schbul/sbw060>
- Cicero, D. C., Martin, E. A., Becker, T. M., & Kerns, J. G. (2014). Reinforcement learning deficits in people with schizophrenia persist after extended trials. *Psychiatry Research*, 220(3), 760–764. <https://doi.org/10.1016/j.psychres.2014.08.013>
- Cullbreth, A. J., Westbrook, A., Xu, Z., Barch, D. M., & Waltz, J. A. (2017). Intact ventral striatal prediction error signaling in medicated schizophrenia patients. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, 1(5), 474–483. <https://doi.org/10.1016/j.bpsc.2016.07.007>
- Daban, C., Amado, I., Bourdel, M.-C., Loo, H., Olié, J.-P., Poirier, M.-F., & Krebs, M.-O. (2005). Cognitive dysfunctions in medicated and unmedicated patients with recent-onset schizophrenia. *Journal of Psychiatric Research*, 39(4), 391–398. <https://doi.org/10.1016/j.jpsychires.2004.09.001>
- Dickinson, D., Ramsey, M. E., & Gold, J. M. (2007). Overlooking the obvious. *Archives of General Psychiatry*, 64(5), 532. <https://doi.org/10.1001/archpsyc.64.5.532>
- Dowd, E. C., Frank, M. J., Collins, A., Gold, J. M., & Barch, D. M. (2016). Probabilistic reinforcement learning in patients with schizophrenia: Relationships to anhedonia and avolition. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*, 1(5), 460–473. <https://doi.org/10.1016/j.bpsc.2016.05.005>
- Élie, D., Poirier, M., Chianetta, J., Durand, M., Grégoire, C., & Grignon, S. (2010). Cognitive effects of antipsychotic dosage and polypharmacy: A study with the BACS in patients with schizophrenia and schizoaffective disorder. *Journal of Psychopharmacology*, 24(7), 1037–1044. <https://doi.org/10.1177/0269881108100777>
- Eum, S., Hill, S. K., Rubin, L. H., Carnahan, R. M., Reilly, J. L., Ivleva, E. I., ... Bishop, J. R. (2017). Cognitive burden of anticholinergic medications in psychotic disorders. *Schizophrenia Research*, 190, 129–135. <https://doi.org/10.1016/j.schres.2017.03.034>
- Everitt, B. J., & Robbins, T. W. (1997). Central cholinergic systems and cognition. *Annual Review of Psychology*, 48(1), 649–684. <https://doi.org/10.1146/annurev.psych.48.1.649>
- Fioravanti, M., Carlone, O., Vitale, B., Cinti, M. E., & Clare, L. (2005). A meta-analysis of cognitive deficits in adults with a diagnosis of schizophrenia. *Neuropsychology Review*, 15(2), 73–95. <https://doi.org/10.1007/s11065-005-6254-9>
- Fox, C., Richardson, K., Maidment, I. D., Savva, G. M., Matthews, F. E., Smithard, D., ... Brayne, C. (2011). Anticholinergic medication use and cognitive impairment in the older population: The medical research council cognitive function and ageing study. *Journal of the American Geriatrics Society*, 59(8), 1477–1483. <https://doi.org/10.1111/j.1532-5415.2011.03491.x>
- Frith, C. D., Stevens, M., Johnstone, E. C., Owens, D. G., & Crow, T. J. (1983). Integration of schematic faces and other complex objects in schizophrenia. *Journal of Nervous and Mental Disease*, 171(1), 34–39.
- Gold, J., Carpenter, C., Randolph, C., Goldberg, T. E., & Weinberger, D. R. (1997). Auditory working memory and Wisconsin card sorting test performance in schizophrenia. *Archives of General Psychiatry*, 54, 159–165.
- Gold, J. M., Waltz, J. A., Matveeva, T. M., Kasanova, Z., Strauss, G. P., Herbener, E. S., ... Frank, M. J. (2012). Negative symptoms and the failure to represent the expected reward value of actions: Behavioral and computational modeling evidence. *Archives of General Psychiatry*, 69(2), 129–138. <https://doi.org/10.1001/archgenpsychiatry.2011.1269>
- Goldberg, T. E., Goldman, R. S., Burdick, K. E., Malhotra, A. K., Lencz, T., Patel, R. C., ... Robinson, D. G. (2007). Cognitive improvement after treatment with second-generation antipsychotic medications in first-episode schizophrenia: Is it a practice effect? *Archives of General Psychiatry*, 64(10), 1115–1122. <https://doi.org/10.1001/archpsyc.64.10.1115>
- Green, M. F., Kern, R. S., Braff, D. L., & Mintz, J. (2000). Neurocognitive deficits and functional outcome in schizophrenia: Are we measuring the right stuff? *Schizophrenia Bulletin*, 26(1), 119–136. <https://doi.org/10.1093/oxfordjournals.schbul.a033430>
- Grove, T. B., Yao, B., Mueller, S. A., McLaughlin, M., Ellingrod, V. L., McClinnis, M. G., ... Tso, I. F. (2018). A Bayesian model comparison approach to test the specificity of visual integration impairment in schizophrenia or psychosis. *Psychiatry Research*, 265(May), 271–278. <https://doi.org/10.1016/j.psychres.2018.04.061>

- Harvey, P. D., & Keefe, R. S. E. (2001). Studies of cognitive change in patients with schizophrenia following novel antipsychotic treatment. *American Journal of Psychiatry*, 158(2), 176–184. <https://doi.org/10.1176/appi.ajp.158.2.176>
- Harvey, P. D., Velligan, D. I., & Bellack, A. S. (2007). Performance-Based measures of functional skills: Usefulness in clinical treatment studies. *Schizophrenia Bulletin*, 33(5), 1138–1148. <https://doi.org/10.1093/schbul/sbm040>
- Henderson, D., Poppe, A. B., Barch, D. M., Carter, C. S., Gold, J. M., Ragland, J. D., ... MacDonald, A. W. (2012). Optimization of a goal maintenance task for use in clinical applications. *Schizophrenia Bulletin*, 38(1), 104–113. <https://doi.org/10.1093/schbul/sbr172>
- Hitri, A., Craft, R. B., Fallon, J., Sethi, R., & Sinha, D. (1987). Serum neuroleptic and anticholinergic activity in relationship to cognitive toxicity of anti-parkinsonian agents in schizophrenic patients. *Psychopharmacology Bulletin*, 23(1), 33–37. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/2885890>
- Hori, H., Noguchi, H., Hashimoto, R., Nakabayashi, T., Omori, M., Takahashi, S., ... Kunugi, H. (2006). Antipsychotic medication and cognitive function in schizophrenia. *Schizophrenia Research*, 86(1–3), 138–146. <https://doi.org/10.1016/j.schres.2006.05.004>
- Hutton, S. B., Puri, B. K., Duncan, L. J., Robbins, T. W., Barnes, T. R. E., & Joyce, E. M. (1998). Executive function in first-episode schizophrenia. *Psychological Medicine*, 28(2), 463–473. Retrieved from <https://www.cambridge.org/core/journals/psychological-medicine/article/executive-function-in-first-episode-schizophrenia/2562651D65E41DE97F2C07579B31B254>
- Insel, C., Reinen, J., Weber, J., Wager, T. D., Jarskog, L. F., Shohamy, D., & Smith, E. E. (2014). Antipsychotic dose modulates behavioral and neural responses to feedback during reinforcement learning in schizophrenia. *Cognitive, Affective, & Behavioral Neuroscience*, 14(1), 189–201. <https://doi.org/10.3758/s13415-014-0261-3>
- Juckel, G., Schlagenhauf, F., Koslowski, M., Wüstenberg, T., Villringer, A., Knutson, B., ... Heinz, A. (2006). Dysfunction of ventral striatal reward prediction in schizophrenia. *NeuroImage*, 29(2), 409–416. <https://doi.org/10.1016/j.neuroimage.2005.07.051>
- Keane, B. P., Paterno, D., Kastner, S., & Silverstein, S. M. (2016). Visual integration dysfunction in schizophrenia arises by first psychotic episode and worsens with illness duration. *Journal of Abnormal Psychology*, 125(4), 543–549.
- Keefe, R. S. E., Bilder, R. M., Davis, S. M., Harvey, P. D., Palmer, B. W., Gold, J. M., ... Lieberman, J. A. (2007a). Neurocognitive effects of antipsychotic medications in patients with chronic schizophrenia in the CATIE Trial. *Archives of General Psychiatry*, 64(6), 633. <https://doi.org/10.1001/archpsyc.64.6.633>
- Keefe, R. S. E., Goldberg, T. E., Harvey, P. D., Gold, J. M., Poe, M. P., & Coughenour, L. (2004). The brief assessment of cognition in schizophrenia: Reliability, sensitivity, and comparison with a standard neurocognitive battery. *Schizophrenia Research*, 68(2–3), 283–297. <https://doi.org/10.1016/j.schres.2003.09.011>
- Keefe, R. S. E., Sweeney, J. A., Gu, H., Hamer, R. M., Perkins, D. O., McEvoy, J. P., & Lieberman, J. A. (2007b). Effects of olanzapine, quetiapine, and risperidone on neurocognitive function in early psychosis: A randomized, double-blind 52-week comparison. *American Journal of Psychiatry*, 164(7), 1061–1071. <https://doi.org/10.1176/appi.ajp.2007.164.7.1061>
- Keri, S., Kiss, I., Kelemen, O., Benedek, G., & Janka, Z. (2005). Anomalous visual experiences, negative symptoms, perceptual organization and the magno-cellular pathway in schizophrenia: A shared construct? *Psychological Medicine*, 35(10), 1445–1455. <https://doi.org/10.1017/S0033291705005398>
- Knight, R. A. (1992). Specifying cognitive deficiencies in poor premorbid schizophrenics. In E. F. Walker, R. Dworkin, & B. Cornblatt (Eds.), *Progress in experimental psychology & psychopathology* (15th ed., pp. 252–289). New York, NY: Springer.
- Kring, A. M., Gur, R. E., Blanchard, J. J., Horan, W. P., & Reise, S. P. (2013). The Clinical Assessment Interview for Negative Symptoms (CAINS): Final development and validation. *American Journal of Psychiatry*, 170(2), 165–172. <https://doi.org/10.1176/appi.ajp.2012.12010109>
- Lee, J., & Park, S. (2005). Working memory impairments in schizophrenia: A meta-analysis. *Journal of Abnormal Psychology*, 114(4), 599–611. <https://doi.org/10.1037/0021-843X.114.4.599>
- Lesh, T. A., Niendam, T. A., Minzenberg, M. J., & Carter, C. S. (2011). Cognitive control deficits in schizophrenia: Mechanisms and meaning. *Neuropsychopharmacology*, 36(1), 316–338. <https://doi.org/10.1038/npp.2010.156>
- Lesh, T. A., Tanase, C., Geib, B. R., Niendam, T. A., Yoon, J. H., Minzenberg, M. J., ... Carter, C. S. (2015). A multimodal analysis of antipsychotic effects on brain structure and function in first-episode schizophrenia. *JAMA Psychiatry*, 72(3), 226. <https://doi.org/10.1001/jamapsychiatry.2014.2178>
- Lussier, I., & Stip, E. (2001). Memory and attention deficits in drug naive patients with schizophrenia. *Schizophrenia Research*, 48(1), 45–55. [https://doi.org/10.1016/S0920-9964\(00\)00102-X](https://doi.org/10.1016/S0920-9964(00)00102-X)
- Macdonald, A. W., & Carter, C. S. (2003). Event-related fmri study of context processing in dorsolateral prefrontal cortex of patients with schizophrenia. *Journal of Abnormal Psychology*, 112(4), 689–697. Retrieved from <https://insights.ovid.com/abnormal-psychology/jabnp/2003/11/000/event-related-fmri-study-context-processing/14/00004468>
- Maia, T. V. (2009). Reinforcement learning, conditioning, and the brain: Successes and challenges. *Cognitive, Affective, & Behavioral Neuroscience*, 9(4), 343–364. <https://doi.org/10.3758/CABN.9.4.343>
- McKendrick, A. M., Weymouth, A. E., & Battista, J. (2010). The effect of normal aging on closed contour shape discrimination. *Journal of Vision*, 10(2), 1–9. <https://doi.org/10.1167/10.2.1>
- Meltzer, H. Y., & McGurk, S. R. (1999). The effects of clozapine, risperidone, and olanzapine on cognitive function in schizophrenia. *Schizophrenia Bulletin*, 25(2), 233–255. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/10416729>
- Meshulam-Gately, R. I., Giuliano, A. J., Goff, K. P., Faraone, S. V., & Seidman, L. J. (2009). Neurocognition in first-episode schizophrenia: A meta-analytic review. *Neuropsychology*, 23(3), 315–336. <https://doi.org/10.1037/a0014708>
- Minzenberg, M. J., Firl, A. J., Yoon, J. H., Gomes, G. C., Reinking, C., & Carter, C. S. (2010). Gamma oscillatory power is impaired during cognitive control independent of medication Status in first-episode schizophrenia. *Neuropsychopharmacology*, 35(13), 2590–2599. <https://doi.org/10.1038/npp.2010.150>
- Minzenberg, M. J., Laird, A. R., Thelen, S., Carter, C. S., & Glahn, D. C. (2009). Meta-analysis of 41 functional neuroimaging studies of executive function in schizophrenia. *Archives of General Psychiatry*, 66(8), 811. <https://doi.org/10.1001/archgenpsychiatry.2009.91>
- Minzenberg, M. J., Poole, J. H., Benton, C., & Vinogradov, S. (2004). Association of anticholinergic load with impairment of complex attention and memory in schizophrenia. *American Journal of Psychiatry*, 161(1), 116–124. <https://doi.org/10.1176/appi.ajp.161.1.116>
- Mishara, A. L., & Goldberg, T. E. (2004). A meta-analysis and critical review of the effects of conventional neuroleptic treatment on cognition in schizophrenia: Opening a closed book. *Biological Psychiatry*, 55(10), 1013–1022. <https://doi.org/10.1016/j.biopsych.2004.01.027>
- Montague, P. R., Dayan, P., & Sejnowski, T. J. (1996). A framework for mesencephalic dopamine systems based on predictive Hebbian learning. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 16(5), 1936–1947. <https://doi.org/10.1523/JNEUROSCI.16-05-01936.1996>
- Murray, G. K., Cheng, F., Clark, L., Barnett, J. H., Blackwell, A. D., Fletcher, P. C., ... Jones, P. B. (2008). Reinforcement and reversal learning in first-episode psychosis. *Schizophrenia Bulletin*, 34(5), 848–855. <https://doi.org/10.1093/schbul/sbn078>
- Naveh-Benjamin, M., Hussain, Z., Guez, J., & Bar-On, M. (2003). Adult age differences in episodic memory: Further support for an associative-deficit hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29(5), 826–837. <https://doi.org/10.1037/0278-7393.29.5.826>
- Nejad, A. B., Ebdrup, B. H., Siebner, H. R., Rasmussen, H., Aggernæs, B., Glenthøj, B. Y., & Baaré, W. F. C. (2011). Impaired temporoparietal deactivation with working memory load in antipsychotic-naïve patients with first-episode schizophrenia. *The World Journal of Biological Psychiatry*, 12(4), 271–281. <https://doi.org/10.3109/15622975.2010.556199>
- Nuechterlein, K. H., Barch, D. M., Gold, J. M., Goldberg, T. E., Green, M. F., & Heaton, R. K. (2004). Identification of separable cognitive factors in schizophrenia. *Schizophrenia Research*, 72(1), 29–39. <https://doi.org/10.1016/j.schres.2004.09.007>

- Overall, J. E., & Gorham, D. R. (1962). The brief psychiatric rating scale. *Psychological Reports*, 10(3), 799–812. <https://doi.org/10.2466/pr0.1962.10.3.799>
- Perlick, D., Stastny, P., Katz, I., Mayer, M., & Mattis, S. (1986). Memory deficits and anticholinergic levels in chronic schizophrenia. *American Journal of Psychiatry*, 143(2), 230–232. <https://doi.org/10.1176/ajp.143.2.230>
- Pizzagalli, D. A., Jahn, A. L., & O'Shea, J. P. (2005). Toward an objective characterization of an anhedonic phenotype: A signal-detection approach. *Biological Psychiatry*, 57(4), 319–327. <https://doi.org/10.1016/j.biopsych.2004.11.026>
- Ragland, J. D., Ranganath, C., Barch, D. M., Gold, J. M., Haley, B., MacDonald, A. W. I., ... Carter, C. S. (2012). Relational and Item-Specific Encoding (RISE): Task development and psychometric characteristics. *Schizophrenia Bulletin*, 38(1), 114–124. <https://doi.org/10.1093/schbul/sbr146>
- Reinen, J. M., Van Snellenberg, J. X., Horga, G., Abi-Dargham, A., Daw, N. D., & Shohamy, D. (2016). Motivational context modulates prediction error response in schizophrenia. *Schizophrenia Bulletin*, 42(6), 1467–1475.
- Roudaia, E., Bennett, P. J., & Sekuler, A. B. (2008). The effect of aging on contour integration. *Vision Research*, 48(28), 2767–2774. <https://doi.org/10.1016/j.visres.2008.07.026>
- Saykin, A. J., Shtasel, D. L., Gur, R. E. R. C., Kester, D. B., Mozley, L. H., Stafniak, P., & Gur, R. E. R. C. (1994). Neuropsychological deficits in neuroleptic naive patients with first-episode schizophrenia. *Archives of General Psychiatry*, 51(2), 124. <https://doi.org/10.1001/archpsyc.1994.03950020048005>
- Schlagenhauf, F., Huys, Q. J. M., Deserno, L., Rapp, M. A., Beck, A., Heinze, H.-J. J., ... Heinz, A. (2014). Striatal dysfunction during reversal learning in unmedicated schizophrenia patients. *NeuroImage*, 89, 171–180. <https://doi.org/https://doi.org/10.1016/j.neuroimage.2013.11.034>
- Schneider, L. C., & Struening, E. L. (1983). SLOF: A behavioral rating scale for assessing the mentally ill. *Social Work Research and Abstracts*, 19(3), 9–21. <https://doi.org/10.1093/swra/19.3.9>
- Schultz, W. (2007). Multiple dopamine functions at different time courses. *Annual Review of Neuroscience*, 30(1), 259–288. <https://doi.org/10.1146/annurev.neuro.28.061604.135722>
- Schultz, W. (2016a). Dopamine reward prediction error coding. *Dialogues in Clinical Neuroscience*, 18(1), 23–32. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/27069377>
- Schultz, W. (2016b). Reward functions of the basal ganglia. *Journal of Neural Transmission*, 123(7), 679–693. <https://doi.org/10.1007/s00702-016-1510-0>
- Seeger, T., Fedorova, I., Zheng, F., Miyakawa, T., Koustova, E., Gomez, J., ... Wess, J. (2004). M2 muscarinic acetylcholine receptor knock-out mice show deficits in behavioral flexibility, working memory, and hippocampal plasticity. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 24(45), 10117–10127. <https://doi.org/10.1523/JNEUROSCI.3581-04.2004>
- Silverstein, S. M., All, S. D., Kasi, R., Berten, S., Essex, B., Lathrop, K. L., & Little, D. M. (2010). Increased fusiform area activation in schizophrenia during processing of spatial frequency-degraded faces, as revealed by fMRI. *Psychological Medicine*, 40(7), 1159–1169. <https://doi.org/10.1017/S0033291709991735>
- Silverstein, S. M., Berten, S., Essex, B., Kovacs, I., Susmaras, T., & Little, D. M. (2009). An fMRI examination of visual integration in schizophrenia. *Journal of Integrative Neuroscience*, 8(2), 175–202. <https://doi.org/10.1142/S0219635209002113>
- Silverstein, S. M., Harms, M. P., Carter, C. S., Gold, J. M., Keane, B. P., MacDonald, A., ... Barch, D. M. (2015). Cortical contributions to impaired contour integration in schizophrenia. *Neuropsychologia*, 75, 469–480. <https://doi.org/10.1016/j.neuropsychologia.2015.07.003>
- Silverstein, S. M., Keane, B. P., Barch, D. M., Carter, C. S., Gold, J. M., Kovacs, I., ... Strauss, M. E. (2011). Optimization and validation of a visual integration test for schizophrenia research. *Schizophrenia Bulletin*, 38(1), 125–134. <https://doi.org/10.1093/schbul/sbr141>
- Silverstein, S. M., Keane, B. P., Barch, D. M., Carter, C. S., Gold, J. M., Kovacs, I., ... Strauss, M. E. (2012). Optimization and validation of a visual integration test for schizophrenia research. *Schizophrenia Bulletin*, 38(1), 125–134. <https://doi.org/10.1093/schbul/sbr141>
- Silverstein, S. M., Kovacs, I., Corry, R., & Valone, C. (2000). Perceptual organization, the disorganization syndrome, and context processing in chronic schizophrenia. *Schizophrenia Research*, 43(1), 11–20. [https://doi.org/10.1016/S0920-9964\(99\)00180-2](https://doi.org/10.1016/S0920-9964(99)00180-2)
- Spagna, A., Dong, Y., Mackie, M.-A., Li, M., Harvey, P. D., Tian, Y., ... Fan, J. (2015). Clozapine improves the orienting of attention in schizophrenia. *Schizophrenia Research*, 168(1–2), 285–291. <https://doi.org/10.1016/j.schres.2015.08.009>
- Spencer, K. M., Nestor, P. G., Perlmutter, R., Niznikiewicz, M. A., Klump, M. C., Frumin, M., ... McCarley, R. W. (2004). Neural synchrony indexes disordered perception and cognition in schizophrenia. *Proceedings of the National Academy of Sciences of the United States of America*, 101(49), 17288 LP–17293. <https://doi.org/10.1073/pnas.0406074101>
- Spohn, H. E., & Strauss, M. E. (1989). Relation of neuroleptic and anticholinergic medication to cognitive functions in schizophrenia. *Journal of Abnormal Psychology*, 98(4), 367–380. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/2574202>
- Stoy, M., Schlagenhaut, F., Sterzer, P., Bermpohl, F., Hägele, C., Suchotzki, K., ... Ströhle, A. (2012). Hyporeactivity of ventral striatum towards incentive stimuli in unmedicated depressed patients normalizes after treatment with escitalopram. *Journal of Psychopharmacology*, 26(5), 677–688. <https://doi.org/10.1177/0269881111416686>
- Strauss, G. P., Frank, M. J., Waltz, J. A., Kasonova, Z., Herbener, E. S., & Gold, J. M. (2011). Deficits in positive reinforcement learning and uncertainty-driven exploration are associated with distinct aspects of negative symptoms in schizophrenia. *Biological Psychiatry*, 69(5), 424–431. <https://doi.org/10.1016/j.biopsych.2010.10.015>
- Strauss, M. E., Reynolds, K. S., Jayaram, G., & Tune, L. E. (1990). Effects of anticholinergic medication on memory in schizophrenia. *Schizophrenia Research*, 3(2), 127–129. [https://doi.org/10.1016/0920-9964\(90\)90045-9](https://doi.org/10.1016/0920-9964(90)90045-9)
- Tracy, J. I., Monaco, C., Giovannetti, T., Abraham, G., & Josiassen, R. C. (2001). Anticholinergic and cognitive processing in chronic schizophrenia. *Biological Psychology*, 56(1), 1–22. [https://doi.org/10.1016/S0301-0511\(00\)00083-1](https://doi.org/10.1016/S0301-0511(00)00083-1)
- Tzavara, E. T., Bymaster, F. P., Felder, C. C., Wade, M., Gomez, J., Wess, J., ... Nomikos, G. G. (2003). Dysregulated hippocampal acetylcholine neurotransmission and impaired cognition in M2, M4 and M2/M4 muscarinic receptor knockout mice. *Molecular Psychiatry*, 8(7), 673–679. <https://doi.org/10.1038/sj.mp.4001270>
- Uchida, H., Rajji, T. K., Mulsant, B. H., Kapur, S., Pollock, B. G., Graff-Guerrero, A., ... Mamo, D. C. (2009). D2 receptor blockade by risperidone correlates with attention deficits in late-life schizophrenia. *Journal of Clinical Psychopharmacology*, 29(6), 571–575. <https://doi.org/10.1097/JCP.0b013e3181bf4ea3>
- Vinogradov, S., Fisher, M., Warm, H., Holland, C., Kirshner, M. A., & Pollock, B. G. (2009). The cognitive cost of anticholinergic burden: Decreased response to cognitive training in schizophrenia. *American Journal of Psychiatry*, 166(9), 1055–1062. <https://doi.org/10.1176/appi.ajp.2009.09010017>
- Waltz, J. A., Demro, C., Schiffman, J., Thompson, E., Kline, E., Reeves, G., ... Gold, J. M. (2017). Reinforcement learning performance and risk for psychosis in youth. *The Journal of Nervous and Mental Disease*, 203(12), 919. <https://doi.org/10.1097/NMD.0000000000000420>
- Waltz, J. A., Frank, M. J., Robinson, B. M., & Gold, J. M. (2007). Selective reinforcement learning deficits in schizophrenia support predictions from computational models of striatal-cortical dysfunction. *Biological Psychiatry*, 62(7), 756–764. <https://doi.org/10.1016/j.biopsych.2006.09.042>
- Wechsler, D. (2001). *Wechsler: Wechsler test of adult reading: WTAR*. San Antonio, TX: The Psychological Corporation.
- Wood, S. J., Pantelis, C., Proffitt, T., Phillips, L. J., Stuart, G. W., Buchanan, J. A., ... McGorry, P. D. (2003). Spatial working memory ability is a marker of risk-for-psychosis. *Psychological Medicine*, 33(7), 1239–1247. <https://doi.org/10.1017/S0033291703008067>
- Woods, S. W. (2003). Chlorpromazine equivalent doses for the newer atypical antipsychotics. *Journal of Clinical Psychiatry*, 64(6), 663–667. <https://doi.org/10.4088/JCP.v64n0607>