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A comparison of cognitive structure in schizophrenia patients and healthy controls using confirmatory factor analysis

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Abstract

There is evidence that cognitive task performance breaks down into the same broad domains in schizophrenia as in healthy populations. However, this does not mean that the domains are independent of one another or that the interrelationships among domains are the same between groups. We used confirmatory factor analysis (CFA) to compare the latent structure of a broad neuropsychological battery in schizophrenia patients ($n=148$) and healthy controls ($n=157$). Main analyses examined the fit of a hierarchical six-factor model, in which associations among the factors were assumed to reflect their strong shared relationship to a general cognitive ability factor. The model incorporated the factors of verbal comprehension, perceptual organization, verbal memory, spatial memory, processing speed, and executive/working memory. The hierarchical model provided a good overall fit to data from both groups. However multiple groups CFA revealed significant differences in factor loadings between groups, reflecting a more generalized latent structure of cognitive ability in schizophrenia. This was also evident in higher bivariate correlations among cognitive domain composite scores calculated from the observed test data. Cognitive ability, as reflected in test performance, appears to be more unitary in schizophrenia than in healthy subjects. This finding may have measurement and treatment implications.

Keywords: Cognition; Schizophrenia; Confirmatory factor analysis; Neuropsychology

1. Introduction

A substantial literature describes the latent structure of cognition in schizophrenia. Factor analytic

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studies were recently reviewed in connection with the NIMH Measurement and Treatment Research to Improve Cognition in Schizophrenia (MATRICS) initiative (Nuechterlein et al., 2004). The review supported the position that, as among healthy individuals, schizophrenia test data is best characterized by multiple cognitive factor models, typically separating cognitive tasks into domains such as working memory, verbal learning and memory, visual learning and memory, abstraction and problem solving, processing speed, and attention/vigilance (see also Baser and Ruff, 1987; Dickinson et al., 2002; Gladsjo et al., 2004; Tulsky and Price, 2003). One of the principles guiding the review was to identify cognitive domains that were "independent or only weakly intercorrelated," which might be viewed as "separable contributors to functional outcome and as potentially separate targets for new treatments" (Nuechterlein et al., 2004, p. 31). Interrelationships among latent factors have not been a focus of the literature. Thus, the review, reflecting the literature more broadly, assumed relative independence of factors when analyses favored multifactor models over single factor models. However, factors may be "separable" without being "independent or only weakly correlated."

Indeed, there is evidence of substantial correlations among separable cognitive factors. In samples of healthy research participants an extensive literature indicates that diverse cognitive measures are positively correlated to at least a moderate degree (Carroll, 1993; Jensen, 1998). It is generally held that this network of correlations is characterized by a hierarchical factor structure in which individual measures load on broad cognitive ability factors, such as verbal comprehension or processing speed, which in turn load on a higher order latent factor representing general cognitive ability or "g" (Carroll, 1993; Deary, 2001; Jensen, 1998). When reported in schizophrenia factor analytic studies, correlations among cognitive test variables and among cognitive domains are typically moderate to high (Allen et al., 1998; Dickinson et al., 2002; Gladsjo et al., 2004; Hill et al., 2004). Indeed, there is some evidence that correlations among cognitive variables are relatively higher in ill than in healthy groups (Dickinson et al., 2002). Strong associations among cognitive variables in schizophrenia suggest that, as among healthy people, cognitive test performance may be characterized by a hierarchical model. If this model is supported, it might lead the field to draw different conclusions about how cognitive test performance relates to functional outcome and rational treatment design and testing. Perhaps cognitive performance should be viewed as a *general predictor* of functional performance in schizophrenia and be a *general target* for the design of new treatments.

Current analyses tested a hierarchical multi-factor model of cognitive test performance in schizophrenia. Data from large groups of schizophrenia patients and healthy controls were available for a broad neuropsychological battery from the database of the University of Pennsylvania Schizophrenia Research Center. As a preliminary step, we used confirmatory factor analysis (CFA) to test six-correlated-factors structural model, similar to ones used in prior analyses (Allen et al., 1998; Dickinson et al., 2002; Gladsjo et al., 2004; Tulsky and Price, 2003). However, our main analyses

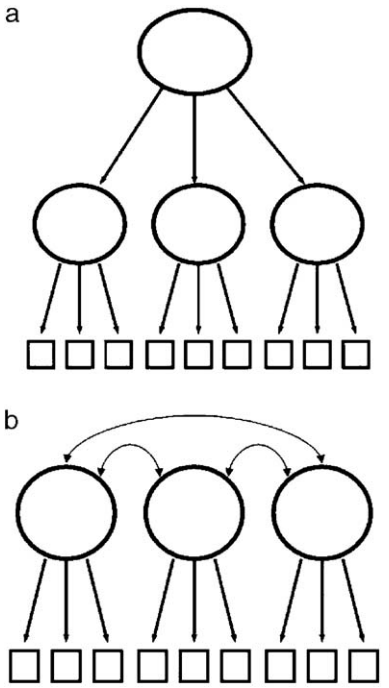

Fig. 1. (a) Representation of a hierarchical model of cognitive performance, in which a single second order latent factor, representing general cognitive ability, causes performance in different cognitive domains, which in turn cause performance on individual tests. (b) A multifactor model, in which separate latent cognitive factors cause performance on the individual tests. The latent factors are assumed to be intercorrelated.

examined the hierarchical model, using the same broad cognitive ability domains but specifying that these domains would be driven by a single, higher order cognitive ability factor. Fig. 1 is a simplified illustration of these two models. We tested the hierarchical model separately for the groups using simple CFA, and used multiple groups CFA to explore whether model parameters (e.g., the factor loadings) differed significantly between groups. We hypothesized that the hierarchical model would demonstrate a good fit to the schizophrenia and healthy control data, highlighting the importance of generalized cognitive performance across clinical and non-clinical groups. We further hypothesized that multiple groups analyses would reveal differences in model factor loadings consistent with greater generalization of cognitive performance in schizophrenia than in healthy controls.

2. Methods

2.1. Subjects

Data were drawn from the Penn database (with all identifying information removed) for the period from January 1993 to May 1998. Detailed inclusion and exclusion criteria are published (Saykin et al., 1991). In short, patients had DSM-III-R diagnoses of schizophrenia established by clinical examination and the Structured Clinical Interview for DSM-III-R (Spitzer et al., 1987), but were free of other psychiatric or major medical conditions including substance abuse. Controls were free of all psychiatric disorders in themselves and their first-degree relatives. Both patients and controls were between the ages of 18 and 45 and free of neurological disorders, head injuries, or medical conditions that might alter cognitive functioning.

2.2. Neuropsychological battery and cognitive domains

From a larger battery of tests, 17 were selected and each was assigned (by DD and JMG) to one of 6 cognitive domains: verbal comprehension (VRB), perceptual organization (POR), verbal learning and memory (VEM), visual learning and memory (VSM), information processing speed (IPS), and executive/working memory (EXWM). There is a reasonable degree of convergence among the proposed structure of the MATRICS consensus battery (Nuechterlein et al., 2004), the most recent CFA study of cognitive structure in schizophrenia (Gladsjo et al., 2004), and the model recently found to best characterize normative data from the WAIS III/WMS III standardization sample (Tulsky and Price, 2003). The guiding principle for the current selection and assignment was to use the test data available from the Penn database to make the best possible approximation of these converging models. Table 1 shows the specific assignments.

2.3. Data screening and preparation

Data from 158 schizophrenia patients and 164 healthy controls were available for analysis. Ten schizo-

Table 1
Neuropsychological battery with tests grouped by cognitive domain

Verbal Comprehension (VRB)
Vocabulary (WAIS-R, Wechsler, 1981)
Visual Naming (MAE, Benton and Hamsher, 1989)
Perceptual Organization (POR)
Block Design (WAIS-R, Wechsler, 1981)
Line Orientation (Benton et al., 1983)
Verbal Learning and Memory (VEM)
Trials 1–5 Total (CVLT, Delis et al., 1983)
Delayed Free Recall (CVLT, Delis et al., 1983)
Logical Memory, immediate recall (WMS-R, Wechsler, 1987)
Logical Memory, delayed recall (WMS-R, Wechsler, 1987)
Visual Learning and Memory (VSM)
Figural Memory, immediate recall (WMS-R, Wechsler, 1987)
Figural Memory, delayed recall (WMS-R, Wechsler, 1987)
Information Processing Speed (IPS)
Symbol Cancellation Test (Mesulam, 1985)
Trail Making Test, Form A (Reitan and Wolfson, 1985)
Animal Naming (BDAE, Goodglass and Kaplan, 1983)
Executive/Working Memory (EXWM)
Digit Span (WAIS-R, Wechsler, 1981)
Trail Making Test, Form B (Reitan and Wolfson, 1985)
Categories (WCST, Heaton, 1981)
Perseverative Errors (WCST, Heaton, 1981)

WAIS-R = Wechsler Adult Intelligence Scale–Revised; MAE = Multilingual Aphasia Examination; CVLT = California Verbal Learning Test; WMS-R = Wechsler Memory Scale-Revised; BDAE = Boston Diagnostic Aphasia Examination; WCST = Wisconsin Card Sorting Test.

phrenia cases and 7 healthy controls were eliminated because of substantial missing data or because they were identified as outliers. These adjustments left data for 148 schizophrenia cases and 157 healthy controls. Values missing from these cases were imputed using a regression-based algorithm.

2.4. CFA

CFA was used to estimate parameters and evaluate the fit of different models of cognitive performance in schizophrenia and healthy control samples. Analyses were conducted using LISREL 8.72 (Joreskog and Sorbom, 2005) with maximum likelihood estimation. Simplified illustrations of the two models considered in our analyses are presented in Fig. 1. Our primary analysis utilized a hierarchical six-factor model of cognitive performance for schizophrenia subjects and healthy controls (see Fig. 1a). The six factors were as described in Table 1 and each individual cognitive test was presumed to load exclusively on the indicated factor. This model contrasts in important respects with multi-factor models used in earlier studies (Allen et al., 1998; Dickinson et al., 2002; Gladsjo et al., 2004; Tulsky and Price, 2003). Those models (illustrated in Fig. 1b) allow the latent cognitive factors to correlate, but make no assumptions about either the cause or the magnitude of the correlations. The hierarchical model does not permit the factors to correlate freely. Rather, the model specifies that interrelations among the factors are caused by their shared relationship to a higher order latent factor representing general cognitive abilretical interpretation, depend on there being substantial and consistent loadings of the cognitive factors on the general ability factor. In sum, while recognizing that cognitive test variables are "separable" into meaningful domains, this model highlights the dependence of the cognitive variables and the cognitive factors on unitary "g".

Based on prior findings of significant method variance in pairs of variables from a single test (Dickinson et al., 2004; Gladsjo et al., 2004), we allowed unique (or error) parameters to covary for four pairs of variables in all models (i.e., the CVLT, Logical Memory, Trail Making Test, and WCST variables, see Table 1). Several widely-used measures were used to index overall goodness of fit of the estimated model variance–covariance matrix to the observed matrix. Included are measures that index fit in an absolute sense (Chi-Square, GFI) and measures that are weighted by complexity (i.e., the number of parameters being estimated) to take model parsimony into account (RMSEA, BNFI, AIC).[1]

2.5. Additional analyses of domain interrelationships

To shed further light on the interrelationships among the cognitive domains, we created *z*-score composites for each domain for each group. Healthy control data were used as the reference point, following procedures previously outlined (Saykin et al., 1991). We calculated correlations among the domain composites separately for the schizophrenia and healthy control groups and mean correlation values for the groups. To avoid problems with non-normal distributions of correlations, mean values were calculated in each case by converting individual Pearson correlations to Fisher's *z*' prior to averaging and then converting the mean value back to into Pearson values (Cohen and Cohen, 1983). Differences between the mean correlations were calculated using Fisher's test for differences in correlation

[1] Chi-square values and degrees of freedom for each model were obtained; χ^2/df values less than 2.0 indicate good model fit (Kline, 1998). The goodness-of-fit index (GFI) (Joreskog, 1993) provides a standardized overall measure of the proportion of the variances and covariances of study variables accounted for by a given model, analogous to multiple R^2 in multiple regression analyses (Kline, 1998). Values vary between 0 and 1, with values above .90 indicating good model fit. We also report the root mean square error of approximation (RMSEA) (Browne and Cudek, 1993), a summary of the standardized covariance residuals, weighted by model complexity (i.e., the number of parameters being estimated). Values below 0.05 indicate a close fit relative to degrees of freedom, while values below 0.08 indicate a reasonable error of approximation (Browne and Cudek, 1993). Because the samples used in this study are small for confirmatory procedures, we report the Bentler and Bonnet non-normed fit index (BNFI) (Bentler and Bonett, 1980), which is relatively independent of sample size (Marsh et al., 1988). Like the RMSEA, the BNFI includes a penalty function for more complex models. Like the GFI, the BNFI varies between 0 and 1. Values below 0.9 indicate models with room for substantially improved fit (Bentler and Bonett, 1980). Finally, Aikaike's information criterion (AIC) is a function of the sum of the discrepancy between observed and modeled data matrix elements, again weighted by the complexity of the model (Akaike, 1987). AIC declines with improved model fit.

coefficients from independent samples (Cohen and Cohen, 1983).

3. Results

3.1. Sample demographic, clinical, and cognitive characteristics

Demographic characteristics and intellectual performance are summarized in Table 2. Patients were significantly older than controls, significantly more likely to be male, and significantly less likely to be of European ancestry. Patients also had significantly fewer years of education although parental education, a better gauge of educational potential (Resnick, 1992), was statistically equivalent for patients and controls. Preliminary analyses indicated that the group of covariates (excepting patient education) made little difference in model fit, and they were not included in the main analyses. On average, patients had an illness duration of 11 years. However, 42 patient participants were in their first episode of illness and had little or no medication history at the time of testing. Seventy-seven patients were on stable doses of antipsychotic medication and 29 patients were missing medication information. One-way ANOVAs showed no significant differences among these groups on any of the cognitive test variables (all p's > .05, all but one p > .25). Therefore, all patients were grouped for further analyses.

Table 2
Demographic characteristics and intellectual performance of schizophrenia patients and healthy controls

	Schizophrenia cases (N=148)		Healthy controls (N=157)	
	Mean	SD	Mean	SD
Age (years)[a]	33.5	7.5	30.2	6.2[b]
Education (years)[c]	13.2	2.2	15.4	2.1[b]
Mother's educ[d]	13.2	2.8	12.4	3.3
Father's educ[e]	13.7	3.6	12.8	3.8
Age of onset[f]	22.5	5.6		
Vocabulary SS	8.8	3.0	11.9	2.3[b]
Digit span SS	8.5	2.6	10.8	2.6[b]
	N	%	N	%
Male	97	65.5	72	45.9[b]
Caucasian[a]	77	52	108	69[b]

[a] Based on 150 HC, 121 SZ.
[b] Group differences significant at p < .001. Other group differences not statistically significant.
[c] Based on 149 HC, 119 SZ.
[d] Based on 147 HC, 100 SZ.
[e] Based on 143 HC, 91 SZ.
[f] Based on 112 SZ.

Standard scores (healthy population mean = 10, SD = 3) for WAIS Vocabulary and WAIS Digit Span indicate that the control subjects were somewhat above average in intellectual performance, while the schizophrenia group was below average. The performance discrepancy between groups on these intellectual measures, approaching 1 SD, is similar to other schizophrenia/control group comparisons on intellectual measures (The Psychological Corporation, 1997). On the other hand, the schizophrenia subjects performed within "normal limits" indicating that this was not a severely intellectually impaired patient group. Across the broad battery of neuropsychological measures, the schizophrenia impairment was significant on every variable (all p's < .01).

3.2. CFA of healthy control and schizophrenia groups

Table 3 shows various indices of fit for the different study models. In separate analyses by group, the six-correlated-factors model showed similarly good fit for both groups. Group by group analyses of the hierarchical model also indicated good fit, negligibly different from the six-correlated-factors model. The maximum likelihood standardized regression weights for the observed test variables on the six latent cognitive factors, and the weights of the six cognitive factors on the general ability factor for the schizophrenia sample only are given in Table 4, along with the total variance explained for each of these variables. Importantly, the factor loadings and variance explained for the associations of the broad cognitive ability factors with the general ability factor are high and consistent. In general, there is substantial consistency of these results with those reported by Gladsjo for the six correlated factors model (Gladsjo et al., 2004, Table 2), despite differences in the batteries and the composition of individual cognitive domains.

The first of the multiple groups CFAs for the hierarchical model, although fitted simultaneously

Table 3
Indices of model fit for healthy controls ($N=157$) and schizophrenia patients ($N=148$)

Model and group	χ^2 (*df*)	χ^2/df	GFI	RMSEA	BNFI	AIC
Hierarchical model						
Modeled by group						
1. Healthy controls	158 (109)	1.45	.894	.0537	.960	246
2. Schizophrenia cases	161 (109)	1.48	.886	.0567	.986	249
Correlated factors model						
Modeled by group						
1. Healthy controls	133 (100)	1.33	.912	.0428	.975	235
2. Schizophrenia cases	148 (100)	1.48	.898	.0530	.986	247
Hierarchical model						
Multiple group analyses						
1. All factor loadings free to vary between groups	319 (218)	1.46		.0552	.978	494
2. All factor loadings constrained to be equal between groups	556 (239)	2.33		.0937	.938	690
3. Loadings equal for domain factors, free to vary for common factor	402 (229)	1.76		.0708	.966	557

Controlling for age, mother's and father's education, gender, and race. *df*=Degrees of freedom; GFI=Goodness of fit index; RMSEA=Root mean square error of approximation; BNFI=Bentler and Bonnet's non-normed fit index; AIC=Akaike's information criterion. Descriptions of the fit statistics and guidelines for interpreting them are described in Footnote 1.

Table 4
Results of the CFA for the hierarchical model of cognitive performance for the patient group ($N=148$) with standardized factor loadings and variance explained

Factor								
Variable	VRB	POR	VEM	VSM	IPS	EXWM	Gen Cog	R^2
Vocabulary	.840							.70
Visual naming	.856							.73
Block design		.825						.68
Line orientation		.826						.68
Trials 1–5			.854					.57
Delayed free recall			.852					.54
Logical memory immediate			.754					.73
Logical memory delayed			.736					.72
Figure memory immediate				.923				.85
Figure memory delayed				.881				.78
Symbol cancellation					.571			.33
Trails A					.568			.32
Animal naming					.645			.42
Digit span						.617		.38
Trails B						.871		.76
Perseverative errors						.540		.29
Categories						.623		.39
Verbal comprehension							.874	.76
Perceptual organization							.888	.79
Verbal memory							.857	.74
Visual memory							.881	.78
Processing speed							.953	.91
Executive/working memory							.973	.95

Controlling for age, mother's and father's education, gender, and race. VRB=Verbal comprehension; POR=Perceptual organization; VEM=Verbal memory; VSM=Visual memory; IPS=Information processing speed; EXWM=Executive/working memory; Gen Cog=General cognitive ability.

across the entire sample, recapitulates the findings from the separate schizophrenia and healthy control CFAs (indeed, the Chi-square and degrees of freedom for this model are simply sums of the same values taken from the separate analyses, while all the other fit indices are intermediate values; see Table 3). Thus, the same broad, hierarchical organization of cognitive performance seems to exist in both groups, so long as model parameters are free to vary between the groups. The second multiple group CFA tested overall model fit when all factor loadings (i.e., the loadings of the observed variables on cognitive domains and the loadings of the cognitive domains on the common factor) were constrained to be equal. All other model parameters (e.g., error variances for the observed variables) remained free to vary between groups in this model. The constraints result in significantly degraded model fit, relative to the first multiple groups CFA (Chi-square difference = 237, $df = 21$, $p < .001$). Therefore, in current analyses, factor loadings cannot be assumed to be equivalent between groups.

3.3. Cognitive domain interrelationships

Examining the standardized parameter estimates from the separate analyses of the hierarchical model in the schizophrenia and healthy control groups, one notable difference is in the level of the loadings of the latent cognitive domain factors on the common factor. In the schizophrenia group, these loadings are high and consistent, ranging from .851 to .973 with a mean value of .92 (the mean was calculated as described in Section 2.5). The loadings in the healthy control group are lower and more variable, ranging from .600 to .826 with a mean value of .77. This difference is significant ($z = 4.92$, $p < .001$), using Fisher's test for differences between coefficients from independent samples (Cohen and Cohen, 1983). The third multiple groups CFA highlights this difference between the groups (see Table 3). This model freed the loadings of the cognitive domain factors to vary between the groups but constrained the other factor loadings to be equivalent between groups. The third multiple groups model fit sample data significantly better than the second model, in which all factor loadings were constrained to be equal (Chi-square difference = 154, $df = 10$, $p < .001$), although it still did not fit the data as well as the first multiple groups CFA (Chi-square difference = 83, $df = 11$, $p < .001$). Thus, different approaches are consistent in indicating significant differences in the magnitude of common factor loadings between the schizophrenia and control groups.

The common factor in these models reflects variation shared in common among latent, cognitive domain *factors*. However, group differences can also be explored in the between-groups pattern of bivariate correlations among cognitive domain *composites*, calculated from the observed variable scores following the process described in Section 2.5. Table 5 presents these correlations. An examination reveals that the correlations between domains for the schizophrenia group are consistently higher than those for the healthy controls. The mean correlation of 0.62 for the schizophrenia group contrasts with a mean of 0.35

Table 5
Pearson's correlations among standardized cognitive domain scores for healthy controls (above the diagonal; $N = 157$) and schizophrenia group (below the diagonal; $N = 148$)

	VRB	POR	VEM	VSM	IPS	EXWM
Verbal comprehension		0.43	0.41	0.43	0.34	0.31
Perceptual organization	0.64		0.34	0.42	0.26	0.31
Verbal memory	0.69	0.57		0.44	0.41	0.42
Visual memory	0.64	0.73	0.63		0.15**	0.20*
Information processing speed	0.49	0.57	0.50	0.56		0.33
Executive/working memory	0.64	0.65	0.64	0.69	0.64	

Controlling for age, mother's and father's education, gender, and race. All values significant at $p < .01$, except **(n.s.), and *($p < .05$). VRB = Verbal comprehension; POR = Perceptual organization; VEM = Verbal memory; VSM = Visual memory; IPS = Information processing speed; EXWM = Executive/working memory. To calculate these correlations, individual test scores for all participants were standardized (transformed to z-scores) with reference to the healthy control group (Saykin et al., 1991). Domain scores for each individual were calculated by averaging standardized test scores across the individual tests loading on each domain (see Table 1).

for the healthy control group. Again using Fisher's test, this difference is significant ($z = 3.11$, $p < .001$).

4. Discussion

There are two major results of current analyses. First, confirmatory factor analysis (CFA) supports the conclusion that the same hierarchical model of cognitive test performance—with individual tests loading on six cognitive domain factors, and these factors loading on the general cognitive ability factor—fits data from schizophrenia patients and healthy research participants. Second, results indicate that, while the broad model fits data from both groups well, there are significant differences in the details of model fit between groups, consistent with a relatively greater generalization of cognitive ability in schizophrenia than in healthy people. We will discuss these conclusions in turn.

Using different CFA approaches, we determined that the hierarchical model provided a good fit to data from both groups. This was evident in separate analyses of schizophrenia and healthy control data and, similarly, in a multiple groups CFA of the full dataset that freed all parameters to vary between groups (see Table 3). Secondary analyses of a six-correlated-factors model also showed good overall fit for both groups. The different models are consistent in indicating (1) that the broad latent structure of cognitive performance is similar in schizophrenia and healthy samples and (2) that it is multifactorial. These results converge with recent findings from the CFA of Gladsjo et al. (2004).

The hierarchical and correlated-factors models are not nested and statistics do not provide a basis to prefer one over the other. However, the hierarchical model arises out of an important theoretical framework. Following the work of John Carroll and others, who have synthesized the healthy subject literature (Carroll, 1993; Deary, 2001; Jensen, 1998), it proposes that associations among the separate cognitive domains reflect their shared association with higher order general intellectual ability or "g." In this sense, the hierarchical model is a more theoretically grounded conception of cognitive structure than the correlated factors model, which incorporates no assumptions about the nature or magnitude of cognitive domain associations. This is, to our knowledge, the first demonstration that the hierarchical model of cognition extends from non-clinical groups to schizophrenia.

Despite the broad similarities in the fit of the hierarchical model to patient and control data, current analyses also revealed important differences between the groups. In a further multiple groups CFA, factor loadings (i.e., between the common cognitive factor and the six cognitive domain factors and between the domain factor and the 17 observed variables) were constrained to be equal between groups and the model's fit to the full dataset degraded significantly. Much of the difference could be traced to significant differences in the magnitude of the path coefficients from the common factor to the cognitive domain factors. While these path values were substantial in both groups, they were significantly higher in the schizophrenia sample. When the common factor/cognitive domain loadings were left free to vary (in the third multiple groups CFA, see Table 3), overall model fit improved significantly relative to the model with all factor loadings constrained to be equal.

These results contrast with those of Gladsjo et al. (2004), who suggested that differences in parameter values between schizophrenia and non-clinical subjects were "negligible." However, the multiple group CFA in that study must be interpreted with caution given that their controls were an average of nearly twenty years older than their patients. Juxtaposing the generalized cognitive decline in normal aging (Salthouse, 1998; Salthouse and Ferrer-Caja, 2003)—including possible cognitive "dedifferentiation" (Ghisletta and Lindenberger, 2003) — with the generalized cognitive impairment in schizophrenia (Bilder et al., 2000; Blanchard and Neale, 1994) may have masked important population level differences.

At the heart of the hierarchical model is the idea that a generalized cognitive ability underlies much, but not all, of performance in different cognitive domains and on individual cognitive measures (Carroll, 1997; Jensen, 1998). Proponents of this model recognize that there are likely to be independent cognitive domain effects as well, not accounted for by the common factor, but assume they are typically of smaller magnitude than those driven by common ability. Current results indicate significantly higher

common factor loadings in schizophrenia than in controls. This means more of the observed cognitive performance variance is determined by generalized cognitive ability in schizophrenia, relative to healthy controls, and less performance variance is associated with domain specific effects. This point was underscored by the significant contrast in the magnitude of correlations among cognitive domain composites between the groups (see Table 5).

If within group cognitive ability is generalized in schizophrenia, in the same way that the between group cognitive deficit appears to be (Dickinson et al., 2004), then questions arise concerning the nature of this generalized phenomenon. One way of understanding it relates to traditional neuropsychological test batteries. It may be that the neuropsychological tasks themselves are so inherently multifactorial that their utility for probing specific treatment or genetic effects, at least in schizophrenia, is sharply limited. Another psychometric concern is the existence of a more restricted range of test performance among healthy controls than schizophrenia patients. That pattern was evident here, as it is in many schizophrenia/control comparisons, and may have contributed to the group differences in domain correlations. Alternatively, the generalized cognitive deficit in schizophrenia may accurately reflect quite widespread cortical and subcortical dysfunction in the illness. Relevant cognitive models include abnormal internal, temporal information processing dynamics, or "cognitive dysmetria," undermining the coordination of various concurrent and successive processing operations (Andreasen et al., 1998; Salthouse, 1996). Candidate neurobiological systems include glutamate neurotransmission dysregulation (Javitt and Zukin, 1991), broad white matter defects (Kubicki et al., 2005) and, possibly, even more global metabolic processes (Fenton et al., 2000; Hanson and Gottesman, 2005). Such broad insults could explain the difficulty in isolating large and reliable differential deficit signals from cognitive test data.

Current analyses offer support for a hierarchical structure of cognition, similar in schizophrenia and control subjects, with a generalized cognitive ability factor strongly influencing a number of separable domains of cognitive performance. However, current findings also call into question the proposition that cognitive domains in schizophrenia are "independent or only weakly correlated" (Nuechterlein et al., 2004). Quite the contrary, our results indicate that the different cognitive domains are strongly related in both groups, and especially so in schizophrenia. If these findings are supported in future analyses, it would suggest that the latent structure of cognitive performance in schizophrenia is more unitary than has often been assumed.

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