DISTINCT PROFILES OF MEMORY PERFORMANCE AS A FUNCTION OF SERIAL POSITION RECALL IN A SAMPLE OF HOMELESS AND PRECARIOUSLY HOUSED ADULTS

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Abstract

Poor cognition is prominent in persons who are homeless, and memory dysfunction frequently emerges at the most pervasive impairment. The nature of this impairment is poorly understood, though prevalent issues of medical and psychiatric multimorbidity in homeless adults suggests that multiple factors may be contributing. This study investigated memory dysfunction in a homeless and precariously housed sample by subtyping unique profiles of serial position recall on a verbal learning and memory test using a latent profile analysis (LPA; $N = 411$). Subsequent logistic regression analyses were conducted in a subsample ($N = 175$) to examine whether regional brain volumes (i.e., dorsolateral prefrontal cortex, hippocampus, entorhinal cortex) and pathological markers (i.e., cerebral small vessel disease burden, hippocampal cavity volume) predicted serial position class membership. Secondary analyses explored between-class differences in attention, processing speed, cognitive control, and mental flexibility using linear regression. LPA identified two classes characterized by (1) reduced primacy relative to recency recall (RP); and (2) reduced recency relative to primacy recall (RR). Neuroanatomical and pathological markers did not emerge as significant predictors of class membership in the regression model. The RR class outperformed the RP class on measures of processing speed, sustained attention, and cognitive control. The present findings have implications for the way memory dysfunction is conceptualized in this complex group, supporting the substantial heterogeneity in their cognition and memory functioning and may aid in the development of discernible targets for interventions and strategies for rehabilitation.

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Distinct Profiles of Memory Performance as a Function of Serial Position Recall in a Sample of Homeless and Precariously Housed Adults

Homeless and precariously housed adults exhibit global dysfunction of their cognition (Stergiopoulos et al., 2015; Stone et al., 2019). Memory frequently emerges as the most compromised domain, with nearly three quarters of representative samples exhibiting impairment (Depp et al., 2015; Spence et al., 2004; Stergiopoulos et al., 2015). This group is clinically heterogeneous product of substantially high rates of comorbid physical and psychiatric illness relative to the general population (Topolovec-Vranic et al., 2017), suggesting that the nature of cognitive impairment is complex and attributable to multifaceted causes. Despite its widespread nature, memory dysfunction in this group is poorly understood. Greater efforts toward delineating this impairment are necessary to support the daily functioning of homeless and precariously housed persons, advance their independence, and detect and reduce risk of later functional and cognitive deterioration.

Issues of medical and psychiatric multimorbidity in homeless and precariously housed populations warrant an in-depth and more nuanced approach to examination of their memory. The standard use of total scores on tests of memory, for example, deprives examiners of information on the processes the examinee used to achieve a given outcome. This information may be especially important in this group who are regularly exposed to risk factors for poor memory and global cognition that may confound the typically used total scores, such as viral infection, traumatic brain injury, and psychiatric illness (Aldridge et al., 2018; Andersen et al., 2014; Jones et al., 2015). Discerning how an examinee arrives at the final outcome on a test of memory is often referred to as the process score approach to neuropsychological assessment (Kaplan, 1988). Process scores utilized in the context of the homeless and precariously housed

population can reveal cognitive variability, possibly indicative of an underlying pathology that is associated with mild cognitive impairment (MCI) and/or Alzheimer's dementia, that may be generally concealed with the use of a total score. For example, measures of proactive interference after a delay have been reported to reliably distinguish between Alzheimer's dementia patients and those with MCI (Loewenstein et al., 2004). Further, patients with Alzheimer's at the early stages of the disease have exhibited significantly higher rates of intrusion errors in comparison to those with MCI, despite similar degrees of impairment on many other neuropsychological measures (Loewenstein et al., 1991). Offering a process-type method to assessment and providing opportunities for more refined interpretations of memory scores, the serial position phenomenon can be leveraged as a unique approach to discern the nature of memory impairment in this group. This phenomenon refers to the tendency among healthy individuals to best recall the beginning (primacy effect) and final (recency effect) items of a series of words and recall the least amount from the middle (Glenberg et al., 1980; Murdock, 1962). Performance on tests that reveal serial position effects may provide greater insight into the nature of a memory impairment (Gicas et al., 2020a), and may be particularly valuable in homeless and precariously housed populations in which memory is apt to break down in a multitude of ways.

Primacy and recency effects can be sensitive indicators of underlying neuropathologies, affecting different aspects of the memory system. Primacy items are thought to have more time to be rehearsed and thus are relocated to, and later recovered from, hippocampal-dependent long-term memory stores at recall (Atkinson & Shiffrin, 1968; Malmberg et al., 2019). Reduced primacy recall has been linked to left hippocampal resection and reduced hippocampal volumes (Bruno et al., 2015; Chander et al., 2018; Hermann et al., 1996) and may be a particularly

sensitive marker of hippocampal-related neuropathologies (Bruno et al., 2013; Gicas et al., 2020a). These include, but are not limited to, neurofibrillary tangles in the projection neurons from the entorhinal cortex and tangles that are deep-rooted in the hippocampus, in addition to an enlargement of hippocampal cavity volume (Barboriak et al., 2000; De Leon et al., 1993; Hekmatnia et al., 2014; McGeer,1986). Clinically, preserved recency effects and reduced primacy effects are characteristic of Alzheimer's dementia (Bayley et al., 2000; Carlesimo et al., 1996; Foldi et al., 2003; Moser et al., 2014). Alzheimer's dementia phenotypes, commonly associated with reduced primacy recall, are also characterized by poor delayed recall, reduced recognition memory, and flattened learning slopes across repeated learning trials on tests of verbal memory (Delis et al., 1991; Russo et al., 2017; Weintraub et al., 2012). A preserved primacy effect may then be considered a marker for intact memory encoding, storage, and consolidation processes (Delis et al., 1991; Kasper et al., 2016; Wixted, 2004).

Distinct from primacy items, recency items are thought to be recalled from short-term working memory (WM) stores and demand sustained attention, though not for long enough to be transferred to LTM (Atkinson & Shiffrin, 1968; Li et al., 2003). The inverse of the Alzheimer's dementia profile, a reduced recency effect and relatively preserved primacy effect, has been associated with cerebral small vessel disease (cSVD) pathology, including increased white matter hyperintensities (Chander et al., 2018). These findings suggest that recency scores may be more sensitive to frontal lobe dysfunction since cSVD preferentially affects fronto-subcortical circuitry (Chen et al., 2018). Taxing the WM system, necessary for recency recall, may also result in poor self-monitoring and increased repetition errors on tests of verbal memory (Milner, et al., 1991; Woods et al., 2005a). Reduced recency performance may therefore be considered to

reflect a compromised executive system as a product of disrupted frontal lobe functioning (Chander et al., 2018; Shallice & Warrington, 1970).

Neural correlates of primacy and recency effects are not well established in multimorbid populations, such as those who are homeless and/or precariously housed. Many contributors to brain insult and injury are commonly reported in this group, though studies supporting prominent structural and functional abnormalities are limited. For example, greater hippocampal cavity volume, an atrophic change observed in the context of Alzheimer's disease (e.g., Barboriak et al., 2000; De Leon et al., 1993; Hekmatnia et al., 2014), has been observed in this group (Cheng et al., 2022). Additionally, poor performance on measures of verbal memory has been previously associated with reduced subfield volumes of the hippocampus in this sample (Gicas et al., 2018). The role of the hippocampus in encoding, consolidation, and retrieval processes merits an in-depth examination of the extent to which damage to this structure may be contributing to poor memory in this group. Memory difficulties attributable to hippocampal dysfunction in homeless and precariously housed adults would likely result in a serial position profile characterized by poor recall of primacy words relative to recency words, as primacy items would not be effectively consolidated and transferred to long-term memory.

In addition to Alzheimer's disease, elevated risk of developing vascular pathologies characteristic of cSVD have been reported in homeless and precariously housed adults (i.e., white matter hyperintensities, lacunes of presumed vascular origin and enlarged perivascular spaces) and may be contributing to frontal abnormalities and, conceivably, memory dysfunction as a secondary consequence (Huijts et al., 2014; Wardlaw et al., 2013; Zhou et al., 2020). Impairment as a product of altered fronto-subcortical circuitry, such as in the case of cSVD,

might result in a serial position profile characterized by poor recall of recency words relative to primacy words, consistent with reduced attentional and WM capacity.

1.1 Current Study

The present study uses existing baseline data from the Hotel study, a longitudinal investigation of adults who are homeless or precariously housed in the impoverished Downtown East Side neighbourhood of Vancouver, Canada (see Vila-Rodriguez et al., 2013). Homelessness in this area of Vancouver has been an ongoing public health crisis for decades and has recently escalated, warranting major social concern over the last few years. This neighbourhood comprises an approximate ten city-block radius and is occupied by thousands of individuals living in tents, makeshift shelters, or single-room occupancy hotels. This neighbourhood is also recognized for disproportionately elevated rates of substance use, criminal activity, and psychiatric illness (City of Vancouver, 2022; Linden et al., 2013; Werb et al., 2010).

The purpose of the current study is to better understand verbal memory functioning in this vulnerable group that exhibits a high rate of cognitive impairment. More specifically, the objectives are two-fold: (1) to identify and describe subgroups with distinct profiles of memory functioning using serial position scores; and (2) to examine the neuroanatomical correlates associated with unique serial position profiles. Consistent with the first aim, it is hypothesized that three subgroups with distinct serial position profiles will be identified, characterized by reduced primacy relative to recency recall (RP), reduced recency relative to primacy recall (RR), and the U-shaped profile (U; i.e., relatively equal recall of primacy and recency items and lower recall from the middle region) that is typically observed in healthy subjects. While memory dysfunction is pervasive in this population, results from previous work suggest that there remains a significant portion of individuals who exhibit memory functioning that is within the expected

range for their age (Bousman et al., 2010; Stergiopoulos et al., 2015). Consistent with this work, it is expected that some portion of the present sample will exhibit verbal memory performance that resembles the U-shaped pattern of recall (Gicas et al., 2020b). It is also predicted that component process scores on tests of verbal memory will differ according to serial position subgroups: (a) learning slope and recognition discrimination will be such that U > RR > RP, reflecting an inability of those with poorer primacy recall to effectively encode and consolidate information over time as a result of hippocampal dysfunction, and (b) frequency of repetition errors will be such that RR > RP > U, consistent with poor self-monitoring and retrieval processes that are associated with dysfunctional frontal lobe circuitry among those with poorer recency recall. In line with the second objective to examine the neural correlates of memory profiles, it is expected that smaller hippocampal and entorhinal cortex volumes and a greater burden of hippocampal pathologies will be associated with the RP subgroup, consistent with faulty core memory circuitry (Petersen et al., 2000). Lastly, it is predicted that reduced dorsolateral prefrontal cortex (DLPFC) volume and greater severity of cSVD markers will be associated with the RR subgroup, consistent with inefficient information processing and attentional dysfunction as drivers of secondary memory impairment (Michalka et al., 2015).

Memory impairments interfere with individuals' functional independence and may increase their risk of becoming or remaining homeless (Mahmood et al., 2021; Stergiopoulos, et al., 2011). Discernible targets for preventative and rehabilitative interventions in this complex group are paramount. Thus, this work will help to identify subgroups of individuals who may be at heightened risk for developing specific types of dementia and who would therefore benefit from greater supports upfront to help manage subsequent functional decline.

2 Methods

2.1 Participants

A total of 474 participants were considered for inclusion in the current study (see Figure 1 for process of inclusion/exclusion). The definition of homelessness is complex. For the purpose of the present investigation, individuals were considered to be experiencing tertiary homelessness if they were precariously housed, which is defined as having accommodations that barely meet local housing standards, having an impending risk for loss of accommodations, or living in single-room housing that does not meet local housing standards (Chamberlain & Mackenzie, 1992). Participants were recruited between November 2008 and November 2021 as part of the ongoing Hotel study; details are reported in Honer et al. (2017) and Vila-Rodriguez et al. (2013). To fully capture the complexity of this population, participants were recruited from the Downtown East Side neighbourhood of Vancouver in a variety of ways: (1) from single-room occupancy (SRO) hotels; (2) records from the community courthouse dated from the prior 6 months; (3) through youth mental health programs servicing 18–27-year olds living in SROs; and (4) from the local hospital emergency room.

Participants were required to be 18 years or older, fluent in English, and able to provide informed consent to be enrolled in the study. All participants were given a cash honorarium for their involvement. Ethics approval was obtained from the University of British Columbia and Simon Fraser University for the purpose of data collection and from York University to conduct primary analyses of these data.

2.2 Measures and Procedures

Neurocognitive assessment. A battery of neuropsychological tests was administered by trained research assistants under the supervision of a registered psychologist. The Hopkins Verbal Learning Test Revised (HVLT-R; Brandt, 1991) was used to assess verbal memory,

comprised of a list of 12 words with four words from three semantic categories. A total immediate recall score was calculated by summing the number of correctly recalled words across three repeated learning trials. After a 20–25-minute delay, participants were instructed to recall as many words as they could without being read the list, yielding the total delayed recall score. Following the delayed recall trial, participants complete a 24-item forced-choice recognition memory task where participants were instructed to respond 'Yes' if a word was from the original learned list or 'No' if it was not.

Primacy and recency regions were considered the first and last four words on any given trial, respectively. The remaining four words define the middle region. Serial position scores were computed by summing the total number of correct words recalled in a region across the three learning trials, divided by the total number of words presented in that region (i.e., 4 per trial = 12 total), and multiplying by 100 to obtain a score that reflects the percentage of correctly recalled items within each region (primacy, middle, or recency; Moser et al., 2014). Several HVLT-R component process indices were also examined, as they may reveal underlying cognitive mechanisms of observed memory deficits (Bruce & Echemendia, 2003; Woods et al., 2005a). These included (1) learning slope (i.e., the average number of new correct words per learning trial; Woods et al., 2005b); (2) recognition discrimination index (i.e., number of false positives on forced-choice recognition task subtracted by number of true positives); and (3) total intrusion and total repetition errors.

Premorbid functioning was measured using the Wechsler Test of Adult Reading (WTAR; Wechsler, 2001). Executive functioning was measured using subtests from the Cambridge Neuropsychological Test Automated Battery (CANTAB; Fray et al., 1996), including the Intra Extra Dimensional subtest for mental flexibility and the Rapid Visual Information Processing

subtest to measure sustained attention. Subtests from the Stroop Test, including Stroop Colour-Word and Stroop Word Reading, were used to assess cognitive control and processing speed, respectively (Golden & Freshwater, 2002).

The validity of all neurocognitive data was subjectively appraised by trained research assistants, ranging from a rating of 1 (Clearly Invalid) to 5 (Clearly Valid). Only data sets with validity scores of 4 or 5 were included in the present analyses. Reasons for ratings ≤ 3 included faulty assessment equipment, participants were intoxicated, too fatigued, and/or agitated, or significant distractions were noted in the testing environment, such as phone or alarm disturbances.

Handedness was measured at the time of the neurocognitive assessment using the Edinburgh Handedness Inventory (Oldfield, 1971). A subject is asked to report the side they prefer to use while performing a given activity (e.g., using a hammer, using a spoon) by indicating a "+" on their left or right side. Tasks with no preference are indicated with a "+" on both sides, and tasks which were never performed are left unmarked. The final score is calculated using a "Laterality Quotient" (Laterality Quotient = (R-L)/(R+L) X 100, where R and L refer to the number of "+" marked on the right and left sides, respectively. Left-handedness was assigned to participants with a score of less than -40, ambidexterity was assigned to participants with a score between -40 and +40, and right-handedness was assigned to participants with a score of more than +40.

Psychiatric diagnoses. Trained research assistants, psychiatrists, and/or neurologists conducted comprehensive clinical assessments for each participant when they enrolled in the study. Information gathered from the Best Estimate Clinical Evaluation and Diagnosis (Endicott, 1988), the Mini-International Neuropsychiatric Interview (Sheehan et al., 1998), and a mental

status examination in accordance with criteria in the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV- TR; American Psychiatric Association, 2000) were used to give diagnoses of substance dependence (cannabis, alcohol, stimulant, and opiate) and/or psychiatric illness (schizophrenia or any psychotic disorder; see Table 1).

Medical and physical assessment. Co-occurring chronic medical illnesses were measured using the Charlson Comorbidity Index (Charlson et al., 1987). This index provides a weighted measure to predict mortality of individuals that have ≥1 physical health conditions included in the index (e.g., diabetes, liver disease), all weighted on a scale of 1-6 based depending on their 1-year mortality rate and summed to produce a final Charlson comorbidity score. Determination of viral infection, including HIV, hepatitis B, hepatitis C, herpes simplex virus, and cytomegalovirus was done using blood samples collected from participants. Participants were considered to have a history of traumatic brain injury by using a previously documented approach (see Fan et al., 2018). A positive history of traumatic brain injury was determined using data from a comprehensive review of their medical history that revealed ≥ 1 injury to the head that was accompanied by (1) loss of consciousness, (2) loss of memory and/or an episode of confusion, (3) MRI scan exhibiting confirmatory evidence for head trauma, or (4) residual effects, such as a seizures, that cannot be meaningfully associated with another cause.

Neuroimaging processes. Structural imaging was performed proximal to the cognitive testing session. Whole brain MRIs were acquired on a Philips Achieva 3T scanner and images were inspected for significant motion artifact. A 3D T1-weighted Fast Field Echo (FFE) sequence was acquired in the sagittal plane with 190 1-mm thick contiguous slices (TR/TE = 8.1/3.5 ms; acquisition matrix = 256 × 250 × 190; field of view = 256 × 256 × 190 mm^3; recon voxel = 1 × 1 × 1 mm; flip angle = 8°; total acquisition time = 7:23 min; see Gicas et al., 2018).

T1-weighted images were then converted to the Neuroimaging Informatics Technology Initiative (Nifti) format using the dcm2nii tool in the MRIcron package. MRI images were processed using FreeSurfer version 6.0 (http://surfer.nmr.mgh.harvard.edu) for intensity bias correction and all scans were reviewed by a neuroradiologist. Only scans that were completed within 1 month before or after the neurocognitive assessment were retained for the present study.

The Desikan-Killiany atlas (Desikan et al., 2006) was used to parcellate the regional brain volumes of interest including the DLPFC, hippocampus, and entorhinal cortex. To assess for neuropathologies, all MR images were first reviewed by an experienced neuroradiologist and imaging neuroscientist. Cerebral small vessel disease burden was characterized using a modified cerebral small vessel disease (cSVD) score. One point each was given for moderate-severe white matter hyperintensities, ≥1 cerebral microbleeds, and ≥1 lacunes (Zhou et al., 2020). Hippocampal cavities are small hollows usually considered incidental findings on MRI. Their etiology remains unclear, though they are considered a product of incomplete obliteration of the hippocampal fissure (Bastos-Leite et al., 2006). Hippocampal cavities were quantified and defined per our previously documented approach detailed by Cheng et al. (2022), as spaces isointense to cerebrospinal fluid on T1-weighted MRI sequences, surrounded by hippocampal tissue on all sides and with ≥ 1 mm^3 volume.

For the purpose of the present study, the DLPFC was calculated as the sum of the volume of the following three regions: rostral middle frontal, caudal middle frontal, and superior frontal. Regional brain volumes, including total DLPFC, entorhinal cortex, and total hippocampus, were adjusted for total intracranial volume (ICV). ICV was calculated by combining grey matter, white matter, and cerebrospinal fluid measurements. ICV corrections were done using the 'residual approach' outlined by Voevodskaya et al. (2014). In a series of linear regressions, ICV

was entered as the independent variable and regional brain volume as the dependent variable. Unstandardized residuals were saved following each regression and then added to each participant's average regional volume to compute a corrected, ICV-adjusted, volume. ICV-adjusted left and right volumes were summed to compute bilateral volumes which were used for the primary analyses. Regional brain volumes were corrected for unilaterally for the purpose of conducting supplementary analyses separately by hemisphere. Hippocampal cavity volume was corrected for total hippocampal volume by dividing cavity volume by raw hippocampal volumes. Left and right hippocampal cavity volumes were corrected for unilaterally, summed to get bilateral corrected cavity volume, and then scaled by multiplying the sum by 100 to obtain a value that reflects the percentage of the hippocampus that is occupied by hippocampal cavities.

2.3 Statistical Analyses

Preliminary analyses. All data was reviewed for any missingness and invalidity. Normality of distribution and the presence of outliers were inspected visually for all continuous variables with histograms and qq-plots. All analyses were conducted using R software (R Core Team, 2020).

Characterizing distinct serial position subgroups of memory. Data from the HVLT-R were analyzed using a latent profile analysis (LPA) to identify subgroups with distinct serial position profiles. LPA protocols outlined by Masyn (2013), briefly detailed below, were adhered to. Participants' raw scores for percent recall of primacy, middle, and recency items were individually calculated and entered into the LPA. Four within-class variance-covariance matrix structures were explored: (1) a class-invariant diagonal structure (i.e., covariance between variables is set to 0, and variance is equal across classes); (2) a class-varying diagonal structure (i.e., variances may be differ between classes and covariance among variables is fixed to zero);

(3) a class-invariant unrestricted structure (i.e., both variances and covariances are kept equal across classes); and (4) a class-varying unrestricted structure (i.e., both variances and covariance can differ across classes). Models that range between two to five latent classes were explored and compared for each of the four models.

An analytic hierarchy process was used to compare the two to five class solutions across the four within-class variance-covariance structures on relative fit to determine the best model solution. Relative simplicity of the final model was favoured in addition to overall indices of fit (Akogul & Erisoglu, 2017; Masyn, 2013). Model solutions associated with lower Bayesian Information Criterion (BIC) and Akaike Information Criterion (AIC) were selected to indicate a better model fit. Entropy, a measure of classification uncertainty, was also considered. Entropy is reverse coded such that a value of 1 indicates complete classification certainty and 0 complete uncertainty (Celeux & Soromenho, 1996); higher values of entropy were favoured. Goodness-of-fit was determined by using bootstrapped likelihood ratio (BLRT) tests to compare all models. An alpha value of 0.05 was selected as the cut-off for statistical significance for BLRT tests, with significance indicating improvement in fit from the one-class model solution. Probability minimum and probability maximum refer to minimum and maximum, respectively, of the diagonal of the average latent class probabilities for most likely class membership by assigned class. Both indices should be as high as possible, reflecting greater classification certainty (i.e., individuals are assigned to classes they have a high probability of being assigned to; Jung & Wickrama, 2008).

Follow-up analyses included a series of Welch's paired-samples and independent samples t-tests to examine the presence of within and between class differences, respectively, in serial position performance (i.e., primacy, middle, and recency scores) to probe the final solution of the

LPA. Welch's t-tests were used product of their decreased probability of Type 1 error rates and have also been found to outperform alternative approaches when comparing groups of unequal sample sizes (Delacre et al., 2017; Zimmerman, 1996). Independent samples t-tests were also used to determine differences between subgroups on sociodemographic variables (i.e., age, self-reported sex, and education history), Charlson comorbidity index scores, diagnoses of psychiatric illness and substance dependence at baseline, viral infection, and history of traumatic brain injury (TBI). Standardized effect sizes for differences between subgroups of individuals with distinct serial position profiles were obtained by calculating Cohen's *d*.

Between-class differences in neurocognitive performance. A series of linear regression models examined differences between serial position classes and HVLT component process scores (raw scores for: learning slope, recognition discrimination index, total intrusion errors, and total repetition errors). Age, self-reported sex, and education were included as covariates given their associations with memory and verbal learning outcomes (Kramer, Delis & Daniel, 1988; Perlmutter, 1978). The assumptions of linearity, homoscedasticity, and independence and normality of residuals were checked. Intrusion and repetition errors were binarized to reflect presence or absence of errors due to their significantly skewed distributions as many participants did not make any intrusion (n = 242 with 0 errors) or repetition (n = 195 with 0 errors) errors. Two subsequent logistic regression analyses were conducted with serial position class as the predictor and error-type (i.e., intrusion or repetition) as the dependent variable. Individual models covaried for age, self-reported sex, and education. The assumption of linearity in the logit was evaluated and models were inspected for multivariate outliers.

A series of secondary analyses were conducted subsequent to the LPA to further characterize cognitive differences between the serial position profile subgroups. Linear

regression models explored possible differences between serial position subgroups and performance on additional domain-specific cognitive measures (raw scores for: Stroop Colour-Word for cognitive control; Stroop Word Reading for processing speed; IDE total adjusted errors for mental flexibility; and RVIP A' for sustained attention). Serial position class was entered as the independent variable and the dependent variables were raw scores on the respective cognitive measure. Models covaried for age, self-reported sex, and education. The assumptions of linearity, homoscedasticity**,** and independence and normality of residuals were evaluated.

Between-class differences in neuroanatomical and pathological markers. To achieve the second objective of examining neuroanatomical and pathological correlates associated with unique serial position profiles, multinomial logistic regression analyses were used. In the primary model, independent variables of interest included bilateral volumes of: DLPFC, hippocampus, entorhinal cortex, hippocampal cavity volume, and modified cSVD burden scores which was entered as a continuous variable in the model. Serial position profile served as the dependent variable, with profiles represented as the resultant LPA classes. Two supplementary models were conducted to analyze the left and right hemisphere volumes separately for each region of interest. Independent variables included unilateral volumes of: DLPFC, hippocampus, entorhinal cortex, hippocampal cavity volume, and modified cSVD burden scores. Serial position profile served as the dependent variable. All three models (i.e., bilateral model, left-hemisphere model, and right-hemisphere model) covaried for age, education, and self-reported sex at birth. These covariates were chosen because of their documented associations with memory and/or executive functioning (Fernández-Serrano et al., 2011; Sampedro-Piquero et al., 2019; Velligan & Bow-Thomas, 1999). The assumption of linearity was evaluated (Hosmer & Lemeshow, 2000) and all models were inspected for multivariate outliers.

Left-handed individuals were excluded from these analyses to control for brain differences associated with handedness (Goulding, 2021). Only participants with valid baseline HVLT-R, neuroimaging, and handedness data were included in the final logistic regression analyses. Reasons for exclusion included missing data, the MRI not being completed within 30 days before or after of the neurocognitive assessment, and being left-handed or ambidextrous (see Figure 1).

3 Results

A total of 411 of individuals had valid baseline HVLT-R data and were included in the latent profile analysis (LPA). Participants with missing and/or invalid data were excluded (see Figure 1). Participants included in the LPA were mostly male (76%) and White (60%), and the average age was 41 years old. Participants had an average of 10 years of education and an estimated premorbid IQ that fell within the average range ($M_{WTAR.FSIQ}$ = 98.6; see Table 1). Descriptive statistics for neurocognitive tests by cognitive domain are indicated in Table 2. Normative data was used to determine mean T-scores for neurocognitive tests, adjusting for participant age (and years of education for the Stroop Test). Scores that fell >1 standard deviation below the mean indicated clinical impairment. Clinical impairment was observed for most cognitive domains assessed in the overall sample with the exception of processing speed and cognitive control, both of which fell within the average range of functioning.

3.1 Characterizing Distinct Serial Position Subgroups of Memory

An analytic hierarchy process based on all fit indices suggested that the best solution was a class-invariant unrestricted model with 2 classes (BLRT_p < .01), indicating that the fit of this model was a significant improvement from the one-class model of identical within-class variance– covariance structure specification. The overall model was not further improved by the

addition of a third class. The BLRT statistic remained significant for the three-class class-invariant unrestricted model (BLRT_p < .05), though to a lesser degree, BIC increased, entropy decreased slightly, and prob_min and prob_max both decreased. Addition of a fourth and fifth class resulted in insignificant BLRT_p statistics (BLRT_p = .78 and BLRT_p = .97, respectively). Examining the average posterior class probabilities by modal latent class assignment revealed that participants had an average probability of 0.90 to be classified into the correct class under the selected model conditions. Table 3 provides details on the model fit indices for the LPA across the four different within- class variance–covariance structure specifications (Σ_k).

The resultant two classes were characterized by (1) reduced primacy relative to recency (RP; n = 150, 36.5%); and (2) reduced recency relative to primacy (RR; n = 261, 63.5%). The RP class included participants with relatively low primacy performance in comparison to recency performance (see Figure 2). Results from paired-samples t-tests within the RP class showed that recency was better than primacy (t(149) = -6.26, p < .001, d = .66) and middle recall (t(149) = -5.07, p < .001, d = .52), with no difference between primacy and middle recall (t(149) = -.41, p = .68, d = .04). All pairwise comparisons were different within the RR class (primacy > middle recall: t(260) = 15.74, p < .001, d = 1.85; primacy > recency recall: t(260) = 17.07, p < .001, d = 1.32; middle > recency recall: t(260) = -2.07, p < .05, d = .13). The percentage of primacy (t(307) = -30.23, p < .001, d = 3.10), but not recency (t(336) = -.51, p = .61, d = .05), items recalled was significantly different between classes. Middle recall (t(331) = -6.81, p < .001, d = .69) was significantly different between classes, with the RP class recalling significantly less items from the middle position compared to the RR class. Individual serial position profiles for

participants in the RP and RR class are plotted in Figure 3 and Figure 4, respectively, in comparison to average class performance.

Demographic and clinical characteristics of the individual classes can be found in Table 1. The RP class included just over one third of the participants from the overall sample (n = 150, 36.5%) and the RR class included over a half of the participants from the overall sample (n = 261, 63.5%). The RP class participants were older ($t(300) = 3.41$, $p < .001$) and had a greater proportion of males in comparison to the RR class participants (χ^2 (1) = 4.61, $p < .05$). Participants in the RR class had significantly more years of education and a higher estimated premorbid IQ compared to the RP class ($t(346) = -3.79$, $p < .001$). Chi-square tests of independence revealed no significant differences in the ethnic composition of the two profiles; most participants in both groups were White. No significant differences were detected in psychiatric or substance dependence diagnoses, though the RR class had a greater, and statistically significant, proportion of participants with an opiate dependence at baseline. No between-group differences were observed in exposure to viral infection. No significant difference between groups in history of traumatic brain injury was detected.

3.2 Between-Class Differences in Neurocognitive Performance

Clinical impairment was observed in both subgroups for most cognitive domains assessed except for processing speed and cognitive control. Processing speed fell within the low average and average range of functioning for participants in the RP class and RR class, respectively. Performance on a task measuring cognitive control fell within the average range of functioning for both classes (see Table 2).

All analyses were conducted with the RP class as the reference group. Linear regression analyses indicated that participants in the RP class had worse performance on total immediate (β

= .46, *SE* = .5, $p < .001$) and delayed verbal recall ($\beta = .36$, *SE* = .26, $p < .001$). Participants in the RP class also had worse recognition of verbal material after a short delay ($\beta = .23$, *SE* = .24, $p < .001$) and had a flatter learning slope in comparison to the RR class ($\beta = .16$, *SE* = .1, $p < .01$; see Table 4). The logistic regression models revealed that class membership was not a significant predictor of the amount of intrusion errors made ($\beta = .27$, *SE* = .21, $p = .21$), but was a significant predictor of the amount of repetition errors made ($\beta = -.94$, *SE* = .22, $p < .001$; see Table 5).

Results from the supplementary analyses using linear regressions to compare classes on neurocognitive test performance are indicated in Table 6. Participants in the RP class had worse performance on measures of processing speed ($\beta = .17$, *SE* = 1.88, $p < .001$), cognitive control ($\beta = .24$, *SE* = 1.05, $p < .001$), and sustained attention ($\beta = .13$, *SE* = .007, $p < .01$). No between-subgroup differences in mental flexibility were detected ($\beta = -.09$, *SE* = 5.17, $p = 1.0$).

3.3 Between-Class Differences in Neuroanatomical and Pathological Markers

A total of 175 participants had valid neuroimaging data and were included in the analysis (see Figure 1). Descriptive statistics for regional brain volumes and pathological markers of interest are indicated in Table 7. See Appendix A for a summary of these statistics separated by hemisphere. None of the regional brain volumes (i.e., DLPFC, hippocampus, entorhinal cortex) or pathological markers (i.e., cSVD burden, hippocampal cavity volume) of interest significantly predicted serial position class membership in the bilateral model (see Table 8). Likewise, the results of the supplementary analyses remain consistent with the primary bilateral analyses, with no significant associations in the left- or right-hemisphere models (see Appendix B).

4 Discussion

The present study identified and described unique profiles of serial position recall in a group of homeless and precariously housed adults. The overall sample was described by two classes with distinct serial position curves. The reduced primacy (RP) class was characterized by reduced recall of primacy items in comparison to recency items. The second subgroup, the reduced recency (RR) class, was characterized by poorer recall of recency items in comparison to primacy items. Participants in the RR class made more errors of repetition, but not intrusion, compared to participants in the RP class. Regional brain volumes of interest (i.e., DLPFC, hippocampal cortex, entorhinal cortex), and pathological markers (i.e., hippocampal cavity volume and cerebral small vessel disease (cSVD) pathology), were not significantly associated with serial position class membership.

Contrary to what was predicted, the hallmark U-shaped serial position profile that is typically observed in cognitively healthy individuals, with equal recall of primacy and recency items and relatively weaker recall of middle items, was not observed in this sample (Murdock Jr., 1962). The absence of a U-shaped class may have been due to an insufficient proportion of participants exhibiting a U-shaped pattern of recall for the LPA to justify a third profile. An objective of this analysis is to maximize between-class variance and minimize within-class variance and this objective may have been vulnerable to the addition of a third class with such few participants. As a result of common physical and psychiatric comorbidities that have substantial impact on cognitive functioning in this population (e.g., psychotic illness, substance dependence, traumatic brain injury, viral infection; Topolovec-Vranic et al., 2017), it is reasonable to expect that most participants in the present sample exhibit some degree of alteration in their serial position recall that is sufficiently distinct from the U-shaped curve observed in healthy adults. Results support the finding that this sample is best represented by the

two non-U shaped profiles that were predicted, one with reduced recency relative to primacy and the other with reduced primacy relative to recency. These distinct subgroups support the cognitive heterogeneity of homeless and precariously housed persons and underscore the complexity of memory functioning in this group. The presence of an RP class may suggest an underlying abnormality of long-term memory systems (Atkinson & Shiffrin, 1968; Malmberg et al., 2019)and the resultant RR class may point to an underlying dysfunction that is secondary to an impairment of long-term, core memory processes, as recency items necessitate the engagement of short-term, working memory systems (Talmi et al., 2005).

Given the absence of any significant neuroanatomical findings, future research should further explore the underlying neural mechanisms that may be driving the different patterns of memory performance in both subgroups. The well-documented notion that primacy and recency recall necessitate the recruitment of distinct brain regions has been supported by findings from various studies measuring regional cerebral activity (e.g., Brueggen et al., 2016; Talmi et al., 2005), though these differential associations are not as authenticated in homeless and precariously housed persons. While the present work did not identify any structural differences between subgroups, there may be neural differences in functional connectivity or activity, for example, though different neuroimaging techniques (e.g., functional magnetic resonance imaging or diffusion tensor imaging) are required to query these differences. Different imaging strategies that support probing at patterns of activity, cortical thickness, and connectivity may allow for a more nuanced approach to future investigations that aim to uncover the underlying neural mechanisms that are driving this pervasive dysfunction of memory.

The rates of learning and recognition discrimination performances were as expected; participants in the RP class exhibited a flatter learning slope and reduced recognition

performance in comparison to the RR class. This pattern helps to validate the conceptualization of the RP profile as reflecting difficulties with effective encoding and consolidation (Daumas et al., 2005). Findings from the Alzheimer's dementia literature also suggest that poor primacy relative to recency recall may be related to faulty processes of consolidation, since the typical 'Alzheimer's dementia profile' of serial position recall is characterized by a reduced primacy compared to recency effect (Bayley et al., 2000; Carlesimo et al., 1996; Foldi et al., 2003; Moser et al., 2014), and the neuropsychological hallmarks of Alzheimer's dementia are related to deterioration of long-term memory systems (Luxenberg et al., 1987; McGeer,1986; Nestor et al., 2008; Thompson et al., 2004). Poor recognition in addition to poor primacy relative to recency recall has been previously observed in a sample of participants with HIV-associated dementia (Scott et al., 2006), interpreted to reflect deficient long-term memory functions, including processes of encoding and retrieval. Poor learning and recognition in conjunction with reduced primacy recall in the RP subgroup may then implicate dysfunction of core long-term memory systems as the key contributors to verbal memory difficulties in this class.

As predicted, the RR class made more errors of repetition compared to those in the RP class, supporting the prediction that this group would experience difficulties with self-monitoring. Self-monitoring is a component of executive functioning (Gioia et al., 2017) implicated in the observing of thoughts and behaviours in order to execute a task objective. Greater errors on neuropsychological measures have previously been reported in the context of poor self-monitoring (Luu et al., 2000). It is possible that difficulties within self-monitoring in this subgroup is a product of elevated rates of substance use that are commonly observed in homeless and precariously housed persons (Fischer & Breakey, 1991). Notably, the RR class was found to have significantly more participants with a diagnosis of opiate dependence at baseline

than those in the RP class. Dysfunction of self-monitoring processes have been observed in heroin users (Chen et al., 2013), in addition to higher incidence of perseveration among opioid-dependent individuals (Lyvers & Yakimoff, 2003), substantiating the interpretation that elevated opiate use may be contributing to weaker overall executive functioning in the RR subgroup.

The neuropsychological implications of middle-region recall are far less explored in comparison to those in the primacy and recency regions in list learning. While there was no significant difference observed in percent recall of recency items between serial position profiles, supplementary analyses revealed a significant disparity in middle recall, which may suggest that the RP class has greater difficulties engaging and sustaining attentional resources (Foldi et al., 2003). This interpretation is consistent with findings from the present secondary analyses, where the RR class with better middle recall outperformed the RP class on a measure of sustained attention. Further, better recall of middle-region items has also been considered to reflect the ability to store newly presented material in long-term memory (Waugh & Norman, 1965). This idea lends support to the present finding that weakened middle recall, in addition to poor primacy recall, among the RP class may reflect poor long-term memory processes such as information consolidation, and inattention to newly presented information. Further research examining the importance of middle recall is needed, especially in a heterogenous group where issues of multimorbidity may confound typical associations with the more frequently explored primacy and recency effects.

The hypothesis that neuroanatomical and pathological markers would be differentially associated with serial position subgroups was not supported. Regional brain volumes of interest (i.e., DLPFC, entorhinal cortex, and hippocampus) and pathological markers (i.e., hippocampal cavity volume and cSVD burden) did not meaningfully differ between the RP and RR subgroups.

In line with inefficient core memory processes in a subset of this population, it was expected that smaller hippocampal and entorhinal cortex volumes, and greater hippocampal cavity volume, would be associated with the RP class (Petersen et al., 2000). On the other hand, it was expected that reduced DLPFC volume and greater severity of cSVD markers would be associated with the RR profile, a product of deficient information processing and attentional dysfunction as the drivers of poor memory functioning (Michalka et al., 2015). While the two resultant profiles from the LPA were characterized by (1) reduced recency and (2) reduced primacy, it may be the case that there is dysfunction in both primacy and recency recall in both classes, though one is more preserved relative to the other. However, in the absence of available normative data or appropriate comparison samples, the extent of any decrements in primacy and recency cannot be determined. If both primacy and recency are impaired in both subgroups, it may be the case that there is dysfunction of both hippocampal and frontal-dependent memory systems, precluding the observation of any distinct neuroanatomical associations with either serial position class in the present study. Further work should investigate neuroanatomical and pathological associations with specific word-list regions (e.g., primacy versus recency) within classes of serial position performance to query this interpretation.

The RP profile may reflect a subgroup with greater global impairment and more widespread markers of poor neuropathology. The RP class demonstrated weaker performance on measures of sustained attention, cognitive control, and processing speed, the latter two of which are measures of frontal functioning (Badre et al., 2009; Wilkins et al., 1987). Participants in this class also demonstrated a substantially weaker primacy effect compared to recency effect and exhibited worse primacy recall compared to the RR class, a pattern that has been consistently reported to index hippocampal dysfunction (Bruno et al., 2015; Chander et al., 2018; Herman et

al., 1996). RP class participants were significantly older than their RR counterparts, placing them at greater risk for both vascular pathologies (Grinberg & Thal, 2010) and hippocampal and entorhinal cortex atrophy (Du et al., 2006) in addition to more widespread cognitive impairment (Murman, 2015). Higher scores on the Charlson Comorbidity Index (CCI) among participants in the RP class further substantiate more widespread cognitive impairment in this subgroup, supported by results reported by Silay et al. (2017), where a one-point increase in CCI score increased the risk of cognitive impairment by three times. While the RR class may be predominantly affected by weaker frontal lobe systems, greater global impairment in the RP class may suggest that this group is dually affected by both frontal-subcortical and hippocampal dysfunction, thus accounting for the absence of DLPFC volume and cSVD burden differences between groups.

Differential neural associations of primacy and recency effects have not been well investigated outside of MCI and dementia populations. Since persons who are homeless or precariously housed are exposed to elevated rates of neural insults such as traumatic brain injury, psychiatric illness, and substance dependence (Maas et al., 2017; Topolovec-Vranic et al., 2017), patterns of neural networks recruited and engaged for different tasks may differ from other clinical or healthy populations. This is analogous to findings indicating that older adults with age-related changes in brain volume, vasculature, and cognition (Peters, 2006) exhibit more widespread activation of neural networks on cognitively demanding tasks compared to younger adults as an adaptive compensatory mechanism (Cabeza & Dennis, 2012; Park & Reuter-Lorenz, 2009). This was the case in a study by Crowell et al. (2020) who administered a test of verbal working memory to older and younger adults and found greater integration of neural networks amongst older adults as task demands increased. Further research is needed to determine whether

distinct profiles of serial position recall require the engagement of separate brain regions in this complex group, where both cognitive and neural abnormalities are widespread and may each be uniquely contributing to this impairment.

The lack of significant neuroanatomical associations between subgroups should also be contextualized using findings from the secondary subgroup comparisons, as RP and RR class participants were observed to be similarly exposed to a wide breadth of factors that differentially confer risk for poor hippocampal and frontal lobe integrity. Firstly, stimulant use was the most common class of drug that was heavily used among both RP and RR subgroups. Stimulant use has been reported to result in abnormalities and reduced volumes of the frontal lobe (e.g., Liu et al., 1998; Mackey & Paulus, 2013; Sim et al., 2007) and greater risk for vascular pathologies in homeless persons (Riley et al., 2021). Conversely, cannabis dependence was also prominent among both subgroups and has been reported to result in reduced hippocampal volumes across various contexts and populations (Cousijn et al., 2012; Lorenzetti et al., 2015; Nader & Sanchez, 2018; Schacht et al., 2012). Prevalence of psychotic disorder and schizophrenia, which is associated with reduced hippocampal volumes and hippocampal deformities, was substantial, though not significantly different between RP and RR participants (Adriano et al., 2012; Csernansky et al., 2002; Lawrie & Abukmeil, 1998; Nelson et al., 1998; Wright et al., 2000). Finally, considerable rates of herpes simplex virus and hepatitis C infection, which are known to affect the hippocampus (Yong et al., 2021) and frontal lobes (Weissenborn et al., 2009), might also account for RP and RR patterns. Due to elevated risk for both hippocampal and frontal dysfunction in both subgroups, it may be the case that erosion of hippocampi and frontal lobe integrity is a ubiquitous feature in the present sample.

An objective of LPA is to minimize within-group variability. However, while the analytic hierarchy process identified two distinct subgroups of serial position recall, there remains a substantial amount of individual variability in serial position performance within both subgroups (see Figure 3 and Figure 4). While this solution was the most parsimonious and best-suited based on the selected indices of fit, many individuals deviated substantially from the 'average' serial position profile for their respective subgroups that are plotted in Figure 2. This variability in performance may partly explain the lack of neuroanatomical and pathological differences observed between the RR and RP classes, since many participants within both subgroups did not exhibit the average profile of serial position recall that characterized their corresponding class.

4.1 Limitations

Several limitations of the present study should be considered. Though supplementary analyses using additional neurocognitive measures aided in the characterization of resultant serial position subgroups, and normative T-scores are available to glean information regarding participants' overall verbal working memory functioning, interpretation of primacy and recency effects in the present sample are limited due to the absence of a control group or normative data. As a result, decreased recall of primacy and recency items can only be interpreted to the degree to which they differ between and within the RP and RR classes. For example, primacy recall was reduced relative to recency recall within the RP class, and vice versa for the RR class. However, the absence of a significant difference in recency recall between classes calls into question the extent to which 'reduced primacy' is an accurate representation of the RP class. A healthy control group exhibiting a U-shaped pattern of recall or accessibility to normative data would help determine whether primacy and recency recall in the RP or RR class were at clinically

impaired levels or if participants were performing worse than would be expected given their age and level of education.

Secondly, while we looked at substance dependence across different classes of drugs, the present study did not investigate substance use at a nuanced level, resulting in the omission of certain aspects of substance use which may have informed the interpretation of our findings. Substance use was only investigated to the extent of whether participants met clinical criteria for a substance dependence at study baseline, and differences in dosing, pattern, and frequency of substance use, for example, were not included. Previous work has demonstrated dose-dependent effects of alcohol and marijuana on neurocognition (Bolla et al., 2002; Marks & MackAvoy, 1989), where greater doses of the substance have produced more profound impairments in cognition. Findings from past research also suggest that chronic, long-term cannabis use can result in altered brain connectivity and volume reductions in brain areas associated with memory, executive functioning, learning, and impulsivity (Batalla et al., 2013; Filbey et al., 2014), and that beginning to use cannabis earlier in life can result in more deleterious effects (Pope et al., 2003; Wilson et al., 2000). Most notably, Waldrop et al. (2004) found that the amount of marijuana and heroin used weekly was significantly correlated with primacy scores, but not recency scores, in their study exploring synergistic effects of HIV-infection and drug use on neurocognition. Jones and Jones (1977) also found that alcohol was associated with impaired recall from primacy, but not recency, regions of a wordlist in a sample of male and female 'social' (i.e., casual) drinkers. Additional information might have revealed whether factors such as dosing and frequency of substance use are impacting the extent to which primacy and recency effects are attenuated in subgroups of the present sample. Further research should consider contextualizing the present findings using a more fulsome examination of substance-use patterns

given the frequency with which they are used among homeless and precariously housed persons (Aldridge et al., 2018) and their multifaceted impacts on the brain and cognition (Cadet et al., 2014; Ramey & Regier, 2019).

Finally, the present study used the regional method to calculate serial position effects, involving a calculation of the percentage of an examinee's total correct items from each region of the list, divided by the total number of words in that region (Foldi et al., 2003), which has been shown to be superior to other methods of calculation (Weitzner & Calamia, 2020). However, the shape of the serial position curve and the magnitude of primacy and recency effects have been shown to dependent on the length of the wordlist used (Bemelmans & Goekoop, 1991). When a wordlist is longer, examinees begin item recall with one of the final recency items (Hogan, 1975; Howard & Kahana, 1999; Laming, 1999), and when the list is shorter, they tend to initiate recall with one of the first primacy items (Ward et al., 2010). The HVLT-R used in the current study is considered a relatively shorter test of verbal memory compared to others (e.g., the 16-item California Verbal Learning Test, Delis et al., 2000), and the use of this test may have resulted in more pronounced primacy effects in both subgroups. Further work might consider examining longer wordlists with more words per serial position to confirm that the degree of primacy and recency effects detected in subgroups of the present sample cannot be partly attributed to the length of the list used.

4.2 Clinical Implications

Memory dysfunction is especially prominent among persons who are homeless or precariously housed, but this area of impairment is poorly understood relative to other domains of cognition. The present findings have implications for the way memory functioning among homeless and precariously housed persons is conceptualized, and findings help to elucidate the

various ways in which the underlying neural systems supporting memory may be compromised in this group. Specifically, there is a subgroup demonstrating weakened primacy recall that may be a product of poor long-term memory processes, while there exists another subgroup with weakened recency recall that may point to an underlying dysfunction of short-term, fronto-subcortical systems.

Results from the present work can inform future endeavors towards rehabilitation of homeless and precariously housed persons. Such efforts should emphasize memory recovery and greater early detection screening to help mitigate functional consequences associated with neurocognitive decline. In addition to interventions that underscore deficient memory systems and re-training of such process, future rehabilitation efforts might also highlight the use of cognitive exercises that focus on improving attention, as deficient attention as it relates to the present population and the RP subgroup may also interfere with functional independence (Alosco et al., 2015), increasing individual risk of becoming and staying homeless. Better overall cognition in the RR class may indicate greater engagement with such interventions, aiming to prevent subsequent functional decline and further deterioration of their cognition.

Homeless and precariously housed individuals already face significantly elevated rates of physical and psychiatric illness relative to the general population, and profiling memory may help to identify vulnerabilities for various types of dementias in this group, though further evidence is required to determine individual risk. Future rehabilitation strategies might also emphasize greater early detection efforts and advocate for more routine neuropsychological screening for vascular-related cognitive decline and/or dementia.

4.3 Conclusion

The present findings highlight the considerable variability in memory functioning in homeless and precariously housed adults. The two distinct serial position profiles observed suggest that memory is disrupted in a variety of ways; conceivably one that is attributable to dysfunction in long-term memory processes and one that is product of disrupted short-term, working memory systems. Despite an inability to detect neuroanatomical or pathological differences between the derived subgroups, the present work underscores the utility of neuropsychological testing and research in a complex and heterogenous group. Greater efforts that build on the present findings, specifically to further probe underlying neuroanatomical and pathological correlates, are needed to broaden the present understanding of verbal memory functioning in this population.

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Table 1

Sample characteristics

	Overall Sample ($N = 411$)				RP Class ($N = 150$)				RR Class ($N = 261$)				
Characteristic	%	M *(SD)*	*Mdn*	*Range*	%	M *(SD)*	*Mdn*	*Range*	%	M *(SD)*	*Mdn*	*Range*	t/ χ^2 *(p)*
Age (years)		40.89 (11.45)	42	20-75		43.43(11.62)	45	20-75		39.43(11.12)	40	20-64	3.41(<.001)
Education (years)		10.48 (2.32)	10	2-17		10.15 (2.25)	10	5-16		10.67(2.34)	11	2-17	-2.25(<.05)
Premorbid IQ (WTAR)		98.26 (9.20)	99	73-122		96.11(8.27)	96	75-117		99.49 (9.49)	100	73-122	-3.79 (< .001)
CCI		2.93 (2.95)	2	0-14		3.45 (3.38)	3	0-14		2.63 (2.64)	2	0-11	2.55 (<.05)
Gender (male)	76				83				73				4.61(<.05)
History of being homeless	67				63				70				1.49 (0.22)
Ethnicity													1.82 (.77)
White	60				57				61				
Indigenous	25				25				25				
Asian	1.7				1.3				1.9				
Black	1.9				2.6				1.53				
Other/Mixed	11.4				13.3				10.3				
Psychiatric diagnosis (current)													
Schizophrenia	18.5				21				17.2				.53 (.47)
Psychotic disorder, any	34.3				34				34				9.88e31 (1.00)
Substance dependence (current)													
Cannabis	35				36				34				.04 (.84)
Alcohol	19				15				21				1.46 (.23)
Stimulant	79				79				79				.001(.98)
Opiate	53				46				58				4.92 (<.05)
Viral infection													
HIV[a]	14.4				23.8				22.1				1.40 (.24)
Hepatitis C[b]	62.5				97.6				95.6				.25 (.61)
Hepatitis B[c]	34.4				52.4				41.2				.45 (.50)
Herpes simplex[d]	84.6				90.4				91.2				.29 (.59)
Cytomegalovirus[e]	65				71.4				70.5				.01 (.90)
History of TBI	42				41				43				.01 (.91)

Note. CCI = Charlson Comorbidity Index. WTAR = Wechsler Test of Adult Reading. [a]$N_{overall} = 374$, [a]$N_{RP} = 136$, [a]$N_{RR} = 238$. [b]$N_{overall} = 368$, [b]$N_{RP} = 134$, [b]$N_{RR} = 234$. [c]$N_{overall} = 372$, [c]$N_{RP} = 135$, [c]N_{RP} 237. [d]$N_{overall} = 365$, [d]$N_{RP} = 135$, [d]$N_{RR} = 230$. [e]$N_{overall} = 346$, [e]$N_{RP} = 123$, [e]$N_{RR} = 223$. Between-group comparisons were conducted using Welch's independent samples t-tests and chi-square tests of independence for continuous and categorical variables, respectively.

Table 2

Descriptive statistics for neurocognitive tests by cognitive domain

	Overall Sample	RP Class	RR Class	
	M (*SD*)	M (*SD*)	M (*SD*)	t (*p*)
Verbal memory[a]				
Immediate recall (raw)	19.59 (5.90)	15.53 (4.58)	21.93 (5.28)	-12.88 (<.001)
Immediate recall (T)	31.65 (11.03)	24.58 (6.47)	35.71 (11.07)	-12.87 (<.001)
Delayed recall (raw)	6.23 (2.88)	4.64 (2.49)	7.14 (2.69)	-9.51 (<.001)
Delayed recall (T)	32.02 (11.36)	26.25 (8.04)	35.34 (11.67)	-9.32 (<.001)
Recognition (raw)	8.95 (2.35)	8.13 (2.41)	9.42 (2.19)	-5.39 (<.001)
Recognition (T)	37.56 (12.82)	32.95 (12.36)	40.22 (12.34)	-5.74 (<.001)
Primacy recall	62.77 (21.69)	39 (12.15)	76.44 (11.98)	-30.23 (<.001)
Middle recall	49.11 (22.9)	39.67 (20.65)	54.54 (22.40)	-6.81 (<.001)
Recency recall	51.12 (22.27)	50.39 (20.89)	51.53 (23.05)	.51 (0.61)
Total intrusion errors	1.02 (1.68)	1.25(1.92)	.89 (1.51)	2.02 (<.05)
Total repetition errors	1.26 (1.76)	.75 (1.30)	1.55 (1.93)	-5.05 (<.001)
Learning slope	1.41 (1.01)	1.18 (.96)	1.53 (1.01)	-3.49 (<.001)
Mental flexibility[b]				
IED total adj. errors (raw)	53.61 (46.00)	61.18 (45.41)	49.43 (45.90)	2.31 (<.05)
IED total adj. errors (T)	37.74 (18.49)	35.49 (17.45)	38.98 (18.96)	-1.74 (0.08)
Sustained attention[c]				
RVIP A' (raw)	.86 (.063)	.85 (.07)	.87 (.06)	-3.20 (<.001)
RVIP A' (T)	37.28 (14.07)	33.60 (15.18)	39.26 (13.04)	-3.41 (<.001)
Cognitive control[d]				
Stroop color-word (raw)	36.40 (10.81)	31.79 (9.65)	38.90 (10.60)	-6.65 (<.001)
Stroop color-word (T)	49.21 (9.79)	45.70 (9.30)	51.11 (9.54)	-5.39 (<.001)
Processing speed[d]				
Stroop word-reading (raw)	87.06 (18.14)	81.56 (17.42)	90.05 (17.85)	-4.52 (<.001)
Stroop word-reading (T)	43.30 (11.92)	40.24 (11.98)	44.96 (11.57)	-3.73 (<.001)

Note. [a]$N_{overall}$ = 411, N_{RP} = 150; N_{RR} = 261. [b]$N_{overall}$ = 352, [b]N_{RP} = 125; [b]N_{RR} = 277. [c]$N_{overall}$ = 333 , [c]N_{RP} = 117; [c]N_{RR} = 216. [d]$N_{overall}$ = 384, [d]N_{RP} = 135; [d]N_{RR} = 249. HVLT-R = Hopkins Verbal Learning Test Revised; RVIP A' = Rapid visual information processing subtest, A prime signal detection; IED = Intra extra dimensional subtest. Primacy, middle, and recency recall were calculated using immediate recall trials 1-3 on the HVLT-R. T-scores have a mean of 50 and standard deviation of 10, and reflect age- (and education, where available) adjusted normative data provided for each test. *p* values reflect mean differences between the Reduced Primacy (RP) and Reduced Recency (RR) class.

Table 3

Model fit indices for latent profile analysis

Model	Classes	AIC	BIC	Entropy	BLRT_p	prob_min	prob_max
Class-invariant diagonal	2	3390.37	3430.55	0.60	0.0099**	0.86	0.89
	3	3368.12	3424.38	0.65	0.0099**	0.69	0.90
	4	3359.78	3432.12	0.63	0.0099**	0.64	0.87
	5	3339.72	3428.13	0.65	0.0099**	0.76	0.85
Class-varying diagonal	2	3382.18	3434.42	0.64	0.0099**	0.86	0.91
	3	3368.07	3448.44	0.72	0.0099**	0.84	0.90
	4	3361.07	3469.57	0.76	0.0792*	0.79	0.88
	5	3330.39	3467.02	0.74	0.0099**	0.80	0.88
Class-invariant unrestricted[a]	2[a]	3353.23[a]	3405.48[a]	0.66 [a]	0.0099[a]**	0.86[a]	0.93[a]
	3	3347.75	3416.07	0.60	0.0495*	0.65	0.88
	4	3355.34	3439.73	0.56	0.7822	0.26	0.89
	5	3363.65	3464.11	0.50	0.9703	0.27	0.92
Class-varying unrestricted	2	3346.50	3422.85	0.56	0.0099**	0.85	0.88
	3	3343.06	3459.60	0.76	0.1881	0.84	0.90
	4	3343.85	3500.57	0.74	0.3465	0.79	0.89
	5	3348.47	3545.38	0.75	0.6337	0.72	0.91

Note. [a] = Chosen as best class solution. AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; BLRT = Bootstrapped Likelihood Ratio Test. Lower AIC and BIC values are favoured. Entropy is measure of classification uncertainty, with higher values reflecting greater model fit. Prob_min and prob_max reflect the minimum and maximum of the diagonal of the average latent class probabilities for most likely class membership, respectively, by assigned class.

Table 4

Between-class differences in HVLT-R component process scores

	Immediate recall			Delayed recall			Recognition			Learning slope		
	β	SE(*β*)	t (*p*)	*β*	SE(*β*)	t (*p*)	*β*	SE(*β*)	t (*p*)	*β*	SE(*β*)	t (*p*)
Class	0.46	0.5	11.24 (< .001)	0.36	0.26	8.16 (< .001)	0.23	0.24	4.81(< .001)	0.16	0.1	3.27 (< .01)
Age	-0.2	0.02	-4.95 (<.01)	-0.19	0.01	-4.39(< .001)	-0.15	0.01	-3.19 (<.01)	0.04	0.004	.81 (.42)
Education	0.22	0.1	5.57 (< .001)	0.21	0.05	4.77 (< .001)	0.1	0.05	2.00 (< .05)	0.09	0.02	1.77 (.08)
Gender	0.05	0.56	1.15 (.25)	0.02	0.29	.51 (.61)	-0.04	0.27	-.85 (.398)	0.02	0.12	.31 (.76)

Note. $N = 411$ for all models.

Table 5

Logistic regression results following transformation of intrusion and repetition errors

Repetition errors[a]	*β*	SE(*β*)	*z*	*p*	OR	95% CI
Class	-.94	0.22	-4.33	<.001	0.39	[-1.37, -.52]
Age	-.01	0.01	-1.09	0.28	1.00	[-.03, .01]
Education	.02	0.04	0.47	0.64	1.02	[-.07, .11]
Gender	-.01	0.24	-.04	0.97	1.00	[-.48, .46]
Intrusion errors[b]	*β*	SE(*β*)	*z*	*p*	OR	95% CI
Class	.27	0.21	1.27	.21	1.31	[-.15, .69]
Age	-.004	0.01	-.47	.64	1.00	[-.02, .01]
Education	-.03	0.04	-.61	.54	0.97	[.11, .06]
Gender	-.001	0.24	-.01	1.00	1.00	[-.47, .47]

Note. $N_{a,b}$ = 411, [a]Model: χ^2 (406) = 19.72, $p < .001$. [b]Model: χ^2 (406) = 2.37, $p = .67$.

Table 6

Between-class differences in additional neurocognitive measures

	Mental flexibility[a]			Sustained attention[b]			Cognitive control[c]			Processing speed[c]		
	β	SE(β)	t (p)	β	SE(β)	t (p)	β	SE(β)	t (p)	β	SE(β)	t (p)
Class	-0.09	5.17	-1.65 (.098)	0.13	0.007	2.29 (<.01)	0.24	1.05	5.10 (<.001)	0.17	1.88	3.46 (<.001)
Age	0.16	0.22	3.10 (<.001)	-0.1	0.0003	-1.80 (.07)	-0.27	0.04	-5.75 (<.001)	-0.13	0.08	-2.74 (<.01)
Education	-0.14	1.04	-2.73 (<.01)	0.25	0.001	4.61 (<.001)	0.25	0.22	5.34 (<.001)	0.22	0.4	4.49 (<.001)
Gender	0.13	5.9	2.46 (<.05)	0.02	0.008	.29 (.77)	0.07	1.15	1.50 (.135)	0.04	2.06	.75 (.45)

Note. [a]N = 352, [b]N = 333, [c]N = 384.

Table 7

Descriptive statistics for neuropathological markers and brain volumes of interest

	Overall sample	RP class	RR class	
	M (*SD*)	M (*SD*)	M (*SD*)	t (*p*)
cSVD burden	.30 (.48)	.26 (.51)	.31 (.54)	-.73 (.46)
HCav volume	.24 (.70)	.17 (.31)	.29 (.84)	-1.33 (.18)
ERC volume	4115.96 (1358.84)	4128.30 (1616.26)	4109.20 (1202.37)	.08 (.94)
HPC volume	7959.17 (1660.05)	7673.60 (1738.31)	8115.90 (1601.74)	-1.65 (.10)
DLPFC volume	85828.99 (7794.56)	85095.46 (6796.56)	86231.46 (8292.61)	-.97 (.33)

Note. Brain volumes reflect corrected volumes (adjusted for intracranial volume) and are bilateral (mm^3). $N = 175$ for the overall sample, $N = 62$ for the RP Class, $N = 113$ for the RR Class; N values reflect the number of participants with valid neuroimaging data. HCav = Hippocampal cavity, cSVD = cerebral small vessel disease, ERC = entorhinal cortex, HPC = hippocampus, DLPFC = dorsolateral prefrontal cortex.

Table 8

Neuroanatomical and pathological predictors of serial position classes

	OR	95% CI of *OR*	*p*
Age	0.95	[-.10, -.006]	< .05
Education	1.16	[.005, .292]	< .01
Gender	1.31	[-.581, 1.18]	0.54
HPC Volume	1.00	[-.0001, .0003]	0.33
ERC Volume	1.00	[-.0003, .0002]	0.59
HCav Volume	1.43	[-.21, 1.27]	0.33
cSVD Burden	1.45	[-.29, 1.08]	0.29
DLPFC Volume	1.00	[-.00007, .00004]	0.51

Note. χ^2 (166) = 19.27, p = .07. N = 175. OR = Odd's Ratio, HPC = Hippocampus, ERC = Entorhinal cortex, HCav = Hippocampal cavity, cSVD = cerebral small vessel disease, DLPFC = dorsolateral prefrontal cortex. Brain volumes reflect corrected volumes (adjusted for intracranial volume) and are bilateral (mm^3).

Figure 1

Flow chart describing participant inclusion/exclusion

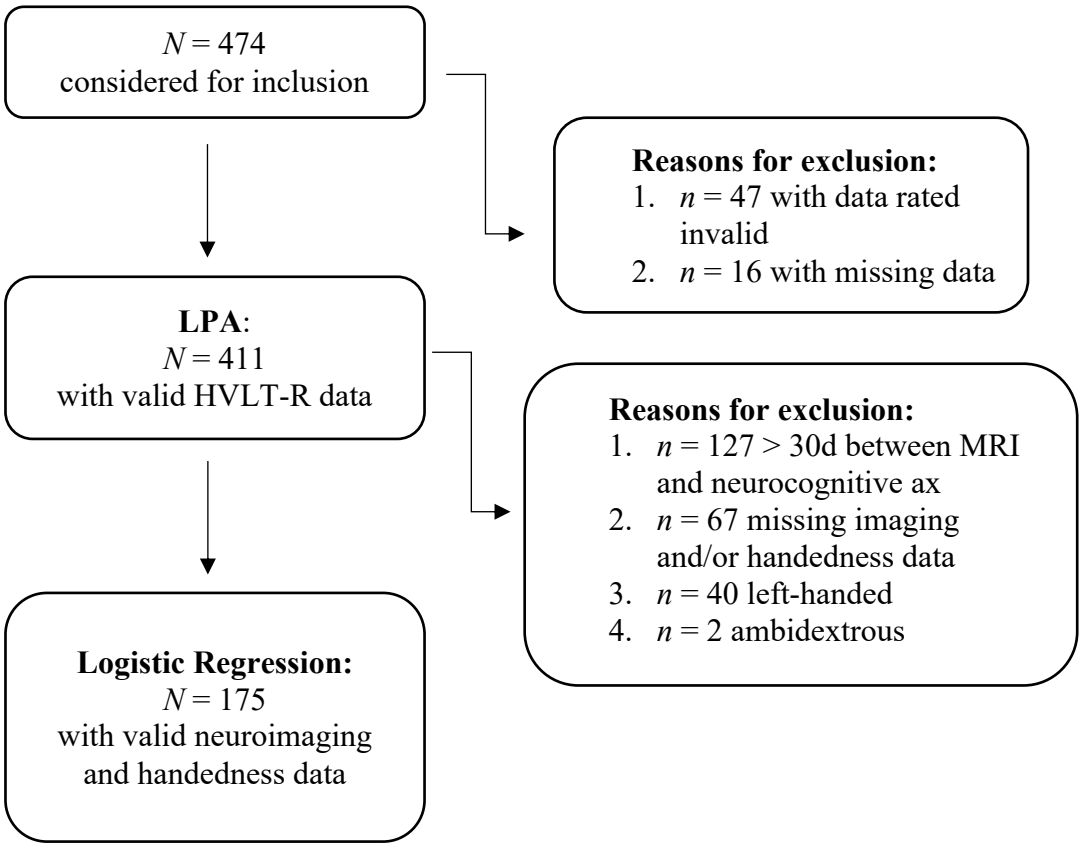
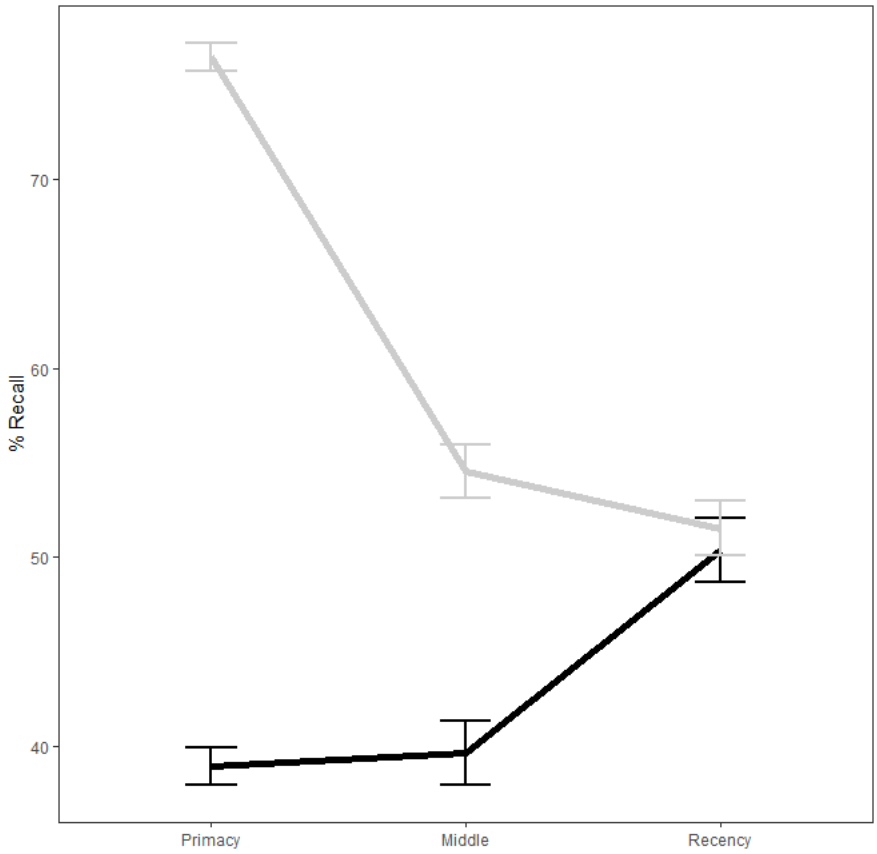


Figure 2

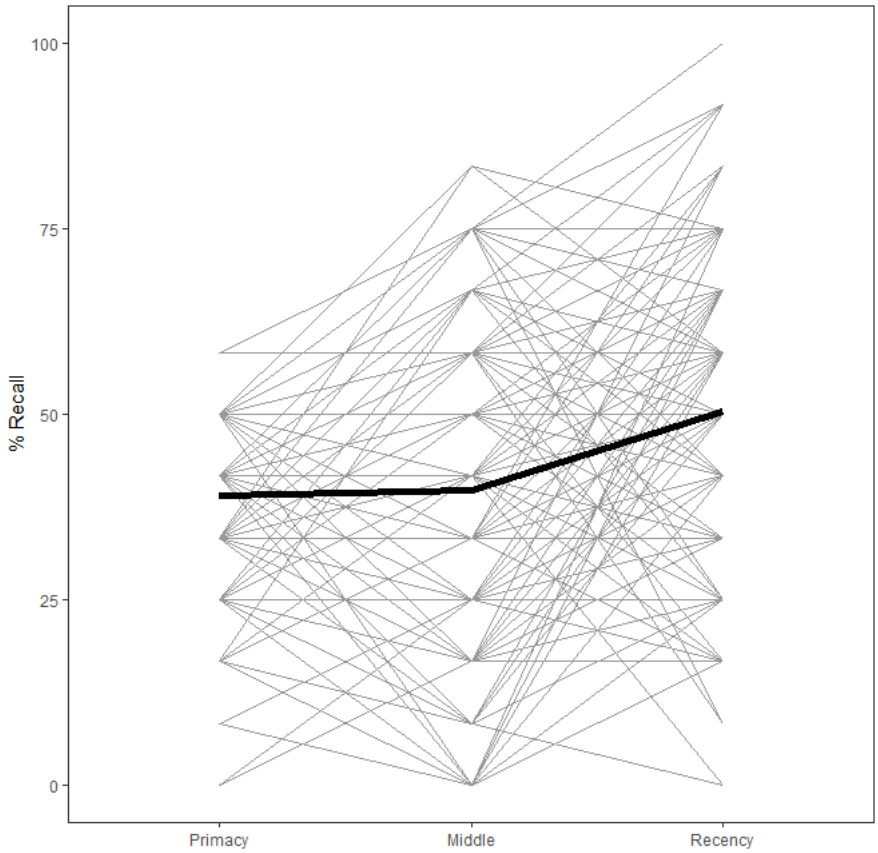
Distinct serial position profiles identified by the LPA



Note. N_{RP} = 150, N_{RR} = 261. Data points represent mean sample values for percent recall of items in each serial position (primacy, middle, recency). RP = Reduced Primacy; RR = Reduced Recency.

Figure 3

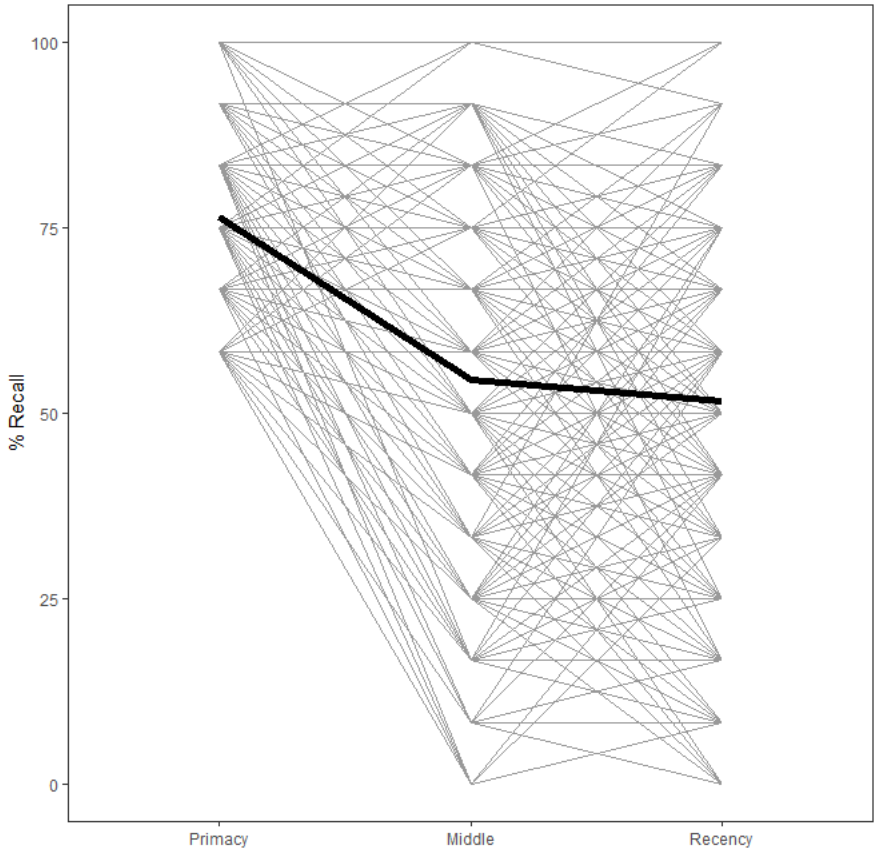
Individual serial position profiles of participants belonging in the RP class



Note. $N = 150$. The thick black line is representative of the average serial position profile for the RP Class. Data points represent values for percent recall of items in each serial position (primacy, middle, recency).

Figure 4

Individual serial position profiles of participants belonging in the RR class



Note. N = 261. The thick black line is representative of the average serial position profile for the RR Class. Data points represent values for percent recall of items in each serial position (primacy, middle, recency).

Appendix A – Descriptive Statistics Separated by Hemisphere

Supplementary Table 1

Descriptive statistics for brain volumes of interest separated by hemisphere

	Left Hemisphere				Right Hemisphere			
	Overall Sample	RP Class	RR Class		Overall Sample	RP Class	RR Class	
	M (*SD*)	M (*SD*)	M (*SD*)	t (*p*)	M (*SD*)	M (*SD*)	M (*SD*)	t (*p*)
HCav Volume	0.13 (.413)	.109 (.243)	.142 (.481)	-.60 (.56)	0.11 (.328)	.058 (.107)	.143 (.398)	-2.15 (.03)
ERC volume	2188.77 (835.36)	2197.02 (977.90)	2184.26(750.49)	.09 (.93)	1891.23 (724.18)	1894.14 (783.22)	1889.63 (693.28)	.04 (.97)
HPC volume	3921 (819.28)	3795.28 (888.67)	3989.85 (774.04)	-1.45 (.15)	4056.3 (885.74)	3895.86 (891.86)	4144.47 (873.79)	-1.78 (.08)
DLPFC volume	43029 (3946.84)	42679 (3379.22)	43222 (4228.04)	-.93 (.36)	42799 (4054.12)	42415 .9 (3604.78)	43009.7 (4281.46)	-.97 (.33)

Note. Brain volumes reflect corrected volumes (adjusted for intracranial volume) and are unilateral (mm^3). $N = 175$ for the overall sample, $N = 62$ for the RP Class, $N = 113$ for the RR Class; N values reflect the number of participants with valid neuroimaging data. HCav = Hippocampal cavity, ERC = entorhinal cortex, HPC = hippocampus, DLPFC = dorsolateral prefrontal cortex.

Appendix B – Multinomial Logistic Regression Analyses Separated by Hemisphere

Supplementary Table 2

Logistic regression results reported separately by hemisphere

	Left Hemisphere[a]			Right Hemisphere[b]		
	OR	95% CI of *OR*	*p*	*OR*	95% CI of *OR*	*p*
Age	0.95	-.09, -.005	0.03	0.95	-.097, -.0079	0.02
Education	1.16	.01, .30	0.04	1.14	-.005, .280	0.06
Gender	1.37	-.53, 1.21	0.48	1.29	-.61, 1.16	0.57
HPC Volume	1.00	-.0003, 0006	0.4	1.00	-.0002, .0006	0.36
ERC Volume	1.00	-.0005, .0003	0.59	1.00	-.0005, .0004	0.79
HCav Volume	1.25	-.59, 1.41	0.63	4.42	-.080, 4.10	0.16
cSVD Burden	1.51	-.23, 1.11	0.22	1.38	-.36, 1.04	0.37
DLPFC Volume	1.00	-.0001, .00007	0.55	1.00	-.00014, -.000072	0.52

Note. [a]χ^2 (166) = 13.32, p = .10; [b]χ^2 (166) = 16.71, p = .03. N = 175. OR = Odd's Ratio, HPC = Hippocampus, ERC = Entorhinal cortex, HCav = Hippocampal cavity, cSVD = cerebral small vessel disease, DLPFC = dorsolateral prefrontal cortex. Brain volumes reflect corrected volumes (adjusted for intracranial volume) and are unilateral (mm^3).