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Modality-Specific Working Memory Systems Verified by Clinical Working Memory Tests

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Objective: This study was to identify whether working memory (WM) can be clearly subdivided according to auditory and visual modality. To do this, we administered the most recent and universal clinical WM measures in a mixed psychiatric sample.
Methods: A total of 115 patients were diagnosed on the basis of DSM-IV diagnostic criteria and with MINI-Plus 5.0, a structured diagnostic interview. WM subtests of Korean version of Wechsler Adult Intelligence Scale-IV and Korean version of Wechsler Memory Scale-IV were administered to assess WM. Confirmatory factor analysis (CFA) was used to observe whether WM measures fit better to a one-factor or two-factor model.
Results: CFA results demonstrated that a two factor model fits the data better than one-factor model as expected.
Conclusion: Our study supports a modality model of WM, or the existence of modality-specific WM systems, and thus poses a clinical significance of assessing both auditory and visual WM tests.

KEY WORDS: Modality-specific working memory; WAIS-IV; WMS-IV.

INTRODUCTION

Working memory (WM) is a cognitive system that allows for transient storage and manipulation of given information.[1)] From a clinical perspective, WM is fairly important. Deficits in WM are reported in many psychiatric diseases as WM is deeply related to clinical symptoms, other complex cognitive functions, and activities of daily living.[2-5)]

WM model proposed by Baddeley[6-8)] is one of the most influential WM models and consists of two domain-specific systems and a domain-general system. Domain-specific systems were divided into phonological loop and visual-spatial sketchpad according to modalities of information and thus is often called as modality-specific systems. Each subsystem has separate and independent capacity-limited storage for temporal retention of verbal or visual-spatial information. However, the subsystems are not perfectly independent and are controlled by the central executive, a domain-general system.

In general, WM tests require the subjects to manipulate the given auditory or visual information all the while maintaining them. Clinicians frequently use psychometric tools such as WM subtests of Wechsler Intelligence or Memory Scales to measure WM capacity. Furthermore, recent versions of Wechsler Scales[9,10)] have placed greater emphasis on WM components than their predecessors. Auditory and visual WM tests were included separately in Wechsler Adult Intelligence Scale-IV (WAIS-IV)[9)] and Wechsler Memory Scale-IV (WMS-IV)[10)]. Routinely measuring both forms of WM is not recommended since they are strongly inter-correlated and functionally similar.[11)] Regardless, investigation is required to identify whether it is sufficient to only administer WM measures of a single modality. Therefore, our study is intended to investigate which of one or two factor model (OFM; TFM) fits better with WM test data from the newest versions of Wechsler Scales in a heterogeneous psychiatric sample. We predicted that WM has modality distinctive constructs (i.e.,

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possible TFM).

METHODS

Participants

Participants were psychiatric out- and in-patients aged 19 to 60 years who visited Hallym University Sacred Heart Hospital from November 2015 through October 2016. Patients were diagnosed by psychiatrists based on the Diagnostic and Statistical Manual of Mental Disorders 4th edition (DSM-IV)[12] diagnostic criteria. A structured diagnostic interview, MINI International Neuropsychiatric Interview Plus 5.0 (MINI-Plus 5.0),[13,14] and psychological tests were conducted by clinical psychology trainees under the supervision of a licensed clinical psychologist. Patients with physical disabilities or other severe medical conditions were excluded from the study, ultimately resulting in a total of 115 participants. Patients' demographic characteristics are presented in Table 1. Written patient consent and research approval by Hallym University Sacred Heat Hospital institutional review board were obtained (IRB No. 2015-I097).

Measures

WM subtests of Korean version of WAIS-IV (K-WAIS-IV)[15] were administered to assess auditory WM: digit span and letter number sequencing (LNS). Each sub-scores of digit span test (forward, backward, and sequential) was coded separately for statistical analysis. WM subtests of Korean version of WMS-IV (K-WMS-IV)[16] were administered to assess visual WM. Spatial addition is required to maintain and manipulate spatial information, while symbol span is required to maintain and manipulate visual details.

Statistical Analysis

Expectation-maximization algorithm[17] was conducted to replace missing data. The estimates of parameters were obtained using maximum likelihood methods. Confirmatory factor analysis (CFA) tested whether psychometric tasks developed to measure WM fit better to OFM or TFM in a mixed clinical sample. Various indices were used to evaluate model fit.[18,19] The χ^2 test was utilized to assess the fit of hypothetical models to the sample data. If χ^2 value is small and its significance is more than 0.10, it indicates good fit. However, since χ^2 statistics is sensitive to sample size, additional indices were to be considered. Our study used Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), Tucker-Lewis Index (TLI), and Standardized Root Mean Square Residual (SRMR) as alterative indices. Hu and Bentler[18] suggested that RMSEA <0.06, CFI >0.95, TLI >0.95, and SRMR <0.08 indicate good fit for continuous data. IBM SPSS version 20.0 and IBM SPSS AMOS version 22.0 (IBM Co., Armonk, NY, USA) were used for data analysis.

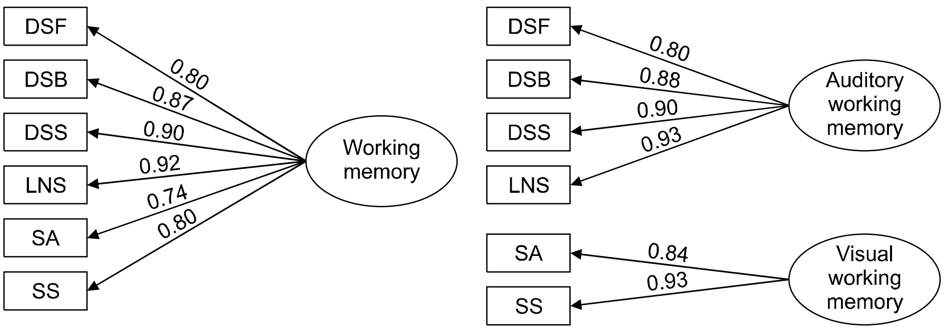
RESULTS

OFM tested the fit of an overall WM factor that encompassed all obtained WM tests. If OFM demonstrated good fit, all measurements may represent the same or unitary construct of WM. Correlated TFM tested whether two WM factors can be separated by modality yet related to each other. The results are presented in Figure 1. In our sample, TFM showed good fit in all fit indices whereas OFM showed good fit in only a few. Furthermore, TFM revealed a significantly better fit to our data than did OFM; χ^2-difference (1)=6.23, $p<0.05$. In short, our result shows that two modalities of WM tests are related to each

Table 1. Demographic information

Charcateristic	Gender (F%)	Education (yr)	Age (yr)
Schizophrenia (n=18)	72.222	12.278±2.653	30.444±11.868
Major depressive disorder (n=39)	33.333	13.000±1.821	27.667±11.577
Bipolar disorder (n=6)	33.333	13.000±5.292	28.333±13.604
Anxiety disorder (n=24)	33.333	14.210±2.377	32.667±14.095
Developmental disorder (n=13) (mental retardation, autism)	38.462	10.408±3.250	28.231±12.050
Neurocognitive disorder (n=10)	20.000	11.400±4.881	43.800±16.457
Others (n=5)	20.000	13.400±1.950	23.400±4.615
Total (n=115)	33.913	12.870±3.002	30.461±13.1751

Values are presented as mean±standard deviation.



	x^2 (p)	df	RMSEA	TLI	CFI	SRMR
One-factor model	*39.104 (0.001)*	9	0.171	0.913	0.948	0.016
Two-factor model	*6.535 (0.588)*	8	0.001	1.005	1.000	0.046

Fig. 1. Confirmatory factor analysis of Korean version of Wechsler Adult Intelligence Scale-IV and Korean version of Wechsler Memory Scale-IV working memory subtests. In the figure, the circles represent latent constructs, and the squares represent the observed variables. Single-headed arrows represent standardized factor loadings and double-headed arrows represent correlations between factors. All parameter estimates are standardized and significant at $p<0.001$.
DSF, digit span forward; DSB, digit span backward; DSS, digit span sequencing; LNS, letter number sequencing; SA, spatial addition; SS, symbol span; df, degree of freedom; RMSEA, Root Mean Square Error of Approximation; TLI, Tucker-Lewis; CFI, Comparative Fit Index; SRMR, Standardized Root Mean Square Residual.

other (r=0.84, $p<0.001$) but measure independent constructs.

DISCUSSION

This study was conducted to examine whether WM can be subdivided by modality using the most current and universal clinical WM measures in a mixed sample of psychiatric patients. CFA results demonstrated that TFM fits the data better than OFM as we had expected. This suggests that there are separate and independent WM stores for auditory and visuospatial information, and supports modality-specific WM systems, ultimately posing clinical significance of assessing both auditory and visual WM tests.

Our study also supports a modality model of WM. The results are in line with previous research that showed WM is divisible by modality.[20-23] Many clinicians have mainly utilized auditory WM tests rather than visual WM tests unless special cases required them to do without the auditory WM tests.[11] However, given our results, clinicians should be cautious when deriving generalized conclusions of WM from a single modality of WM; administering both WM modalities may be more desirable and informative in the clinical setting. Particularly, doing so is important for not only neurological diseases with unilateral lesions but also language disorders, non-verbal learning disorders, and attention deficit hyperactivity disorder with domain-specific impairments.[23,24] Although a previous study that used CFA on WAIS-IV and WMS-IV, supported both OFM and TFM,[25] the study had used a normal standardized sample and included arithmetic but not LNS as a variable reflecting WM construct. These differences may have contributed to the discordant results.

To test the models in CFA, we replaced arithmetic, a core WM subtest, with LNS, a supplemental WM subtest. LNS is considered as the best predictor of WM among other clinical WM measures[20,25] and, with respect to the most recently published Wechsler Intelligence Scale for Children, fifth edition (WISC-V),[26] LNS along with digit span is a core subtest to make up auditory WM index and arithmetic comprises quantitative reasoning index. On the other hand, existing studies have found arithmetic subtest requires diverse cognitive processes such as attention/concentration, verbal comprehension, and mathematical skills as well as WM.[25,27] It also has the lowest factor loading among clinical WM constructs.[28]

Additionally, our findings revealed how well each WM measures represent its corresponding construct of WM. LNS was the best measure of its WM construct in both OFM and TFM. This endorses the assertion by Shelton *et al.*[28] that LNS is the best clinical WM test and has processing demands most comparable to those of laboratory WM tests. Digit span sequencing (DSS) has factor loading higher than digit span forward (DSF) but similar to digit span backward (DSB). It is consistent with the finding that DSB and DSS similarly require more WM capacity than DSF.[11] However, Egeland[20] argued that the difference in processing levels among these three sub-tasks are not sufficient to distinguish between passive storage and active executive processing. If this holds true, these sub-tasks might be limited to detect task-specific performance patterns in clinical groups. Further study is required to investigate whether this reflects insufficient differences in WM load, or the tasks being different from what they were originally intended to measure, or the characteristics of the clinical sample. Although visual WM subtests of WMS-IV well represent the construct of visual WM, symbol span seems slightly better to reflect the construct and have slightly higher WM load than spatial addition. However, replication by additional empirical research is necessary.

This study also has some limitations. The study found only content dimension (i.e., modality), not functional dimensions (i.e., storage and processing) of clinical WM tests suggested by Baddeley's model. Also, since the study data is based on various diagnostic groups, the interpretation and generalization of our results may be limited; cross-validation in other types of clinical groups or healthy controls is needed.

In summary, present study has an important clinical implication in that, by demonstrating modality-specific properties of clinical WM tests in a mixed clinical group, it serves as a wake-up call for clinicians who make a hasty decision for deficits in WM based on only single modality of WM measures.

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