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Validity and Normative Data for the Biber Figure Learning Test: A Visual Supraspan Memory Measure

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Abstract

The Biber Figure Learning Test (BFLT), a visuospatial serial figure learning test, was evaluated for biological correlates and psychometric properties, and normative data were generated.

Nondemented individuals ($n = 332$, 73 ± 7 , 41% female) from the Vanderbilt Memory & Aging Project completed a comprehensive neuropsychological protocol. Adjusted regression models related BFLT indices to structural brain magnetic resonance imaging and cerebrospinal fluid (CSF) markers of brain health. Regression-based normative data were generated. Lower BFLT performances (Total Learning, Delayed Recall, Recognition) related to smaller medial temporal lobe volumes and higher CSF tau concentrations but not CSF amyloid. BFLT indices were most strongly correlated with other measures of verbal and nonverbal memory and visuospatial skills. The BFLT provides a comprehensive assessment of all aspects of visuospatial learning and memory and is sensitive to biomarkers of unhealthy brain aging. Enhanced normative data enriches the clinical utility of this visual serial figure learning test for use with older adults.

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Keywords

episodic memory; visual memory; normative data; aging; regression-based normative data

Alzheimer's disease (AD) is a major public health issue, and early diagnosis is critical to managing disease burden. As such, neuropsychological assessment, specifically episodic learning and memory, is an integral component for early and accurate diagnosis of AD (Karantzoulis & Galvin, 2011). Clinically, AD is often characterized by an insidious decline in episodic memory, particularly in the early phases of illness. Serial verbal list-learning tests (Brandt, 2001; Delis, Kramer, Kaplan, & Ober, 2000) have demonstrated great utility in early detection of AD because they assess key constructs underlying memory and learning, including encoding, rate of acquisition, retrieval, and susceptibility to proactive and retroactive interference (Albert et al., 2011). Examples of such verbal supraspan tests include the California Verbal Learning Test–Second edition (CVLT-II; Delis et al., 2000), the Rey Auditory Verbal Learning Test (Tierney et al., 1994), the Hopkins Verbal Learning Test–Revised (Brandt, 2001), and the Philadelphia Verbal Learning Test (Price et al., 2009).

Surprisingly, a nonverbal analogue to these verbal list-learning tests is lacking given the number of commonly used tools to assess aspects of visual encoding, retrieval, and memory. While each measure is valuable in assessing some aspects of visual learning and memory, no single tool provides a full assessment of episodic memory constructs that are essential to define cognitive impairment. For example, common visual measures, such as Rey–Osterrieth Complex Figure Test (Osterrieth, 1944; Rey, 1941), Wechsler Memory Scale Visual Reproduction (Wechsler, 2009), or Benton Visual Retention Test (BVRT; Sivan, 1992) assess memory using a single exposure or learning trial, limiting measurement of learning (acquisition). While tests such as the Brief Visuospatial Memory Test–Revised (Benedict, Schretlen, Groninger, Dobraski, & Shpritz, 1996) and the Visual Spatial Learning Test (Malec, Ivnik, & Hinkeldey, 1991) include presentation of material over several learning trials, neither tool assesses vulnerability to proactive or retroactive interference through the introduction of a distractor trial. Assessing this vulnerability may be important to detecting early cognitive decline, as proactive interference on verbal episodic tests is highly sensitive to the emerging clinical symptoms of a dementia (Loewenstein, Acevedo, Agron, & Duara, 2007) due to temporal lobe pathology (Bartko, Cowell, Winters, Bussey, & Saksida, 2010). In some cases, normative information for recognition test performance is lacking. Thus, while several visual learning and memory tools are available for clinical implementation, their varied methodologies do not permit a comprehensive assessment of well-known constructs underlying episodic memory, including encoding, retrieval, recognition, and susceptibility to interference. Furthermore, the existing visual memory tests generally preclude direct comparison with existing verbal supraspan tests.

The Biber Figure Learning Test (BFLT) is a visuospatial serial figure learning test designed to assess key components underlying episodic memory (Glosser, Goodglass, & Biber, 1989). It was modelled after supraspan tests (Delis et al., 2000; Delis, Kramer, Kaplan, & Ober, 1987) and Rey's (1968) visuospatial task, and was originally developed as a 10-item memory test (Glosser et al., 1989). The BFLT Extended Version (Glosser, Cole, Khatri,

DellaPietra, & Kaplan, 2002) is composed of five Immediate Free Recall Learning trials of 15 nonfamiliar geometric shapes of moderate visual complexity, an interference condition that presents a new list of 15 items (Distractor Trial), Short and Long Delay Free Recall trials for the original 15 items, and a Recognition trial that includes the original items, interference items, and new test items.

The BFLT offers several advantages over other available visual memory tools. First, it is a visuospatial analogue to verbal list-learning tasks, such as the CVLT-II, with indices capturing encoding/rate of acquisition, retrieval, susceptibility to proactive and retroactive interference, and recognition test performance. Thus, when used together, these tools provide parallel information to inform the potential presence of modality-specific memory impairment. Second, the BFLT has an alternate test form for repeat administration needs. Third, the BFLT includes an abbreviated 10-item version to accommodate patients suspected of more compromised neuropsychological function, such as dementia (Glosser et al., 1989; Glosser et al., 2002). Collectively, the BFLT provides an opportunity to comprehensively assess specific visual episodic modalities using a format consistent with a verbal serial list-learning paradigm, making the BFLT potentially more useful than many widely used visual memory tools.

Despite the BFLT's potential clinical utility, the test has not been widely used. Foremost, the validity of this visuospatial memory test is not well delineated. Establishing a link between BFLT indices and markers of unhealthy brain aging, including AD, such as amyloid, neurodegeneration, and white matter disease is essential to demonstrating the utility and validity of this test in older adult populations. Existing BFLT data have been restricted to individuals with epilepsy or non-AD amnesic syndromes implicating medial temporal lobe and subcortical-limbic pathways (Glosser et al., 1989), particularly within the right hemisphere (Glosser et al., 2002). Similarly, establishing evidence of convergent and discriminant validity with other neuropsychological measures is needed. Second, there is a lack of comprehensive normative data; existing normative data are restricted to a few dozen individuals (Glosser et al., 1989) with minimal consideration of how important demographic variables, such as age, sex, education, and race/ethnicity may confound performance (Norman, Evans, Miller, & Heaton, 2000)."

Leveraging a community-based sample, this study has several objectives. First, we aim to examine the biological correlates of the BFLT, hypothesizing that BFLT indices would relate to markers of unhealthy brain aging, including amyloid pathology assessed by cerebrospinal fluid (CSF) amyloid β 42 (A β 42; Mandecka et al., 2016), neurodegeneration measured by hippocampal volume on brain magnetic resonance imaging (MRI) and inferior lateral ventricle volume on brain MRI with a preferential association in the right hemisphere (Glosser et al., 2002; Lange, Waked, Kirshblum, & DeLuca, 2000), and CSF tau (Mandecka et al., 2016; Murphy et al., 2010; Wolk & Dickerson, 2011), as well as white matter disease/axonal integrity as measured by white matter hyperintensities (WMHs) on brain MRI and CSF neurofilament light (NFL; Lee et al., 2016; Zetterberg et al., 2016). Second, we will test associations between the BFLT and other neuropsychological tests, hypothesizing BFLT indices will correlate most strongly with tests assessing verbal learning and memory (Benedict et al., 1996) and visuospatial and executive function (Jefferson et al., 2006), but

not language (Meyers & Meyers, 1995). Last, we provide regression-based normative data accounting for demographic variables that often confound cognitive performance including age, sex, race/ethnicity, and education (Glosser et al., 1989; Norman et al., 2000). These efforts will enhance the BFLT's utilization as a more valuable tool in the assessment of visuospatial serial figure learning in older adults.

Method

Participants

Participant data were drawn from the Vanderbilt Memory & Aging Project (Jefferson et al., 2016), a longitudinal observational study investigating vascular health and unhealthy brain aging. Participants were recruited through postal mailings, radio advertisements, newsletters, research distribution e-mails, community events, websites, and word of mouth. Inclusion required participants be aged 60 years or older, speak English, have adequate auditory and visual acuity for testing purposes, and have a reliable study partner defined as someone the participant has known for a minimum of 2 years, with weekly contact, and knowledge of the participant's cognitive and functional abilities. At eligibility, participants underwent medical history and record review, clinical interview with the participant and their informant using the Clinical Dementia Rating (CDR; Morris, 1993) and Functional Activities Questionnaire (Pfeffer, Kurosaki, Harrah, Chance, & Filos, 1982), and a comprehensive neuropsychological protocol assessing multiple cognitive systems. Collectively, this information was used by a consensus team to determine each participant's cognitive diagnosis, which includes the following:

1. Cognitively normal participants (NC): Defined as (a) CDR = 0 (no dementia), (b) no deficits in activities of daily living directly attributable to cognitive impairment, and (c) no evidence of neuropsychological impairment defined as standard scores falling within 1.5 standard deviations of the age-adjusted normative mean.
2. Early mild cognitive impairment (MCI): Defined as (a) CDR = 0.5 (reflecting mild severity of impairment), (b) no deficits in activities of daily living attributable to cognitive issues, and (c) no neuropsychological impairment defined as standard scores falling within 1.5 standard deviations of the age-adjusted normative mean (Aisen et al., 2010).
3. MCI: Defined as (a) CDR = 0 or 0.5 (b) relatively spared activities of daily living; (c) neuropsychological impairment within at least one cognitive domain (i.e., performances falling greater than 1.5 standard deviations outside the age-adjusted normative mean or premorbid level of functioning); (d) concern of a cognitive change by the participant, informant, or clinician; and (e) absence of a dementing syndrome (Albert et al., 2011).

Participants were excluded for a diagnosis other than normal cognition, early MCI, or MCI, history of neurological disease (e.g., dementia, multiple sclerosis, stroke); heart failure, major psychiatric illness (e.g., bipolar disorder, schizophrenia, history of severe and/or current major depressive episode); head injury with loss of consciousness >5 minutes; and

systemic or terminal illness that could affect the ability to participate in follow-up examinations. Ultimately, this study enrolled 335 community-dwelling individuals aged 60 years to 92 years. The Vanderbilt University Medical Center Institutional Review Board approved the protocol. Written informed consent was obtained from all participants prior to data collection.

Neuropsychological Assessment

As part of the study enrollment visit, participants completed a neuropsychological protocol assessing multiple cognitive systems. Note, this protocol was different than what was used for eligibility determination and cognitive diagnosis at study entry. The BFLT methods are described in the introduction above and require about 30 minutes for total administration. As noted, BFLT administration includes presentation of 15 target items over 5 learning trials with 15 novel distractor items presented as an interference condition. Each figure is composed of two component shapes with the possible score for each figure ranging from 0 to 3: one point per accurate reproduction of each shape and one point for accurately orienting the shapes in relation to each other. Indices analyzed in the current study include Trial 1 Learning, Trial 2 Learning, Trial 3 Learning, Trial 4 Learning, Trial 5 Learning, Trials 1 to 5 Total Learning, Distractor Trial (Trial B), Short Delay Free Recall, Long Delay Free Recall (following a 20-minute filled delay), Long Delay Recognition Measures (including Recognition Total Correct, Distractor Trial False Alarms, Novel False Alarms, Total False Alarms, Long Delay Recognition Total Discrimination) calculated as follows: $([\text{Recognition Total Correct} + 0.5]/16) - ([\text{Total False Alarms} + 0.5]/31)$, Total Repetitions, Total Intrusions, Proactive Interference (Trial B – Trial 1), and Retroactive Interference (Short Delay Free Recall – Trial 5). See Table 1 for a more detailed description of these indices and information regarding the remaining measures in the neuropsychological protocol.

Brain MRI

Participants were scanned at the Vanderbilt University Institute of Imaging Science on a 3T Philips Achieva system (Best, The Netherlands) with 8-channel SENSE reception (Pruessmann, Weiger, Scheidegger, & Boesiger, 1999). T1-weighted MPRAGE (isotropic spatial resolution = 1 mm) images were postprocessed for tissue volume quantification using Multi-Atlas Segmentation (Asman & Landman, 2012). Specific regions of interest included hippocampal volume and inferior lateral ventricle volume measured within each hemisphere. Intracranial volume (ICV) was defined using voxel-based morphometry in SPM8 (<http://www.fil.ion.ucl.ac.uk/spm/software/spm8/>). T2-weighted fluid-attenuated inversion recovery was acquired for quantification of WMH and postprocessed using the Lesion Segmentation Tool for SPM8 (Schmidt et al., 2012) excluding cerebellum and brainstem. Manual corrections were then made by a board-certified neuroradiologist using the Medical Image Processing, Analysis, and Visualization application (<http://mipav.cit.nih.gov>).

Cerebrospinal Fluid Acquisition

A subset of individuals (155 participants) completed an optional morning fasting lumbar puncture. CSF was collected with polypropylene syringes using a Sprotte 25-gauge spinal needle in the L3/L4 or L4/L5 intervertebral lumbar space. Samples were immediately mixed

and centrifuged, and supernatants were aliquoted in 0.5 mL polypropylene tubes and stored at -80°C . Samples were analyzed in batch using commercially available enzyme-linked immunosorbent assays (Fujirebio, Ghent, Belgium) to determine the levels of A β 1–42 (INNOTEST® β -AMYLOID_(1–42)), total tau (INNOTEST® hTAU), and tau phosphorylated at threonine 181 (P-tau; INNOTEST® PHOSPHO-TAU_(181P)). NFL was measured using a commercially available ELISA (UmanDiagnostics). Processing was completed by board-certified laboratory technicians who were blinded to clinical information (Palmqvist et al., 2014). Intraassay coefficients of variation were <10%.

Statistical Analysis

Descriptive statistics for participant characteristics including age, sex, race/ethnicity, education, mood (assessed with Geriatric Depression Scale [GDS] total score; Yesavage et al., 1983), CSF levels, brain MRI variables, and neuropsychological performances are presented in Table 2. To assess construct validity, linear regression related selected BFLT indices (Total Learning Trials 1–5, Short Delay Recall, Long Delay Recall, Total Discrimination, Proactive Interference, Retroactive Interference) to markers of unhealthy brain aging adjusting for age, sex, education, race/ethnicity, and diagnosis in the entire cohort. Specifically, we assessed amyloidosis (CSF A β 42), neurodegeneration (CSF tau, CSF P-tau, hippocampal volume, inferior lateral ventricle volume), and white matter disease (WMH, CSF, NFL). WMH values were log-transformed due to nonnormal distributions. Models analyzing brain volume outcomes additionally adjusted for ICV. To assess the added benefit of the BFLT beyond existing visual memory tasks, we also related BVRT Total Score to all markers of unhealthy brain aging. The diagnostic accuracy of the selected BFLT variables and BVRT to differentiate NC from any cognitive impairment (NC vs. Early MCI and MCI) was assessed with receiver operating characteristic (ROC) analysis and area under the curve (AUC) with the optimal cutoff determined at the maximum sum of sensitivity and specificity on ROC curve. Convergent and discriminant validity were assessed in the NC subsample using Spearman's rank correlation coefficients to relate selected BFLT indices with other neuropsychological variables and GDS total score adjusting for global cognition (Montreal Cognitive Assessment [MoCA] total score; see Table 1 for a comprehensive list of measures). Regression-based normative data of the above selected BFLT indices was generated from the NC subgroup using multiple regression analyses adjusting for age, sex, education, and race/ethnicity. The raw score on the selected BFLT indices were used as outcomes. Sex was coded as male = 0, female = 1, and race/ethnicity was coded as White/Non-Hispanic = 0, Non-White/Hispanic = 1. Age and education in years were treated as continuous variables. Multicollinearity was assessed by calculating variance inflation factors (VIFs) and residuals plots were visually inspected for goodness of fit. Intercepts, beta-coefficients, and the root mean square error for each model were presented for calculation of a predicted BFLT performance value using the following equation (see Equation 1):

$$\begin{aligned} \text{Predicted score} = & \beta_0(\text{intercept}) + \beta_{\text{age}} \times \text{age (actual age in years)} + \beta_{\text{sex}} \\ & \times \text{sex (0 = male, 1 = female)} + \beta_{\text{race/ethnicity}} \times \text{race} \\ & / \text{ethnicity (0 = White/non-Hispanic, 1 = non-White/Hispanic)} \\ & + \beta_{\text{education}} \times \text{education (years of education completed)} \end{aligned} \quad (1)$$

To calculate a z-score normative value, the predicted score calculated in Equation 1 was used within the following equation (see Equation 2; Shirk et al., 2011):

$$z \text{ score} = (\text{observed score} - \text{predicted score}) / \text{root mean square error} \quad (2)$$

Significance was set a priori at $p < .05$. All analyses were conducted using R 3.4.3 (www.r-project.org).

Results

Participant Characteristics

The participants included in this study comprised 332 participants with an age range of 60 to 92 years (73 ± 7) and an education range of 7 to 20 years (16 ± 3). Approximately half (52%, $n = 174$) of individuals had normal cognition, 41% were women and 86% self-declared as White/non-Hispanic. Global cognition, as assessed by the MoCA, ranged from 14 to 30 (25.4 ± 3.3). Table 2 contains full details on participant characteristics, brain volumes, CSF levels, and neuropsychological performances.

Normative data analyses included only NC participants, representing a subsample of 174 individuals with an age range of 60 to 92 years (72 ± 7) and 41% women. A majority of NC participants self-declared as White/non-Hispanic (87%) with an education range of 10 to 20 years (16 ± 3). MoCA scores ranged from 17 to 30 (27.0 ± 2.2). See Table 2 for full details on NC participant characteristics and Table 3 for neuropsychological performances.

BFLT and Biomarkers of Brain Health

Amyloidosis.—None of the examined BFLT indices were associated with CSF A β 42 values (all $p > .12$; see Table 4).

Neurodegeneration.—Worse performance on all BFLT indices were related to CSF markers thought to represent neurodegeneration, including higher T-tau ($p < .01$) and P-tau levels ($p < .02$). Similarly, in adjusted models (including ICV), lower scores on all BFLT variables were related to smaller left hippocampal volume ($p < .001$) and larger left inferior lateral ventricle volume ($p < .03$). Only BFLT Short Delay Free Recall and Long Delay Free Recall were positively associated with right hippocampal volume ($p < .01$). Only BFLT Long Delay Total Discrimination was negatively associated with right inferior lateral ventricle volume ($p = .004$; see Table 4).

White Matter Disease.—None of the BFLT indices were related to WMH volume (all $p > .14$; see Table 4) in adjusted models (including ICV).

BVRT and Biomarkers of Brain Health

BVRT Total Score related to WMH volume in adjusted models (including ICV; $p = .02$), but not to any other brain MRI marker of neurodegeneration or CSF measure of amyloidosis, neurodegeneration, or white matter disease (all $p > .08$; see Table 4).

Visuospatial Memory Indices and Diagnostic Discrimination

ROC analysis and inspection of AUC values for the BFLT indices revealed the majority of BFLT indices had very good discrimination between diagnostic groups with AUC greater than 0.8. BFLT Total Learning had the largest AUC (AUC = 0.84, 95% confidence interval [CI: 0.80, 0.88]) with an optimal cut-off score of 116.5. BFLT Short Delay Free recall (AUC = 0.82, 95% CI [0.78, 0.87]; cut-off score 28.5), BFLT Long Delay Free Recall (AUC = 0.82, 95% CI [0.78, 0.87]; cut-off score 30.5), and BFLT Long Delay Total Discrimination (AUC = 0.82, 95% CI [0.77, 0.86]; cut-off score 0.60) had nearly equivalent discrimination. BFLT Proactive Interference (AUC = 0.59, 95% CI [0.53, 0.65]; optimal cut-off score -3.5) and BFLT Retroactive Interference (AUC = 0.54, 95% CI [0.48, 0.60]; optimal cut-off score -1.5) had similar classification abilities. BVRT total score had lower discrimination than the majority of BFLT indices with an AUC of 0.77 (95% CI [0.72, 0.82]) at an optimal cut-off score of 5.5.

BFLT Correlations With Other Cognitive Measures

Global Cognition.—MoCA performance was moderately correlated with all BFLT indices ($r = .43-.54$; all $p < .001$; see Table 5).

Verbal Learning and Memory.—Adjusting for global cognition, CVLT-II Total Learning (Trials 1–5), Short Delay Free Recall, Long Delay Free Recall, and Recognition Total Discrimination correlated with all selected BFLT indices ($p < .002$; see Table 5).

Visuospatial Learning and Memory.—Adjusting for global cognition, BVRT Total Score correlated with most BFLT indices ($p < .001$) except BFLT Recognition Total Discrimination ($p = .05$; see Table 5).

Visuospatial Abilities.—Adjusting for global cognition, Wechsler Adult Intelligence Scale–Fourth edition (WAIS-IV) Block Design correlated with all BFLT indices ($p < .01$; see Table 5). Hooper Visual Organization Test (Hooper, 1983) performance was related to all selected BFLT indices ($p < .01$). See Table 5 for full details.

Language.—Adjusting for global cognition, both Boston Naming Test (30-item; $p < .003$) and Category Fluency ($p < .02$) performances were correlated with all BFLT indices. See Table 5 for full details.

Attention/Information Processing Speed.—Adjusting for global cognition, Delis–Kaplan Executive Functioning System (DKEFS) Number Sequencing Test was related to most BFLT indices ($p < .02$) except for BFLT Total Learning and Recognition Total Discrimination ($p > .28$). WAIS-IV Coding performance related to most BFLT indices ($p < .001$) except BFLT Recognition Total Discrimination ($p = .06$). See Table 5 for full details.

Executive Functioning.—Adjusting for global cognition, DKEFS Tower Test ($p < .01$) and Letter Fluency ($p < .002$) performances were related to most BFLT indices except BFLT Recognition Total Discrimination ($p > .08$). DKEFS Number–Letter Switching Test was related only to BFLT Short Delay Free Recall and Long Delay Free Recall ($p < .01$) and

DKEFS Color–Word Interference Test Inhibition performance was related only to BFLT Total Learning ($p = .049$). See Table 5 for full details.

Mood.—Adjusting for global cognition, GDS was unrelated to all BFLT indices (all $p > .09$). See Table 5 for details.

BFLT Regression-Based Normative Data

Review of VIF revealed no multicollinearity between predictor and demographic variables (all $VIF < 1.11$). The residual plots against predicted values did not reveal any systematic patterns, suggesting sufficient goodness of fit. Means, intercepts, and regression coefficients are presented in Table 6 for transforming raw scores into demographically adjusted z scores using Equations 1 and 2 in the Statistical Analysis section.

For illustrative purposes, normative data for BFLT Total Learning is calculated for an individual with the following demographics: 75-year-old female, White/non-Hispanic, with 16 years of education with a BFLT Total Learning score of 130. Using Equation 1, the predicted score is calculated as follows:

$$223.7 \text{ (BFLT Total Learning intercept)} + -1.79 \times 75 \text{ (BFLT Total Learning } \beta_{\text{age}} \times \text{actual age)} + 12.78 \times 1 \text{ (BFLT Total Learning } \beta_{\text{sex}} \times 1 = \text{female)} + -10.30 \times 0 \text{ (BFLT Total Learning } \beta_{\text{race/ethnicity}} \times 0 = \text{White/non-Hispanic)} + 2.26 \times 16 \text{ (BFLT Total Learning } \beta_{\text{education}} \times \# \text{ years of education completed)} = \text{predicted score of } 138.39.$$

To calculate a normative value with an obtained score of 130, Equation 2 is used:

$$130 \text{ (observed score)} - 138.39 \text{ (predicted score)} / 27.25 \text{ (root mean square error for BFLT Total Learning)} = z \text{ score of } -0.31.$$

Discussion

The BFLT is a visuospatial serial figure learning test that allows for comprehensive assessment of visual learning and memory and offers advantages to existing visual memory tests. This study aimed to improve the clinical utility of the BFLT among older adults by demonstrating the test's psychometric properties, including validity. Specifically, BFLT performances were broadly related to CSF tau and medial temporal lobe brain volumes, but minimal associations with CSF amyloid or markers of white matter disease (WMH or CSF NFL) were observed. Conversely, another common visuospatial memory task (BVRT) related to WMH but was unrelated to all other brain MRI markers of atrophy or CSF markers of amyloid, tau, and axonal damage. BFLT Total Learning, Short Delay Free Recall, Long Delay Free Recall, and Discrimination all provided strong classification properties for differentiating NC from MCI. Furthermore, compared with other neuropsychological tests, BFLT indices correlated most strongly with measures of verbal and visuospatial learning and memory and visuospatial performances, with more modest associations with information processing and executive functioning, as expected. BFLT was also unexpectedly related to language tests. These associations were notable after adjusting for global cognition. To

further maximize the measure's usefulness, regression-based normative data are provided with adjustments for common demographic confounds.

The current results suggest that performance on the BFLT is related to medial temporal lobe structures involved in successful learning and memory. These structures include the hippocampus and surrounding perirhinal areas critical for the formation of new memories (Fell et al., 2001). These regions have been linked with performance on verbal supraspan episodic memory tests (Wolk & Dickerson, 2011) and existing visual memory tests (Buffalo, Reber, & Squire, 1998). However, performance on BVRT was not related to these same structures. The current results are among the first to highlight the construct validity of the BFLT to measure integrity of learning and memory structures and suggest that the BFLT is reflective of underlying neuroanatomy, a pattern not observed with another commonly used visuospatial memory task.

In addition to structural evidence of neurodegeneration, the BFLT was associated with CSF tau levels, both T-tau reflecting neurodegeneration and P-tau that is hypothesized to reflect tau pathology, but not amyloidosis or white matter disease. Early patterns of atrophy seen on brain MRI are most notable within the medial temporal lobe (Convit et al., 2000), including the hippocampus (Fox et al., 1996) and inferior lateral ventricles (Thompson et al., 2004) because this region is the first to be affected by AD pathology. Tau deposition begins in the entorhinal cortex, spreading to the hippocampus and surrounding medial temporal regions (Braak & Braak, 1991; Duyckaerts, Delatour, & Potier, 2009), resulting in axonal loss and neurodegeneration. Tau deposition levels and brain volume loss are thought to be closely related (Fjell et al., 2010) and represent disease or symptom severity (Blennow, 2004). Additionally, tau correlates with objective cognitive performance (Samgard et al., 2010), including episodic memory (Fjell et al., 2008), often more closely than markers of amyloidosis (Brier et al., 2016). This lack of association between cognitive performance and amyloid burden has been demonstrated previously (Vemuri et al., 2009) and may be related to the temporal cascade of AD pathology with amyloid being hypothesized to deposit well before substantial loss of neuronal integrity (reflected by CSF tau) and subsequent cognitive changes (Han et al., 2012; Ingelsson et al., 2004; Negash, Bennett, Wilson, Schneider, & Arnold, 2011). Taken cumulatively, the BFLT may be an important tool to assess for underlying neurodegenerative disorders offering support for its inclusion in assessment protocols given the notable advantages to other similar metrics.

The stronger association between BFLT indices and regions within the left medial temporal lobe as compared with the right was somewhat unexpected given earlier work linking the right medial temporal lobe with BFLT performances in epilepsy or non-AD related amnesic syndromes (Glosser et al., 1989; Glosser et al., 2002). However, this discrepant finding may be related to differing methodology given the previous results did not include any neuroimaging analyses and focused on clinical presentation of epilepsy patients. The current finding highlights the importance of left medial temporal lobe integrity for visual memory tasks, an observation supported by a functional MRI study linking activation in the left hippocampus to visual memory (Ranganath, Cohen, Dam, & D'Esposito, 2004). Alternatively, the right hippocampus may be integral in encoding/recalling information regarding spatial navigation or location (Burgess, Maguire, & O'Keefe, 2002; Kesner,

Bolland, & Dakis, 1993), a component of visuospatial memory and processing that is less essential to successful BFLT performance. Notably, the current findings suggest bilateral hippocampal integrity for retrieval of visual information, consistent with a recent meta-analysis implicating both the right and left hippocampus in retrieval of visual information (Lepage, Habib, & Tulving, 1998). The preferential association with the left hemisphere in encoding visual information provides additional evidence that individuals often utilize verbal strategies to encode visual material, even non-meaningful visual information, thus employing left hemisphere regions. Alternatively, the preferential association observed within the left medial temporal lobe could be a reflection of the cohort and sample, given the inclusion of individuals with amnesic MCI who may be more likely to have left-predominant neurodegeneration.

Surprisingly, there was a paucity of associations between BFLT indices and white matter disease. These null associations were unexpected given the noted association between BVRT and WMH and existing link between white matter disease and verbal memory, including supraspan paradigms analogous to the BFLT (Kennedy & Raz, 2009). Also, BFLT performance was related to measures of information processing speed and executive functioning, cognitive domains that are often closely correlated with WMH burden (Madden, Bennett, & Song, 2009; Prins et al., 2005). The null findings could be due to the inclusion of NC in the analyses as well as the low prevalence of cardiovascular disease across the entire sample. The observed association between BVRT and WMH could be related to the reliance of working memory and attention on the BVRT (Le Carret et al., 2003), cognitive abilities heavily reliant on white matter integrity (Charlton et al., 2006; Tullberg et al., 2004; Ylikoski et al., 1993).

BFLT was related to verbal memory and visuospatial performances as measured by other popular tools (Benton, 1974; Delis et al., 2000). Similarly, BFLT correlated with executive function performances, an expected finding given the executive demands of the BFLT and existing support linking visuospatial abilities with executive skills. Prior research has suggested that executive functions, such as the capability to monitor and switch between the target and distractor set of stimuli and the ability to organize the geometric shapes into accurate designs, is important during visuospatial tasks (Jefferson et al., 2006; Libon et al., 1994). Unexpectedly, BFLT was related to language performances possibly because individuals with more intact language abilities utilize verbal cues or assign common object descriptions or verbal labels to the BFLT design stimuli as a tool for successfully remembering design details (Schacter, Cooper, & Delaney, 1990). This idea is supported by our finding that BFLT performance appeared preferentially related to left hemisphere medial temporal lobe functioning and suggesting that successful performance on BFLT indices relies on integrity of brain regions also important for language abilities.

Advancing age was related to poorer performance on all BFLT indices, consistent with previous research linking increasing age with declines in verbal memory (Gunning-Dixon & Raz, 2003; Norman et al., 2000) and visual retention (Coman et al., 1999). Sex, race/ethnicity, and education were inconsistently related to the various BFLT indices, although results are aligned with previous research suggesting better cognitive performance is related to more years of education, female sex, and White/non-Hispanic ethnicity (Norman et al.,

2000). Given these potential demographic confounds on task performance, the regression-based normative data provided here incorporate all of these demographic factors, allowing for more robust generation of normative data. Additionally, the sample size of 174 well-characterized, cognitively normal, adults aged 60 to 92 years represents an improvement to the existing normative data, facilitating more widespread clinical use of the BFLT.

The current study has several strengths. First, the extensive phenotyping of cognitive status for all enrolled participants included a CDR interview with the participant and a reliable informant, medical record and health history review, comprehensive neuropsychological protocol, and consensus decision for diagnostic status by experienced clinicians. Second, the comprehensive neuropsychological protocol examined in the current methods (which was separate from the protocol used to diagnose and enroll participants as NC) encompassed multiple cognitive domains, permitting detailed comparisons between BFLT and other cognitive task performances. Third, the normative sample size of the current study ($n = 174$), use of regression norms considering multiple demographic confounders, and examination of specific indices and cutoffs that differentiate normal from impaired cognition enhances the one existing BFLT normative data report (Glosser et al., 2002). Fourth, the correlation data with other common neuropsychological tests, including an analogous verbal supraspan test, also provide context for interpreting underlying BFLT impairments in a comprehensive clinical evaluation. Last, this study is the first linking the BFLT to biological markers of brain health to assess the measure's validity.

Despite these strengths, there are several limitations. First, aspects of the cohort could limit the generalizability of the findings. For example, the sample is predominantly White with a mean college education level. Similarly, the inclusion and exclusion criteria associated with enrollment into the Vanderbilt Memory & Aging Project, including minimal cardiovascular disease and specific geographic location may limit generalized applicability. Second, the current study includes a smaller sample size in comparison with previous normative research with other learning and memory tests (Fine, Kramer, Lui, Yaffe, & Study of Osteoporotic Fractures Research Group, 2012; Gallassi et al., 2014). However, regression-based normative procedures require smaller samples sizes than traditional-based normative procedures (Oosterhuis, van der Ark, & Sijtsma, 2016), and this study represents an initial and more comprehensive approach. Last, the normative data presented are inclusive of older adults, limiting the use of this tool in younger adults. Future research should examine performances in younger and middle-age adults.

Overall, our findings provide novel information about the BFLT to enhance the clinical utility of this visuospatial serial figure learning test. The BFLT measures brain health and integrity through the assessment of multiple aspects of learning and memory, including learning or rate of acquisition, encoding or storage, retrieval, recognition, and freedom from interference. Results suggest the BFLT has good psychometric properties and regression-based normative data based on age, sex, education, and race/ethnicity are provided. The BFLT relates to medial temporal lobe integrity and may be sensitive to emerging pathology in older adults, offering advantages to other existing visuospatial memory measures. These results support and enhance the clinical utility of this promising visuospatial memory test.

Further work is needed linking BFLT performance to longitudinal change in markers of pathology.

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Table 1.

Neuropsychological Protocol.

Domain	Test	Description	Range
Global cognition	Montreal Cognitive Assessment (Nasreddine et al., 2005)	Measures global cognitive status	0–30
Episodic learning and memory	<i>Biber Figure Learning Test (BFLT; Glosser et al., 1989; Glosser et al., 2002)</i>		
	BFLT Total Learning (Trials 1–5)	Assesses learning for a set of 15 geometric designs across 5 trials	0–225
	BFLT Distractor Trial (Trial B)	Assesses interference of learning a similar, novel set of 15 geometric designs	0–45
	BFLT Short Delay Free Recall	Assesses immediate free recall for a set of 15 geometric designs following 5 learning trials and presentation of a 15-item Distractor Trial (without reexposure to the original 15 test items)	0–45
	BFLT Long Delay Free Recall	Assesses delayed recall for a set of 15 geometric designs following a 20-minute filled delay	0–45
	BFLT Long Delay Recognition Total Correct	Total number of correctly recognized geometric designs following a 20-minute filled delay	0–15
	BFLT Long Delay Recognition Distractor Trial False Alarms	Number of Distractor Trial geometric designs endorsed following a 20-minute filled delay	0–7
	BFLT Long Delay Recognition Novel False Alarms	Number of novel geometric designs endorsed following a 20-minute filled delay	0–23
	BFLT Long Delay Recognition Total False Alarms	Total number of nontarget geometric designs recognized following a 20-minute filled delay	0–30
	BFLT Long Delay Recognition Total Discrimination	Assesses ability to discriminate the list of 15 geometric designs from Distractor and nontarget designs after a 20-minute filled delay using the following formula: $([\text{Recognition Total Correct} + 0.5]/16) - ([\text{Total False Alarms} + 0.5]/31)$	–30–15
	BFLT Repetitions	Total number of geometric designs repeated during Total Learning (Trials 1–5), Distractor Trial, Short Delay Recall, Long Delay Recall	n/a
	BFLT Intrusions	Total number of nontarget geometric designs endorsed during Total Learning (Trials 1–5), Distractor Trial, Short Delay Recall, Long Delay Recall	n/a
	BFLT Proactive Interference	Assesses how prior learning impairs retention of new information (Trial B–Trial 1)	–45–45
	BFLT Retroactive Interference	Assesses how novel learning impairs retention of prior learning (Short Delay Free Recall–Trial 5)	–45–45
	<i>California Verbal Learning Test–Second edition (CVLT-II; Delis et al., 2000)</i>		
	CVLT-II Total Learning (Trials 1–5)	Assesses learning for a list of 16 words across 5 trials	0–80
	CVLT-II Short Delay Free Recall	Assesses Short Delay Free Recall for a list of 16 words following 5 learning trials and presentation of a 16-item Distractor Trial (without reexposure to the original 16 test items)	0–16
	CVLT-II Long Delay Free Recall	Assesses delayed free recall for a list of 16 words after a 20-minute filled delay	0–16
	CVLT-II Recognition Total Discrimination	Assesses ability to recognize the list of 16 words from related and nonrelated nontarget words after a 20-minute filled delay	–4–4
	Benton Visual Retention Test–Fifth edition (BVRT-V; Benton, 1974) Administration A Form C*	Assesses immediate visual memory for 10 designs presented for 10 seconds before reproducing them	0–10

Domain	Test	Description	Range
Visuospatial skills	Wechsler Adult Intelligence Scale–Fourth Edition Block Design (WAIS-IV; Wechsler, 2008) *	Assesses the ability to visuospatial organization and construction	0–66
	Hooper Visual Organization Test (HVOT; Hooper, 1983)	Measures proficiency of object recognition	0–30
Language	Boston Naming Test-30 Item (even items; Kaplan, Goodglass, & Weintraub, 1983)	Assesses confrontation naming and lexical retrieval abilities	0–30
	Category Fluency (animal naming; Goodglass & Kaplan, 1983)	Measures rapid word generation in 60 seconds based on a specified category	n/a
Information processing	DKEFS Trail Making Test Number Sequencing (Delis, Kaplan, & Kramer, 2001) [‡]	Measures visual scanning and attention in a number sequencing task	0–150
	WAIS-IV Coding (Wechsler, 2008)	Speeded measure assessing psychomotor, attention, and processing speed	0–93
Executive functioning	DKEFS Tower Test (Delis et al., 2001)	Measures planning and problem solving abilities	0–30
	DKEFS Color–Word Interference Test Inhibition (Delis et al., 2001) [‡]	Measures inhibition involving suppression of an automatic response in favor of a novel response	0–180
	DKEFS Trail Making Test Number–Letter Switching (Delis et al., 2001) [‡]	Measures sequencing and mental flexibility in a number and letter set-shifting task	0–240
	Letter Fluency (Controlled Oral Word Association; Benton, Hamsher, & Sivan, 1994)	Measures rapid word generation based on a specified letter across three trials (F, A, and S), each lasting 60 seconds	n/a
Mood	Geriatric Depression Scale (GDS)-30 Item (Yesavage et al., 1983)	Assesses symptoms of depressed mood	0–30
Estimated premorbid intelligence	Wide Range Achievement Test–Third edition (WRAT-3) Reading Subtest (Wilkinson, 1993) *	Measures reading for words with irregular sound-to-spelling correspondence	0–57

Note. DKEFS = Delis–Kaplan Executive Function System; n/a = not applicable.

* Measure administered at the eligibility visit. All other tests administered at enrollment visit.

[‡]Speeded test where time to completion is the outcome and higher score denotes worse performance.

Table 2.**Participant Characteristics.**

	NC	Early MCI	MCI	Combined sample	<i>p</i>
Sample size	174	27	131	332	—
Demographic characteristics					
Age, years	72 ± 7	73 ± 6	73 ± 8	73 ± 7	.66
Sex, % female	41	26	44	41	.24
Race, % White/non-Hispanic	87	85	85	86	.88
Education, years	16 ± 3	16 ± 3	15 ± 3	16 ± 3	<.001 ^{*,§,¶}
Biber Figure Learning Test performances					
Trial 1	14.4 ± 5.4	11.1 ± 5.2	8.6 ± 5.4	11.8 ± 6.1	<.001 ^{*,†,§,¶}
Trial 2	24.4 ± 6.8	18.4 ± 7.1	14.2 ± 6.9	19.9 ± 8.4	<.001 ^{*,†,§,¶}
Trial 3	29.4 ± 7.3	23.9 ± 6.9	17.9 ± 7.7	24.4 ± 9.2	<.001 ^{*,†,§,¶}
Trial 4	32.5 ± 7.3	27.2 ± 6.2	19.8 ± 8.3	27.1 ± 9.7	<.001 ^{*,†,§,¶}
Trial 5	34.5 ± 7.1	29.4 ± 5.9	21.8 ± 9.4	29.1 ± 10.0	<.001 ^{*,†,§,¶}
Total Learning (Trials 1–5)	135 ± 31	110 ± 28	82 ± 35	112 ± 41	<.001 ^{*,†,§,¶}
Distractor Trial (Trial B)	11.7 ± 5.8	8.9 ± 4.8	7.3 ± 4.8	9.7 ± 5.7	<.001 ^{*,†,§}
Short Delay Free Recall	31.2 ± 8.1	26.3 ± 6.2	17.6 ± 9.8	25.4 ± 10.8	<.001 ^{*,†,§,¶}
Long Delay Free Recall	32.5 ± 7.6	28.0 ± 6.6	19.1 ± 9.9	26.8 ± 10.6	<.001 ^{*,†,§,¶}
Long Delay Recognition–Hits	14.0 ± 1.5	13.2 ± 1.6	12.5 ± 2.4	13.4 ± 2.0	<.001 ^{*,†,§}
Long Delay Recognition–Related False Alarms	0.9 ± 1.3	1.2 ± 1.3	2.3 ± 1.6	1.5 ± 1.6	<.001 ^{*,§,¶}
Long Delay Recognition–Unrelated False Alarms	1.2 ± 1.9	2.5 ± 2.7	4.5 ± 3.7	2.6 ± 3.2	<.001 ^{*,†,§,¶}
Long Delay Recognition–Total False Alarms	2.1 ± 2.8	3.7 ± 3.7	6.8 ± 4.9	4.1 ± 4.4	<.001 ^{*,†,§,¶}
Long Delay Recognition–Discrimination	0.8 ± 0.2	0.7 ± 0.2	0.6 ± 0.2	0.7 ± 0.2	<.001 ^{*,†,§,¶}
Total Repetitions	0.2 ± 0.5	0.2 ± 0.4	0.3 ± 0.8	0.2 ± 0.6	.88
Total Intrusions	0.6 ± 1.5	0.3 ± 0.5	0.7 ± 3.2	0.6 ± 2.3	.18
Proactive Interference	−2.7 ± 5.7	−2.2 ± 5.2	−1.25 ± 4.8	−2.1 ± 5.4	.01 ^{*,§}
Retroactive Interference	−3.3 ± 4.4	−3.2 ± 2.5	−4.2 ± 4.7	−3.7 ± 4.4	.32
Brain MRI measures					
Right hippocampal volume, mm ³	3875 ± 437	3741 ± 343	3613 ± 468	3759 ± 459	<.001 ^{*,§}
Left hippocampal volume, mm ³	3537 ± 425	3348 ± 323	3243 ± 467	3404 ± 456	<.001 ^{*,†,§}
Total hippocampal volume, mm ³	7412 ± 840	7089 ± 629	6856 ± 878	7163 ± 879	<.001 ^{*,§}
Right inferior lateral ventricle volume, mm ³	807 ± 439	964 ± 652	1147 ± 747	956 ± 617	<.001 ^{*,§}
Left inferior lateral ventricle volume, mm ³	869 ± 471	1011 ± 615	1254 ± 836	1034 ± 675	<.001 [*]
Total inferior lateral ventricle volume, mm ³	1676 ± 879	1974 ± 1232	2401 ± 1493	1990 ± 1235	<.001 ^{*,§}

	NC	Early MCI	MCI	Combined sample	<i>p</i>
Intracranial volume, cm ³	1377 ± 142	1406 ± 106	1380 ± 150	1381 ± 142	.47
White matter hyperintensity volume (log-transformed)	2.0 ± 1.0	2.2 ± 0.7	2.5 ± 1.0	2.2 ± 1.0	<.001 ^{*,§}
Cerebrospinal fluid markers					
Amyloid-β ₄₂ , pg/mL	757 ± 230	817 ± 282	620 ± 234	713 ± 246	.001 ^{*,§,¶}
Total-tau, pg/mL	373 ± 175	429 ± 125	505 ± 289	427 ± 228	.011 ^{*,§}
Phosphorylated-tau, pg/mL	56 ± 22	63 ± 17	68 ± 31	61 ± 26	.049 ^{*,§}
Neurofilament light, pg/mL	936 ± 453	1088 ± 465	1253 ± 718	1069 ± 583	.003 ^{*,§}

Note. NC = cognitively normal control; MCI = mild cognitive impairment. Data presented as mean ± standard deviation or frequencies.

^{*}*p* < .05.

[†]NC > early MCI.

[§]NC > MCI;

[¶]Early MCI > MCI.

Table 3.

Neuropsychological Performances in Cognitively Normal Participants.

	<i>n</i> = 174
Montreal Cognitive Assessment	27.0 ± 2.2
CVLT-II Total Learning (Trials 1–5)	46.9 ± 9.4
CVLT-II Short Delay Free Recall	10.0 ± 3.3
CVLT-II Long Delay Free Recall	10.5 ± 3.3
CVLT-II Recognition Total Discrimination	3.0 ± 0.7
Benton Visual Retention Test–V Total Score	6.8 ± 1.5
Wechsler Adult Intelligence Scale–IV Block Design	34.7 ± 10.4
Hooper Visual Organization Test	25.3 ± 2.5
Boston Naming Test 30-item (even items)	27.9 ± 2.0
Category Fluency (Animals)	21.0 ± 4.9
DKEFS Trail Making Test Number Sequencing *	36 ± 13
Wechsler Adult Intelligence Scale–IV Coding	57 ± 12
DKEFS Tower Test	16.1 ± 4.3
DKEFS Color–Word Interference Test Inhibition *	60 ± 14
Letter Fluency (FAS)	42.9 ± 11.4
DKEFS Trail Making Test Number–Letter Switching *	87 ± 34
Geriatric Depression Scale 30-item	2.4 ± 2.8
Wide Range Assessment Test–3 Reading Subtest	51.3 ± 4.3

Note. CVLT-II = California Verbal Learning Test–Second edition; DKEFS = Delis–Kaplan Executive Functioning System.

* Higher score reflects worse performance.

Table 4.

Cognitive Performance and Markers of Amyloid, Neurodegeneration, and White Matter Disease.

	BFLT Total Learning		BFLT Short Delay Free Recall		BFLT Long Delay Free Recall		BFLT Discrimination		BFLT Proactive Interference		BFLT Retroactive Interference		BVRT [†]	
	β	<i>p</i>	β	<i>p</i>	β	<i>p</i>	β	<i>p</i>	β	<i>p</i>	β	<i>p</i>	β	<i>p</i>
CSF A β 42	0.64	.30	3.00	.20	3.69	.12	124.35	.28	-0.70	.85	-4.46	.30	23.50	.08
CSF T-tau	-1.44	.01*	-6.70	.002*	-7.84	<.001*	-450.13	<.001*	1.82	.59	-1.89	.64	-4.06	.74
CSF P-tau	-0.15	.02*	-0.70	.005*	-0.80	.001*	-43.31	<.001*	0.13	.73	-0.40	.39	-0.11	.94
CSF NFL	-3.03	.03*	-8.00	.14	-6.85	.22	-307.32	.25	4.27	.62	-0.60	.95	-11.95	.70
Right Hippocampus Volume	1.20	.06	6.30	.01*	8.05	<.001*	165.96	.14	1.37	.71	5.50	.22	5.50	.69
Left Hippocampus Volume	2.34	<.001*	10.03	<.001*	11.80	<.001*	387.52	<.001*	-0.48	.90	6.27	.18	22.71	.11
Right Inferior Lateral Ventricle Volume	-1.39	.15	-6.11	.09	-7.12	.05	-488.21	.004*	4.52	.42	-0.80	.91	-25.31	.22
Left Inferior Lateral Ventricle Volume	-2.34	.03*	-7.95	.04*	-11.24	.004*	-583.18	.001*	2.72	.65	3.08	.67	-20.99	.35
WMH Volume (log-transformed)	-0.002	.24	-0.005	.42	-0.004	.45	-0.39	.15	-0.002	.78	0.007	.54	-0.08	.02*

Note. BFLT = Biber Figure Learning Test; BVRT = Benton Visual Retention Test–Fifth edition; CSF = cerebrospinal fluid; A β = amyloid beta; T-tau = total tau; P-tau = phosphorylated tau; NFL = neurofilament light; WMH = white matter hyperintensity (log-transformed).

* Significance threshold at $p < .05$.

[†] BVRT included for comparative purposes.

Table 5.

Biber Figure Learning Test Correlations with Other Neuropsychological Measures in Cognitively Normal.

	BFLT Total Learning		BFLT Short Delay Free Recall		BFLT Long Delay Free Recall		BFLT Discrimination	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
CVLT-II Total Learning (Trials 1–5)	.40	<.001 *	.37	<.001 *	.39	<.001 *	.29	<.001 *
CVLT-II Short Delay Free Recall	.41	<.001 *	.42	<.001 *	.42	<.001 *	.35	<.001 *
CVLT-II Long Delay Free Recall	.40	<.001 *	.44	<.001 *	.41	<.001 *	.32	<.001 *
CVLT-II Recognition Discrimination	.23	.002 *	.27	<.001 *	.25	.001 *	.23	.002 *
BVRT Total Score	.33	<.001 *	.38	<.001 *	.38	<.001 *	.15	.053
WAIS-IV Block Design	.19	.01 *	.20	.007 *	.23	.003 *	.24	.001 *
Hooper Visual Organization Test	.27	<.001 *	.32	<.001 *	.21	.007 *	.19	.01 *
Boston Naming Test 30-Item	.23	.003 *	.26	.001 *	.16	.032 *	.22	.003 *
Category Fluency (Animals)	.21	.006 *	.28	<.001 *	.21	.005 *	.18	.02 *
DKEFS Number Sequencing [†]	-.08	.29	-.19	.01 *	-.17	.02 *	-.08	.28
WAIS-IV Coding	.30	<.001 *	.34	<.001 *	.31	<.001 *	.14	.06
DKEFS Tower Test	.21	.005 *	.19	.01 *	.19	.01 *	.14	.08
DKEFS Color–Word Inhibition [†]	-.15	.049 *	-.12	.12	-.07	.39	-.01	.85
DKEFS Number–Letter Switching [†]	-.15	.06	-.21	.006 *	-.20	.01 *	-.14	.07
Letter Fluency (FAS)	.27	<.001 *	.26	.001 *	.15	.051	.23	.002 *
Geriatric Depression Scale 30-Item	.13	.09	.10	.19	.09	.25	-.004	.96

Note. *r* = Spearman's rank correlation adjusting for global cognition (total Montreal Cognitive Assessment Score); CVLT-II = California Verbal Learning Test–Second edition; BVRT = Benton Visual Retention Test–Fifth edition; WAIS-IV = Wechsler Adult Intelligence Scale–Fourth edition; DKEFS = Delis–Kaplan Executive Functioning System.

* Significance threshold at $p < .05$.

[†] Higher scores reflect worse performance.

Table 6.

Mean and Regression Coefficients for Normative Data Calculation.

	<i>M</i> ± <i>SD</i>	Intercept	β (age)	β (sex)	β (race/ethnicity)	β (education)	RMSE
BFLT Total Learning (Trials 1–5)	135 ± 31	223.7	−1.79 ***	12.78 **	−10.30	2.26 *	27.25
BFLT Distractor Trial	11.7 ± 5.8	21.6	−0.21 ***	2.09 *	1.68	0.23	5.49
BFLT Short Delay Free Recall	31.2 ± 8.1	59.9	−0.46 ***	1.26	−4.75 **	0.30	7.26
BFLT Long Delay Free Recall	32.5 ± 7.6	54.4	−0.40 ***	1.11	−3.59 *	0.45	6.96
BFLT Recognition Discrimination	0.82 ± 0.15	0.9	−0.004 **	0.03	−0.08 *	0.01 **	0.14
BFLT Proactive Interference	−2.71 ± 5.7	2.7	−0.03	0.13	1.98	−0.22	5.63
BFLT Retroactive Interference	−3.3 ± 4.4	3.5	−0.04	−1.59	−1.55	−0.18	4.31

Note. RMSE = root mean square error; BFLT = Biber Figure Learning Test.

* $p < .05$.

** $p < .01$.

*** $p < .001$.