# Latent structure of cognition in schizophrenia: a confirmatory factor analysis of the MATRICS Consensus Cognitive Battery (MCCB)

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**Background.** The number of separable cognitive dimensions in schizophrenia has been debated. Guided by the extant factor analytic literature, the NIMH Measurement and Treatment Research to Improve Cognition in Schizophrenia (MATRICS) initiative selected seven cognitive domains relevant to treatment studies in schizophrenia: speed of processing, attention/vigilance, working memory, verbal learning, visual learning, reasoning and problem solving, and social cognition. These domains are assessed in the MATRICS Consensus Cognitive Battery (MCCB). The aim of this study was to conduct a confirmatory factor analysis (CFA) of the beta battery of the MCCB to compare the fit of the MATRICS consensus seven-domain model to other models in the current literature on cognition in schizophrenia.

**Method.** Using data from 281 schizophrenia outpatients, we compared the seven correlated factors model with alternative models. Specifically, we compared the 7-factor model to (*a*) a single-factor model, (*b*) a three correlated factors model including speed of processing, working memory, and general cognition, and (*c*) a hierarchical model in which seven first-order factors loaded onto a second-order general cognitive factor.

**Results.** Multiple fit indices indicated the seven correlated factors model was the best fit for the data and provided significant improvement in model fit beyond the comparison models.

**Conclusions.** These results support the assessment of these seven cognitive dimensions in clinical trials of interventions to improve cognition in schizophrenia. Because these cognitive factors are separable to some degree, it is plausible that specific interventions may have differential effects on the domains.

## Introduction

Schizophrenia is associated with marked cognitive impairment, with effects in the medium to large range across a variety of cognitive tests (Heinrichs & Zakzanis, [1998](#); Mesholam-Gately *et al.* [2009](#)). Various conceptualizations of the underlying or latent structure of cognition in schizophrenia have been proposed in the literature. The models vary with respect to their complexity, and can be broadly categorized as: (1) single-factor models, in which all cognitive tasks load onto a single cognitive factor, (2) correlated factors models, in which a certain number of cognitive domains are modeled as separable but associated factors, and (3) hierarchical models, in which cognitive domains are modeled as loading on a higher-order general cognitive factor.

Identifying the latent structure of cognition in schizophrenia has implications for clinical research. The various models make different assumptions about the associations among cognitive domains and they offer differing conceptualizations about the

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separability of causal factors in cognitive impairment. In turn, the various models have implications for development of potential treatments to improve cognitive functioning.

The NIMH Measurement and Treatment Research to Improve Cognition in Schizophrenia (MATRICS) initiative proposed that seven cognitive domains were relevant to treatment studies in schizophrenia, including: speed of processing, attention/vigilance, working memory, verbal learning, visual learning, reasoning and problem solving, and social cognition (Nuechterlein, et al. 2004). These domains were selected based on a review of existing factor analyses of cognitive performance in schizophrenia patients. The seven domains were conceptualized as separable, but inter-correlated with each other. These cognitive factors are not unique to schizophrenia, as they can be found in other multi-factorial models of cognition in healthy samples (Tulsky & Price, 2003; Genderson et al. 2007; Schretlen et al. 2013). Likewise, although fewer factor analytic studies have been conducted in bipolar disorder, a similar multi-factorial structure of cognition has also been reported in that disorder (Czobor et al. 2007; Schretlen et al. 2013).

The seven cognitive domains are represented by ten tests in the MATRICS Consensus Cognitive Battery (MCCB) (Nuechterlein et al. 2008), but this factor structure was not specifically evaluated with the MCCB. In fact, because five of the seven domains are represented by only one measure each, it is not possible to fully confirm the factor structure using only the final 10-test MCCB. The psychometric study that was used to validate the MCCB included a beta battery with at least two tests per domain. Hence, the beta version can be used to determine whether the underlying structure of cognition can be validly represented by seven factors, or if alternative factor structures better capture the variance in performance.

The number of separable cognitive dimensions in schizophrenia has been debated. Starting with the simplest model, some authors have hypothesized that cognition in schizophrenia is sufficiently represented by a single cognitive factor. A single factor may reflect a generalized deficit in performance across neuropsychological tests that may be attributable to diffuse dysfunction of the central nervous system in schizophrenia (Dickinson & Harvey, 2008). When single-factor models have been tested empirically, the conclusions are partly dependent on which statistical method is used. Studies that use principal components analysis indicate that a single component captures a large proportion of the total variance (i.e. both the shared variance and the variance unique to individual cognitive measures) (Keefe et al. 2004, 2006). However, studies that have tested the single-factor model using

confirmatory factor analysis (CFA), a technique in which the latent structure of the shared variance is modeled, generally do not support this conceptualization (e.g. Gladsjo et al. 2004; Ojeda et al. 2012; Schretlen et al. 2013, but see Keefe et al. 2006).

In contrast to the single factor model, others have proposed models with multiple correlated factors, and these models vary with respect to the number of factors specified. In healthy samples, speed of processing and working-memory factors reliably emerge in factor analytic studies of the WAIS (Arnau & Thompson, 2000). Similarly, these factors emerged in a recent CFA conducted on nine of the 10 core MCCB tests (Burton et al. 2013). Thus, a potential model of intermediate complexity between the single-factor model and the 7-factor model is a 3-factor model consisting of speed of processing and working-memory factors, as well as a general factor (i.e. the remaining measures).

Hierarchical models include features of the single-factor model and multi-factorial models. Specifically, hierarchical models consist of multiple cognitive factors that arise from a single, second-order general cognitive factor. Some have argued that these models can explain cognitive impairment in schizophrenia (Dickinson et al. 2006), perhaps reflecting dysfunction of an underlying central mechanism, such as cognitive control, that serves a rate-limiting function for performance across various cognitive domains (Braver et al. 1999; Barch & Ceaser, 2012). Hierarchical models are also consistent with models of intelligence in healthy samples (e.g. combinations of a psychometric 'g' as well as separable intellectual factors (Carroll, 1993; Arnau & Thompson, 2000).

The aim of this paper was to directly compare these competing models of the latent structure of cognition in schizophrenia by conducting CFA of a modified beta version of the MCCB. The modified beta version of MCCB is comprised of 16 tests and has at least two measures for each cognitive domain. Thus, it is suitable for CFA. We compared four possible models (see Fig. 1). These include the seven correlated factors model (which was the basis for the MCCB) with alternative models including: (1) a single-factor solution, (2) a three correlated factors solution with processing speed, working memory, and general cognition, and (3) a hierarchical model where the seven MCCB domains load onto a higher-order general cognitive factor.

## Method

### Participants

A total of 281 patients from two separate samples provided data for these analyses. One hundred five were from the UCLA Aftercare Research Program, an
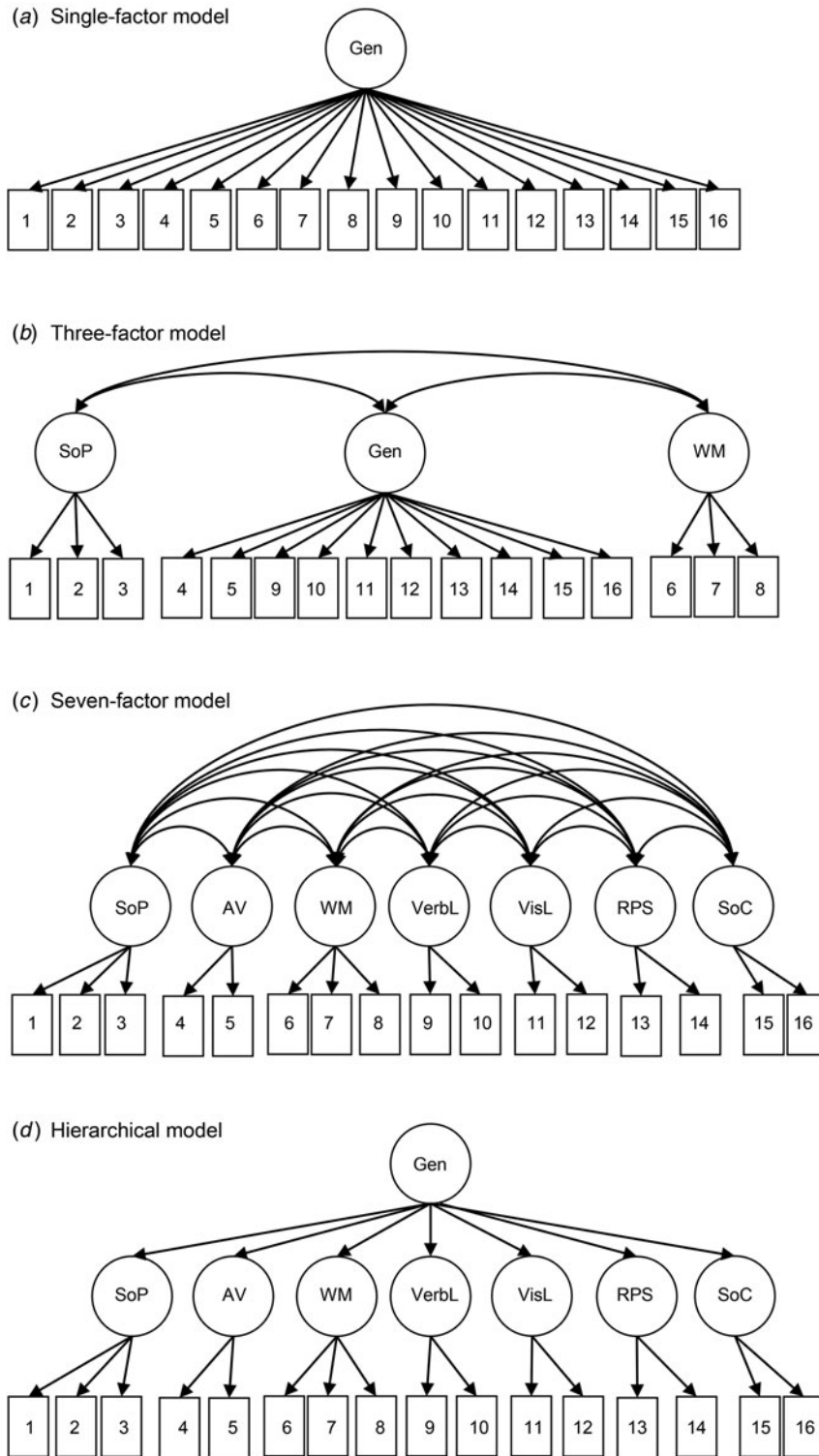
**Fig. 1.** Simplified graphical representations of the various confirmatory factor analysis models. An error term associated with each observed variable has been omitted for clarity. Gen: General cognitive factor, SoP: Speed of Processing, AV: Attention & Vigilance, WM: Working Memory, VerbL: Verbal Learning, VisL: Visual Learning, RPS: Reasoning and Problem Solving, SoC: Social Cognition, 1: BACS Symbol Coding, 2: Category Fluency, 3: Trail Making Test A, 4: 3-7 Continuous Performance Test, 5: Continuous Performance Test, Identical Pairs, 6: BACS Digit Sequencing, 7: Maryland Letter-Number Span, 8: WAIS-III Spatial Span, 9: Hopkins Verbal Learning Test – Revised, 10: NAB Daily Living Memory, 11: Benton Verbal Memory Test – Revised, 12: NAB Shape Learning, 13: NAB Mazes, 14: WAIS-III Block Design, 15: MSCEIT Managing Emotions, 16: MSCEIT Perceiving Emotions.

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outpatient clinical research program for recent-onset schizophrenia ($n = 56$ with schizophrenia, $n = 13$ with schizoaffective disorder, depressed type, $n = 36$ with schizophreniform disorder). In addition, 176 patients ($n = 151$ with schizophrenia, $n = 25$ with schizoaffective disorder, depressed type) participated in the MATRICS Psychometric and Standardization Study (MATRICS PASS) (Nuechterlein *et al.* 2008; Kern *et al.* 2011). The PASS included five academic sites: Duke University, Harvard University, University of Kansas, Maryland Psychiatric Research Center, and UCLA. The mean age of the combined sample was 35.8 (s.d. = 14.0) years, and the mean level of education was 12.5 (s.d. = 2.2) years. The combined sample was 75.8% male; 19.2% were of Hispanic ethnicity, and 29.9% were African American. Additional demographic information can be found in online Supplementary Table S1.

Recent-onset patients from the Aftercare Program were all taking oral risperidone at the time of this baseline MCCB assessment (Subotnik *et al.* in press). The majority of the MATRICS PASS participants were prescribed atypical antipsychotic medications (83%). Informed consent was obtained from all patients using consent forms that were approved by the local universities. Inclusion criteria for patients from both studies were: (1) a DSM-IV (APA, 1994) diagnosis of schizophreniform, schizophrenia, or schizoaffective disorder, depressed subtype based on SCID interview (First *et al.* 2001), (2) age 18–65 years (MATRICS PASS) or 18–45 years (Aftercare Program), and (3) clinical stability, indicated by stable outpatient or rehabilitation center status and no medication changes in the month prior to testing. Exclusion criteria were: (1) evidence of a neurological disorder or head injury, and (2) current substance or alcohol abuse or dependence.

### Procedure

All participants completed a modified beta version of the MCCB. Aftercare Program participants completed testing as part of a baseline assessment, which typically occurred within 3 months of program entry. Recruitment and testing procedures for the MATRICS PASS sample are described elsewhere (Nuechterlein *et al.* 2008). For patients prescribed anti-parkinsonian medication, it was discontinued (if judged clinically feasible) 48 h prior to testing to avoid anticholinergic effects on cognitive measures. Assessments were conducted by testers trained to certification criteria. Ongoing quality assurance included periodic checks on test administration and scoring practices.

The modified beta version of the MCCB consists of 16 tests assessing seven cognitive domains. A brief description of the domains and associated tests is presented in Table 1. The original beta version of the MCCB included 20 tests that were reduced to 10 tests in the final battery (Nuechterlein *et al.* 2008). The Aftercare Program assessments included 16 of the 20 tests in the beta version of the MCCB; therefore, they are the tests used in this data analysis. The remaining four beta battery tests were excluded from the Aftercare protocol due to psychometric or practicality concerns, or redundancy with included measures.

### Data analysis

Prior to analysis, the data were screened for univariate and multivariate normality. Missing data were minimal (1.27% of data points) and were imputed using the expectation-maximization (EM) algorithm. The MCCB scoring program does not provide age- and gender-corrected $T$ scores for the additional beta version tasks. Thus, raw scores for all of the tests were standardized ($z$ score) so that convergence of the statistical model would not be complicated by differences in test variance. These preliminary analyses were conducted using IBM SPSS version 21 (IBM, 2012). CFA was conducted using EQS version 6.2 (Bentler & Wu, 2005). We were particularly interested in a model based on the seven factors (allowed to correlate with each other) that was the basis of the MCCB (Nuechterlein, *et al.* 2004). We then compared this 7-factor model to three alternative models of varying complexity: (*a*) a single-factor model, (*b*) a model of three correlated factors that included speed of processing, working memory, and all remaining tests (i.e. general cognition), and (*c*) a hierarchical model with seven first-order factors that loaded onto a single second-order general factor.

The single-factor and 3-factor models were nested within the 7-factor model: constraining the correlations between all seven factors to 1 is equivalent to the single-factor model, while constraining the correlations between all factors except speed of processing and working memory to 1 is equivalent to the 3-factor model. The hierarchical model was non-nested as it contained an additional second-order general cognitive factor that was not present in any of the other models.

Nested models were evaluated using the chi-square difference test ($\Delta\chi^2$), which determines whether the model fit is significantly changed as a result of adding or removing free parameters from the model (Bollen, 1989). Specifically, the $\Delta\chi^2$ explicitly tests whether the change in $\chi^2$ value is meaningful considering the change in degrees of freedom (df), and a significant $\Delta\chi^2$ statistic favors the model with the lower $\chi^2$ value. Non-nested models were compared using parsimony-adjusted information criterion-based fit indices: Akaike's Information Criterion (AIC) and corrected AIC (AIC$_c$), and the

**Table 1.** *Description of MCCB beta version tests and descriptive data (n = 281)*

| Domain | Test | Dependent variable | Mean (s.d.) |
|---|---|---|---|
| Speed of processing | BACS, Symbol Coding (SC)[a] (Keefe, 1999) | Total number correct | 43.48 (12.28) |
| | Category Fluency Test, Animal Naming (Fluency)[a] (Spreen & Strauss, 1998) | Total number of animals named in 60 s | 18.45 (5.22) |
| | Trail Making, Part A (TMT)[a] (US Army Individual Test Battery: Manual of Directions and Scoring, 1944) | Time to completion | 38.66 (15.22) |
| Attention/vigilance | 3–7 CPT (Nuechterlein *et al.* 1986) | Overall *d'* | 3.94 (1.01) |
| | CPT, Identical Pairs (CPT-IP)[a] (Cornblatt *et al.* 1988) | Mean *d'* across 2-, 3-, and 4-digit conditions | 2.21 (0.80) |
| Working memory | BACS, Digit Sequencing Test (DS) (Keefe, 1999) | Total number correct | 17.78 (4.99) |
| | Letter-Number Span Test (LNS)[a] (Gold *et al.* 1997) | Number of correct trials | 12.39 (4.19) |
| | WMS, 3rd edn. Spatial Span (SS)[a] (Wechsler, 1987) | Sum of raw scores, forward and backward | 14.54 (3.95) |
| Verbal learning | Hopkins Verbal Learning Test – Revised (HVLT-R)[a] (Brandt, 2001) | Total recall over three learning trials | 21.67 (5.44) |
| | NAB, Daily Living Memory (DLM) (White & Stern, 2003) | Total recall across three trials | 44.41 (11.41) |
| Visual learning | Brief Visual Memory Test – Revised (BVMT-R)[a] (Benedict, 1997) | Total recall score over three learning trials | 19.15 (7.93) |
| | NAB Shape Learning (SL) (White & Stern, 2003) | Total learning score over three trials | 14.73 (4.57) |
| Reasoning and problem solving | NAB Mazes (Mazes)[a] (White & Stern, 2003) | Total raw score | 14.26 (7.14) |
| | WAIS – 3rd edn. Block Design (BD) (Wechsler, 1995) | Total raw score | 32.75 (13.88) |
| Social cognition | MSCEIT, Managing Emotions Branch (ME)[a] (Mayer *et al.* 2002) | Branch score using general consensus scoring | 97.48 (17.30) |
| | MSCEIT, Perceiving Emotions Branch (PE) (Mayer *et al.* 2002) | Branch score using general consensus scoring | 85.76 (11.08) |

BACS, Brief Assessment of Cognition in Schizophrenia; CPT, Continuous Performance Test; MSCEIT, Mayer-Salovey-Caruso Emotional Intelligence Test; NAB, Neuropsychological Assessment Battery; WAIS, Wechsler Adult Intelligence Scale; WMS, Wechsler Memory Scale.

[a] Included in the final 10-test MCCB.

Bayesian Information Criterion (BIC) and sample-size adjusted BIC (BIC$_{SA}$), in which the model with lower values is favored. All models were evaluated using model $\chi^2$ divided by df ($\chi^2$/df), in which lower values are preferred, as well as parsimony-adjusted fit indices root mean square error of approximation (RMSEA) and comparative fit index (CFI). For the RMSEA, varying recommendations for cut-points have been suggested, typically ranging from <0.05 to <0.10 (Hooper *et al.* 2008). For the CFI, values <0.90 suggest that the model could be substantially improved (Bentler & Bonett, 1980). Hu & Bentler (1999) recommend cut-off values close to 0.06 for RMSEA and 0.95 for CFI to reduce the number of misspecified models in the literature.

## Ethical standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

## Results

Descriptive data and bivariate correlations for all modified MCCB beta version tests are presented in Table 1 and online Supplementary Table S2.

Results of the CFA, including fit indices for the competing models, are presented in Table 2. The results of the $\Delta\chi^2$ tests for nested models are presented in Table 3. The single-factor solution, where all modified MCCB beta version indicators loaded onto a single general cognitive latent factor, provided a poor fit for the data (see Table 2, 'Single-factor'). The single-factor model was then compared to the three correlated factors solution (working memory, speed of processing, and all remaining tests). The 3-factor solution yielded

**Table 2.** *Confirmatory factor analysis results*

| Model | df (no. of est. parameters) | $\chi^2$ | $\chi^2$/df | AIC | $AIC_c$ | BIC | $BIC_{SA}$ | CFI | RMSEA (90% CI) |
|---|---|---|---|---|---|---|---|---|---|
| Nested | | | | | | | | | |
| Single-factor | 104 (32) | 508.69* | 4.89 | 572.69 | 546.98 | 689.12 | 516.22 | 0.82 | 0.12 (0.11–0.13) |
| 3-factor | 101 (35) | 447.04* | 4.43 | 517.04 | 489.76 | 644.38 | 517.04 | 0.84 | 0.11 (0.10–0.12) |
| Alternative model (5-factor) | 97 (39) | 333.89* | 3.44 | 411.89 | 382.72 | 553.79 | 411.89 | 0.89 | 0.09 (0.08–0.10) |
| 7-factor | 88 (48) | 255.56* | 2.90 | 351.56 | 318.96 | 526.20 | 351.56 | 0.93 | 0.08 (0.07–0.09) |
| Non-nested | | | | | | | | | |
| Hierarchical | 95 (41) | 358.30* | 3.77 | 440.30 | 410.27 | 589.47 | 440.30 | 0.88 | 0.10 (0.09–0.11) |

AIC, Akaike's Information Criterion; $AIC_c$, Corrected Akaike's Information Criterion; BIC, Bayesian Information Criterion; $BIC_{SA}$, sample-size adjusted Bayesian Information Criterion; CFI, comparative fit index; RMSEA, root mean square error of approximation.

*$p < 0.05$.

**Table 3.** $\chi^2$ *difference tests for nested models*

| Model | $\chi^2$ | df | Contrast | $\Delta\chi^2$ | $\Delta$df | $p$ |
|---|---|---|---|---|---|---|
| Single-factor | 508.69 | 104 | – | – | – | – |
| 3-factor | 447.04 | 101 | Single- *v.* 3-factor | 61.65 | 3 | <0.001 |
| Alternative model (5-factor) | 333.89 | 97 | 3- *v.* 5-factor | 113.15 | 4 | <0.001 |
| 7-factor | 255.56 | 88 | 5- *v.* 7-factor | 78.33 | 9 | <0.001 |

a significant increase in model fit over the single-factor solution [$\Delta\chi^2(3) = 61.65$, $p < 0.001$], but the fit was still relatively poor (see Table 2, '3-factor'). Next, we compared the 3-factor model to the seven correlated factors solution. For this model, latent factors with only two indicators were constrained so that the loadings were equivalent. The 7-factor solution further improved the model fit beyond the 3-factor solution [$\Delta\chi^2(13) = 191.48$, $p < 0.001$], and was a reasonable fit for the data, as the RMSEA is <0.10 and the CFI is >0.90 (see Table 2, '7-factor'; Fig. 2). Finally, a hierarchical model, with seven first-order factors loading onto a second-order general cognitive factor was fit to the data. The larger values for the information criterion-based fit indices (i.e. AIC, $AIC_c$, BIC, $BIC_{SA}$) for the hierarchical model, along with the poorer fit indices (see Table 2, 'Hierarchical'), demonstrate that addition of a general cognitive factor did not yield improved model fit over the seven correlated factors solution.

For the 7-factor model, high correlations were observed between working memory and verbal learning ($r = 0.94$), and between visual learning and verbal learning ($r = 0.96$), suggesting that these factors may be tapping into facets of a common memory construct. The 7-factor solution was re-specified to a nested model that contained five correlated factors: speed of processing, attention/vigilance, reasoning and problem solving, social cognition, and a memory factor encompassing indicators for working memory (i.e. digit span, letter-number span, spatial span), verbal learning (i.e. HVLT-R, daily living memory), and visual learning (BVMT-R, shape learning). The alternative model provided a reasonable fit (see Table 2, 'Alternative model'); however, the 7-factor solution remained a superior fit for the data [$\Delta\chi^2(9) = 78.33$, $p < 0.001$].

## Discussion

In this paper, we used CFA in a reasonably large sample of patients with schizophrenia to examine the factor structure of a modified beta version of the MCCB in which there were at least two measures per domain. Specifically, we compared four models that have been proposed in the schizophrenia literature and that vary in their complexity. These include: (1) a single-factor model, in which all cognitive tasks represent a single cognitive factor, (2) a correlated factors model in which three cognitive factors were modeled as separable but intercorrelated, (3) a correlated factors model in which seven cognitive domains were modeled as separable but intercorrelated, and (4) a hierarchical model in which seven cognitive domains were
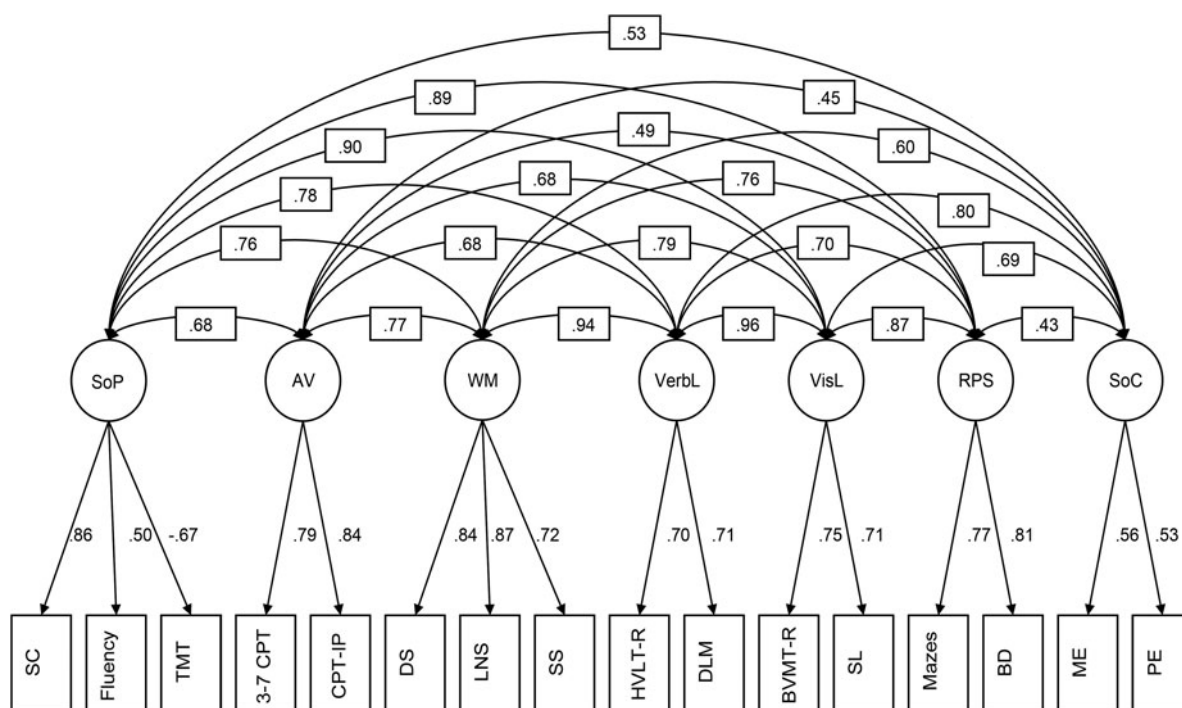
**Fig. 2.** Seven-factor model, standardized solution. SoP: Speed of Processing, AV: Attention & Vigilance, WM: Working Memory, VerbL: Verbal Learning, VisL: Visual Learning, RPS: Reasoning and Problem Solving, SoC: Social Cognition, SC: BACS Symbol Coding, Fluency: Category Fluency, TMT: Trail Making Test A, 3-7 CPT: 3-7 Continuous Performance Test, CPT-IP: Continuous Performance Test, Identical Pairs, DS: BACS Digit Sequencing, LNS: Maryland Letter-Number Span, SS: WAIS-III Spatial Span, HVLT-R: Hopkins Verbal Learning Test – Revised, DLM: NAB Daily Living Memory, BVMT-R: Benton Verbal Memory Test – Revised, SL: NAB Shape Learning, Mazes: NAB Mazes, BD: WAIS-III Block Design, ME: MSCEIT Managing Emotions, PE: MSCEIT Perceiving Emotions.

modeled as loading on a higher-order general cognitive factor. Our results best support a 7-factor model, which provided a better fit for the data than the other models. Further, collapsing the highly intercorrelated memory factors into a single factor resulted in a significant loss of model fit compared to the 7-factor solution.

These findings support the 7-factor model that guided development of the MCCB. A review of the factor analytic literature led to the inclusion of seven cognitive domains that were relevant to treatment studies in schizophrenia (Nuechterlein, *et al.* 2004). However, the existing factor analytic literature at that time was limited in that no single study had assessed all of the proposed factors. The factor analytic literature is larger now; however, conclusions about predominant factor structure in schizophrenia still vary.

Similar to previous CFA studies (Gladsjo *et al.* 2004; Ojeda *et al.* 2012; Schretlen *et al.* 2013), the single-factor solution provided a poor fit for our data. Although we found clear evidence for a 7-factor solution, other studies have supported models with a fewer number of factors or a hierarchical model. There are several

possible reasons for these discrepant findings, including the range of domains assessed and the number of measures included for each domain in a given study. For example, a recent CFA of nine of the 10 core MCCB tests supported a 3-factor solution that included processing speed, working memory/attention, and learning (Burton *et al.* 2013). In that study, six of the seven MCCB domains were represented and four of the six domains were assessed with a single test. CFA requires at least two indicators per factor for model identification (Bollen, 1989). In fact, the core MCCB with ten tests and seven factors is not well-suited for CFA without supplementary tests, as five of the seven domains are assessed by a single test.

In some ways, the hierarchical models are most intuitive and fit the common claim that impairment in schizophrenia exists at both the general and specific level. Previous studies supported the hierarchical model of cognition in schizophrenia (Dickinson *et al.* 2006, 2011). However, in the current analyses, the hierarchical model was comparable but not a superior fit for the data relative to the 7-factor model. In the papers that have compared hierarchical models to correlated factors

models in schizophrenia, the advantage of hierarchical models was typically slight and inconsistent across reported fit indices (Dickinson *et al.* 2006, 2011). In addition, the discrepant findings may be partly attributable to inclusion of social cognition indicators in the current analyses but not in the previous studies that supported a hierarchical model. For example, although associations among the non-social neurocognitive factors were moderate to large in magnitude, associations between social cognition and the remaining factors were somewhat weaker. This is congruent with the pattern of MCCB intercorrelations reported previously (August *et al.* 2012). There is growing evidence surrounding the separability of social and non-social cognition in schizophrenia (Allen *et al.* 2007; Sergi *et al.* 2007; Van Hooren *et al.* 2008; Williams *et al.* 2008; Bell *et al.* 2009; Hoe *et al.* 2012). Thus, the inclusion of tasks assessing social cognition in the current study may have contributed to the reduced fit of the hierarchical model in comparison to the 7-factor model.

One limitation of this study is the number of indicators. Although a minimum of two indicators per factor are required for model identification in CFA, it would be ideal to use three or more indicators per factor (Bollen, 1989). However, in studies of a severely impaired group such as schizophrenia patients, lengthy test batteries are associated with fatigue. In addition, although the current sample size is reasonably large, there were many estimated parameters, and a larger sample might have yielded a more stable solution with improved fit indices. In addition, a larger sample size would permit examination of more complex models (e.g. bifactor models), and consistency of model fit across different subgroups of patients (e.g. recent-onset *v.* chronic patients; entire sample *v.* schizophrenia only). Finally, since our list of alternative models was not exhaustive, it is possible that an untested model may provide a better fit for the data that the 7-factor model.

In conclusion, these analyses provide support for the 7-factor model of cognition in schizophrenia, and support the assessment of these cognitive dimensions in clinical trials of interventions to improve cognition in schizophrenia. Moreover, because these factors are separable to some degree, it is at least plausible that specific neuropharmacological or training-based interventions may impact some domains more than others. Although the 7-factor structure of cognition was evaluated in a large sample with schizophrenia in the current study, there is increasing evidence that similar models of cognitive structure apply to healthy samples and to bipolar disorder. Thus, schizophrenia patients may differ from the healthy population in having substantially poorer level of cognitive performance, while retaining a very similar cognitive structure.

## Supplementary material

For supplementary material accompanying this paper visit http://dx.doi.org/10.1017/S0033291715000641.

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