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The Role of Processing Speed in the Brief Visuospatial Memory Test - Revised

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Abstract

The Brief Visuospatial Memory Test - Revised (BVMT-R) is a commonly used, commercialized, assessment tool to measure visuospatial learning and memory abilities across research and clinical settings. In this study, we evaluated the influence of processing speed and executive functioning on BVMT-R learning, memory, and percent retention scores. One-hundred and forty-one cognitively healthy older adults completed the BVMT-R along with measures of visuoconstructional abilities (BVMT-R copy), speeded processing (Symbol Digit Modalities Test-oral), and executive function (FAS). After controlling for age and visuoconstructional abilities, hierarchical regression models showed that the processing speed measure was a unique predictor of both BVMT-R learning and memory performances, while the executive function measure was not. The visuoconstructional measure was the only unique predictor of BVMT-R percent retention. The findings suggest that when interpreting the BVMT-R learning and memory scores of patients who exhibit speeded processing deficits, the impact of slowed processing speed on performance should be considered.

Keywords

BVMT-R; visuospatial memory; speed of processing; executive function

The Brief Visuospatial Memory Test - Revised (BVMT-R) has been commonly used to evaluate visuospatial memory abilities in neuropsychological populations. Several neurocognitive batteries, including those for assessment of individuals with multiple sclerosis (Benedict et al., 2006), schizophrenia (Green et al., 2004; Nuechterlein & Green, 2006), and bipolar disorder (Yatham et al., 2010), recommend that the BVMT-R be used for evaluation of visual learning and memory. The BVMT-R has also demonstrated sensitivity to visuospatial learning and memory difficulties in individuals with traumatic brain injury (Benedict & Groninger, 1995; Morey, Cilo, Berry, & Cusick, 2003), sports-related concussions (Field, Collins, Lovell, & Maroon, 2003), HIV infection (Woods et al., 2006), and Parkinson's disease (Foster et al., 2010). Concomitantly, it is not uncommon for individuals with these disorders to experience slowed processing speed (e.g., DeLuca, Chelune, Tulsky, Lengenfelder, & Chiaravalloti, 2004; Johnson et al., 2003; Madigan, DeLuca, Diamond, Tramontano, & Averill, 2000; Saccuzzo & Braff, 1981). Given the short exposure duration of the BVMT-R stimuli and its sensitivity to conditions that are characterized by slowed processing speed, this study aims to evaluate the role of processing speed in BVMT-R performance.

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In the current revised version of the BVMT, a visual display of six simple figures arranged in a 2 × 3 matrix on an 8 × 11 booklet is shown to participants for three consecutive 10-second trials. After each trial, participants are to draw as many designs as accurately as they can and in the correct location. They are again asked to reproduce the designs in the exact layout after a 25-minute delay filled with other distractor tasks. A forced-choice recognition trial is administered immediately following the delayed memory trial. An optional copy trial is included at the end of the test where the participants are asked to copy the figure display as accurately as they can. Scoring of the immediate and delayed recall as well as copy trials are based on the accuracy of the drawings and the location of the figures. For each figure, one point is awarded to each satisfactory domain resulting in a maximum of 12-points per trial (Benedict, 1997).

Compared to the original version, the augmentation of the scoring system to award points for both accuracy and placement of each figure as well as the inclusion of additional learning trials increased the test's sensitivity to detect impairment (Benedict, Schretlen, Groninger, Dobraski, & Shpritz, 1996). The revised test also provides indexes of learning and recognition as well as six alternate forms with good reliability and validity. The BVMT-R differs from other visual learning and memory tests (e.g., Rey-Osterrieth Complex figure Test or Rey-O and Visual Reproduction on the Wechsler Memory Scale) in that a learning index over three trials is available. In addition, individuals are given 10 seconds to process six figures as compared to the insignificant time constraint on the Rey-O and the 10 seconds to look at a single design in Visual Reproduction. According to Benedict et al. (1996), given the same time limit, viewing multiple designs rather than just one figure could result in participants having to rely more on visual memory as opposed to using verbal mediation. However, given the 10 second time restriction for displaying the six figures, poor performances on the BVMT-R may reflect not only visuospatial memory difficulties, but also slower speed of processing as individuals may not be able to fully process all of the figures in the time available. While the optional copy trial allows clinicians to identify visuoconstructional difficulties that may impact BVMT-R performance, it may also be important to consider the impact of slower processing speed on BVMT-R learning and memory performance.

In this study, after controlling for age, we evaluated the impact of processing speed on BVMT-R performance in a cognitively healthy older adult population. Prior studies have demonstrated that processing speed can predict verbal learning and memory performances and attenuate age-related memory deficits in cognitively healthy populations (e.g., Salthouse & Coon, 1993; Sliwinski & Buschke, 1997). A recent study, which investigated both processing speed and executive functioning as potential mediators of age-related variation in episodic memory, found that processing speed had a stronger mediational effect than executive function (Lee at el., 2012). This pattern held true for both a composite general memory measure and for verbal and visual memory measures. In this study, the measure of visual memory was the number of correct designs recognized from the Benton Visual Retention Test. In another recent study examining visual working memory abilities in older adults (Brown, Brockmole, Gow, & Deary, 2012), even after controlling for childhood intelligence (i.e., IQ at age 11), measures of processing speed were found to account for greater variance in visual working memory performance than measures of executive function. The authors hypothesized that either a slower speed of encoding and/or a slower rate of rehearsal might lead to poorer visual working memory performance with age.

While processing speed has been implicated as a factor that can affect memory performance, to our knowledge, the impact of processing speed on BVMT-R performances has not been evaluated. Given the sensitivity of the BVMT-R to detecting visuospatial learning and memory difficulties in populations that typically experience speeded processing deficits, this is an important question. Participants in this study were older adults who completed the BVMT-R in addition to tests assessing speeded processing (Symbol Digit Modalities Test; SDMT; Smith, 1991) and executive functioning (Letter Fluency subtest; FAS; Delis, Kaplan & Kramer, 2001). Rather than looking at the mediational effects of processing speed on age-related changes in visuospatial learning and memory, we were interested in whether processing speed deficits would impact BVMT-R performance even after controlling for age and visuoconstructional ability (i.e., BVMT-R Copy Trial). We hypothesized that speeded processing abilities would significantly predict the BVMT-R learning trial score given the 10 second visual display presentation rate. We expected that the influence of speeded processes on the BVMT-R delayed memory score would be less given that an individual's ability to hold information in memory over a time delay would also significantly influence their BVMT-R delayed memory performance. We did not expect that speeded processing would significantly impact the percent of information retained after it was encoded (i.e., BVMT-R percent retention score). In addition, executive functioning was not expected to be a significant predictor of BVMT-R performance after controlling for age and visuoconstructional ability.

Method

Participants and Procedures

From a sample of 163 healthy older adults, 141 older adults served as participants in this study (105 females, 36 males; age range 50–91 years old; see Table 1). Five participants with a history of stroke and seven individuals who reported visual impairments (i.e., blurred vision, double vision, reduced visual field, or >40/20 on the Snellen chart) were excluded from the sample. Of the remaining 10 participants removed, one failed to meet the inclusion criteria (i.e. Clinical Dementia Rating > 0; CDR; Hughes, Berg, Danzinger, Coben, & Martin, 1982; Morris, 1993), seven did not complete the BVMT-R, and two participants did not complete the SDMT. Participants were recruited as part of a larger study examining the relationship between cognitive functioning and everyday functional status (see Schmitter-Edgecombe, Parsey, and Cook, 2011). They were recruited through local advertisements, community health fairs, and presentations to senior communities. Prospective participants completed an initial telephone screening, which consisted of a medical interview, the Telephone Interview for Cognitive Status (TICS; Brandt & Folstein, 2003), and the CDR. Individuals who reported a history of head trauma resulting in permanent brain lesion, history of cardiovascular accidents, current or recent (within the last year) psychoactive substance abuse, known medical, neurological, and/or psychiatric disorders that may alter cognitive functioning (e.g. schizophrenia, epilepsy), and significant memory complaints or changes in cognition (according to individual and/or collateral source) were excluded from the study. All healthy older adults in this study did not meet the exclusion criteria, demonstrated generally normal global cognitive functioning (TICS > 27), and lacked evidence of questionable dementia (CDR = 0) or severe depression (GDS < 18; Yesavage et al., 1983).

Participants completed a three-hour battery of standardized and experimental neuropsychological tests conducted in a laboratory setting. At the end of the study, participants received a report outlining the results on the neuropsychological tests. Data included in this paper were collected as part of that battery. For those who traveled from outside of Whitman or Latah County, a $50 voucher was given as travel reimbursement. This study was approved by the Institutional Review Board at WSU.

Measures

Non-Cognitive risk factors—Information regarding individuals' age, gender, and level of education were obtained though the initial screening interview. The number of depressive symptoms endorsed by the participants was measured using the Geriatric Depressive Symptom scale (Yesavage et al., 1983).

Cognitive Test Variables—As part of the neuropsychological test battery, participants were administered the BVMT-R. They were also administered tests that evaluated the following cognitive domains: speed of processing, visuospatial constructional skills, and executive functioning. Because neuropsychological tests are not process pure, analyses were conducted with both single tests that exemplified each cognitive domain and with composite measures. With one exception, the analyses revealed a similar pattern of findings regardless of whether single or composite measures were utilized. Because the neuropsychological tests that made up the composites for visuospatial constructional skills and executive functioning were not highly correlated, we chose to use the single tests in the primary analyses and report the results from the composite measures in a footnote.

Visuospatial Learning, Memory & Retention: The BVMT-R learning total (aggregate of the three consecutive learning trials) and the 25-minute delayed recall trial were used as the measures of visuospatial learning and memory, respectively. Percent retention was the percentage of delayed recall raw score over the higher raw score from the second or third immediate recall trial.

Speed of processing: The SDMT was used in this study as an index of processing speed, as it has been demonstrated that the Digit Symbol Substitution test is primarily a test of processing speed (Salthouse, 1992a). The total correct score from the oral subtest was used in the analyses to eliminate motor-related effects on test performances that may be present in the written subtest (e.g. arthritis).

Visuoconstructional skills: The raw score from the copy trial of the BVMT-R was used as the primary measure of visuoperceptual abilities. This measure is commonly used clinically to identify visuoconstructional difficulties that may impact BVMT-R performance.

Executive Functions: The total number of correct words produced for the letters F, A, and S was used as the measure of executive functioning. Letter fluency measures have been widely used and accepted as a measure of central executive function (e.g., Lezak, Howieson, & Loring, 2004; Stuss et al., 1998).

Results

Correlations among demographic, predictor, and dependent variables

Because there was a larger percentage of female participants in the study sample (74%), t-tests were first conducted to evaluate for possible gender differences on the demographic (education and depression), predictor (age, SDMT-oral, BVMT-R copy, FAS), and dependent variables (BVMT-R learning, memory, and retention scores). Male participants (M = 17.72, SD = 2.64) reported achieving a higher level of education than female participants (M = 16.20, SD = 2.72), $t(139) = -2.92$, $p = .004$. However, there were no gender differences found for the predictor variables, $ts(139) = -0.45 - 0.10$, $p > .66$, or the dependent variables, $ts(139) = -0.36 - 0.60$, $p > .71$. In addition, there was no difference between the number of depressive symptoms endorsed by the male and female participants, $t(132) = 1.46$, $p = .15$. We therefore did not consider gender as a predictor in the regression analyses.

Pearson's correlations were then computed to evaluate the relationship between demographic variables, predictor variables, and the dependent variables. Raw scores were used in the correlational analyses as well as all subsequent statistical analyses, unless otherwise specified. As shown in Table 2, age was moderately correlated with the BVMT-R learning and memory measures. Age, BVMT-R learning, BVMT-R memory, and the executive functioning measure (i.e., FAS) all significantly correlated with the speeded processing measure (i.e., SDMT-oral). In addition, BVMT-R copy correlated with the BVMT-R learning, memory, and percent retention scores.

Regression Analyses: BVMT-R learning, memory, and percent retention

Hierarchical regressions were performed to determine the role of processing speed in BVMT-R learning and memory performance as well as percent retention. Age was entered in the first block of the regression analysis, as slowing in speeded processing is a ubiquitous finding in the aging literature (e.g. Salthouse, 1991; Salthouse, 1992b). No other demographic factors (i.e., education, depression) were entered into the regression equations because they did not correlate significantly with the predictor or dependent variables (see Table 2). The BVMT-R copy trial was entered in Block 2 to control for visuospatial constructional abilities. The measures of speeded processing (SDMT-oral) and executive functioning (FAS) were then entered simultaneously in Block 3. The Variance Inflation Factors for the four predictor variables were less than 1.44, indicating no significant multicollinearity among the predictor variables.

As seen in Table 3, results from the three-step regression model evaluating the influence of processing speed on BVMT-R learning showed that the processing speed (SDMT-oral) and executive functioning (FAS) measures accounted for significant variance over and above that accounted for by age and the BVMT-R copy score, $\Delta F(2, 136) = 4.78$, $p = .01$. However, while SDMT-oral was a unique predictor of BVMT-R learning along with age and BVMT-R copy, FAS was not.

Similarly, the regression model for BVMT-R memory showed that speed of processing and executive functioning accounted for significant variance in BVMT-R memory over and above that accounted for by age and visuospatial constructional skills, $\Delta F(2, 136) = 3.11$, $p < .05$. Again, with the exception of the executive functioning measure (FAS), all predictor variables were unique predictors of BVMT-R memory performance (see Table 3).

In contrast, the regression analyses for percent retention demonstrated that the BVMT-R copy raw score accounted for significant variance over and above age, $\Delta F(1, 138) = 22.19$, $p < .001$, with almost no additional variance accounted for by the speeded processing and executive variables, $\Delta F(2, 136) = .58$, $p = .56$. Only BVMT-R copy was a unique predictor of percent retention.[1]

[1]Composite measures of processing speed (SDMT-oral, SDMT-written, and inverted Trails A), visuoconstructional skills (BVMT-R copy trial and Clox2), and executive functions (FAS, D-KEFS Category switching, D-KEFS Design Fluency) were formed as the average of the Z-scores of the component tests. The SDMT-oral raw score correlated significantly with the SDMT-written score ($r = .86$, $p < .001$) and Trails A ($r = -.48$, $p < .001$). BVMT-R copy and Clox2 raw scores were not correlated ($r = .13$, $p = .13$). The D-KEFS letter fluency raw score (FAS) correlated significantly with D-KEFS Design Fluency total correct ($r = .19$, $p = .02$), but not with the D-KEFS Category Fluency switching score ($r = .14$, $p = .09$). With the exception of the visuoconstructional composite score not being a significant unique predictor of BVMT-R learning, the pattern of findings was identical to that found with the single test scores. For BVMT-R learning, age ($\beta = -.34$, $t = -3.76$, $p < .001$) and the processing speed composite ($\beta = .31$, $t = 3.21$, $p = .002$) were significant predictors. Age ($\beta = -.28$, $t = -3.13$, $p = .002$), the processing speed composite ($\beta = .29$, $t = 3.2$, $p = .003$), and the visuoconstructional composite ($\beta = .21$, $t = 2.90$, $p = .004$) were unique predictors of BVMT-R memory. Only the visuoconstructional composite score ($\beta = .25$, $t = 3.02$, $p = .003$) was a unique predictor of BVMT-R percent retention. The executive functioning composite score was not a unique predictor for any of the BVMT-R memory measures.

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Discussion

The BVMT-R has been widely used in neuropsychological evaluations to assess visuospatial learning and memory. This assessment tool is designed to measure immediate visual learning and delayed visual memory as well as recognition. In addition, a copy trial is available for qualitative observation of possible visuoconstructional deficits. In this study, we investigated whether processing speed deficits should also be considered when interpreting BVMT-R performance in a healthy older adult population.

Consistent with prior research (e.g., Brown et al., 2012; Foster et al., 2010), correlational analyses showed a significant relationship between processing speed and BVMT-R learning and memory performances as well as age. More specifically, a slower processing speed was associated with poorer learning and memory performance on the BVMT-R and with higher age. Despite the strong correlation between age and speeded processing, we found that processing speed was a significant predictor of both BVMT-R learning and memory scores even after controlling for both age and visuoconstructional abilities. In contrast, executive functioning, which along with processing speed has been hypothesized to be an important contributing factor to age-related cognitive decline (e.g., Perrotin, Isingrini, Souchay, Clarys, & Taconnat, 2006; West, 1996) and to memory performance (e.g. Duff, Schoenberg, Scott, & Adams, 2005), did not emerge as a significant predictor of BVMT-R learning or memory performance. This suggests some specificity of the speed-BVMT-R association.

The findings also suggest that when interpreting the BVMT-R learning and memory scores of patients exhibiting speeded processing deficits, the impact of slowed processing speed on performance should be considered. A slowed speed of processing could reduce the number of BVMT-R figures that an individual might be able to encode and/or rehearse into memory, subsequently impacting raw learning and memory scores given the 10 second presentation rate of the six-figure stimulus. As hypothesized, processing speed was not found to be a significant predictor of the BVMT-R percent retention score. This is consistent with the supposition that once information has been successfully encoded into memory, processing speed would not be expected to significantly impact later retention of the learned information. Future research is needed to determine whether the BVMT-R percent retention score provides accurate information about ability to successfully retain learned visuospatial information over a time delay, in individuals who demonstrate slowed speeded processing but intact visuoconstructional abilities. Of note, while the percentage of learned visuospatial information retained across the 25 minute delay was not found to be predicted by either age or speed of processing, visuoconstructional performance (measured by the BVMT-R copy) was found to be a significant predictor. The BVMT-R copy score was also found to be a significant predictor of the BVMT-R learning and memory score. This is consistent with the BVMT-R copy trial being used clinically to identify visuoconstructional difficulties that could impact BVMT-R performance.

In patients with Multiple Sclerosis (MS), amongst the measures of the Minimal Assessment of Cognitive Function in MS battery, the BVMT-R and the SDMT (Rao adaptation) have demonstrated the largest effects for differentiating between MS and normal controls (Benedict et al., 2006). These measures have also been found to be useful in assessing children and adolescents with MS (Smerbeck et al., 2011). Given that slowed speeded processing is common in patients with MS, it is possible that part of the sensitivity of the BVMT-R measure in distinguishing between MS and normal controls results from the 10 second time limit imposed for encoding the figures. Future research is needed to evaluate the role that slowed processing speed may play in the BVMT-R performance of MS patients, and other populations that typically demonstrate slowed processing speed (e.g., traumatic brain injury).

The findings from this study need to be generalized cautiously. Our sample consisted of highly educated healthy older adults who were predominantly female Caucasians and highly educated. The lack of diversity in our sample may have contributed to the non-significant correlation between BVMT-R performance and education. In addition, a limited number of predictors were considered under each cognitive domain, thus, restricting the extent to which the current findings can be applied to other tests of the same construct. There was also overlap in some of the test components used to measure the separate cognitive domains. For example, the measure of processing speed (i.e. SDMT-oral) used in this study also required spatial processing, which partially overlaps with visuoconstructional ability (i.e. BVMT-R copy trial). This overlap, however, made it more difficult for us to demonstrate the relationship between speeded processing and BVMT-R learning and memory performances. Future research utilizing different predictors of the same cognitive constructs or different cognitive constructs with clinical populations is needed to further understand the impact and specificity of slowed speed of processing on BVMT-R visuospatial learning and memory scores.

In summary, we evaluated the role of processing speed in visuospatial learning and memory after controlling for age and visuospatial constructional abilities in healthy older adults. Our data showed that speed of processing significantly impacted performance on the BVMT-R. More importantly, the data suggest that slowed processing speed should be considered when interpreting BVMT-R learning and delayed memory performances as deficient.

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Table 1

Participant Demographic Data and Mean Summary Data

	Healthy Older Adults (N=141)	
	Mean	**SD**
Demographics		
Age (years)	67.04	9.86
Education (years)	16.59	2.78
Gender	105f, 36m	--
GDS	1.60[a]	1.85
Tests		
SDMT written total	50.33	9.30
SDMT oral total	57.60	10.34
D-KEFS FAS	43.03	11.30
BVMT-R learning	23.64	5.25
BVMT-R delayed recall	9.72	2.10
BVMT-R percent retained	95.86	11.75
BVMT-R copy trial	11.77	0.62

Note. All mean scores are raw scores unless otherwise indicated. GDS = Geriatric Depression Scale; SDMT = Symbol Digit Modalities Test; D-KEFS = Delis-Kaplan Executive Function System; BVMT-R = Brief Visuospatial Memory Test - Revised.

[a] n = 134.

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Table 2

Correlations Among Demographic and Predictive Variables and Dependent Variables

	1	2	3	4	5	6	7	8	9
1. BVMT-R learning	---								
2. BVMT-R memory	.79**	---							
3. BVMT-R % ret	.31**	.70**	---						
4. Age	−.52**	−.48**	−.21*	---					
5. Education	.13	.10	.04	−.05	---				
6. Depression	.02	.07	.09	−.07	−.06	---			
7. SDMT-oral	.46**	.39**	.17*	−.54**	.16	.04	---		
8. BVMT-R copy	.23*	.36**	.39**	−.11	.02	.14	.05	---	
9. D-KEFS FAS	.09	.01	−.07	−.07	.15	.13	.25*	.01	---

Note. BVMT-R = Brief Visuospatial Memory Test - Revised; % ret = percent retention; SDMT = Symbol Digit Modalities Test, D-KEFS = Delis-Kaplan Executive Function System.

* $p < .05$.

** $p < .001$.

Table 3

Hierarchical Multiple Regression Analyses Predicting BVMT-R Learning, Memory, and Percent Retention from Age, Visuoconstructional Abilities, Speed of Processing, and Executive Functioning

	BVMT-R performance					
	BVMT-R Learning		BVMT-R Memory		BVMT-R Percent Retention	
Predictor	ΔR^2	β	ΔR^2	β	ΔR^2	β
Model 1	.27**		.23**		.05*	
Age		−0.52**		−0.47**		−0.21*
Model 2	.03*		.10**		.13**	
Age		−0.50**		−0.44**		−0.17*
BVMT-R copy		0.18*		0.31**		0.37**
Model 3	.05*		.03*		.01	
Age		−0.36**		−0.33**		−0.12
BVMT-R copy		0.18*		0.31**		0.37**
SDMT-O		0.25**		0.21*		0 .10
D-KEFS FAS		0.01		−0.07		−0.05
N	141		141		141	

Note. BVMT-R = Brief Visuospatial Memory Test - Revised; SDMT-O = Symbol Digit Modalities Test, Oral subtest; D-KEFS = Delis-Kaplan Executive Function System.

* $p < .05$.

** $p < .005$.