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Strategic encoding and retrieval processes in verbal recall among middle-aged and older adults

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The authors used an analysis of individual differences to examine the role of executive control in strategic encoding and retrieval in verbal recall. Participants enrolled in the Louisiana Healthy Aging Study completed measures of working memory (WM), cognitive status, vocabulary, and free recall of words. Indices of clustering in free recall were calculated to permit inferences on strategic encoding and retrieval processes. We hypothesized that WM would be more strongly associated with strategic encoding and retrieval metrics than vocabulary based on the assumption that successful remembering requires executive control in WM. Regression analyses, together with a variance portioning procedure, confirmed that WM had comparable levels of unique and shared variance with the strategic encoding and retrieval metrics, and both exceeded vocabulary. Theoretical and clinical implications of these data are considered, with the suggestion of future research in lifespan samples as opposed to exclusively young adult or older adult samples.

Statement of contribution

What is already known on the subject?

- There is a dearth of research on the relationships of working memory and long-term memory recall in older adults.
- Furthermore, long-term memory recall is related to successful encoding and retrieval processes in young adults but has been less researched in older adults.
- The use of retrieval strategies declines with increasing age.

What the present study adds?

- Executive functions may contribute more to encoding and retrieval processes in long-term memory retrieval in older adults than does vocabulary.

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- Individual differences in working memory (WM) play a large role in verbal recall for middle-aged and older adults.
- The cognitive predictor variables investigated here included working memory and vocabulary. Our main finding was that WM had comparable levels of unique and shared variance with the strategic encoding and retrieval metrics, and both exceeded vocabulary.

Background

One of the most basic observations about memory is that successful performance is the net effect of interactive processes that occur during acquisition (encoding), storage, and retrieval of information (Brown & Craik, 2000; Craik & Rose, 2012; Tulving & Thomson, 1973; Unsworth, 2016). Each of these stages provides opportunities to leverage memory effectiveness and increase performance through the use of strategies. The purpose of the present research was to examine the role of executive functions in strategy use in an older sample of adults who ranged in age from 44 to 97 years. Specifically, we focus on clustering in free recall in the context of cognitive ageing as a way to permit new inferences regarding long-term memory processes among healthy older adults.

Executive function in older adults

Executive function refers broadly to attentional control processes, including inhibition, task switching, and updating, or the coordination of information that is actively maintained in working memory (WM; Baddeley, 2012; Cowan, 2017; Miyake & Friedman, 2012). Declines in executive function processes, mediated in part by prefrontal and associated subcortical networks, have been implicated as a factor in cognitive ageing, but the extent is controversial (Cabeza & Dennis, 2012; Phillips & Henry, 2005). For each of these control processes, one can distinguish between strategic knowledge (what to do) and successful implementation. For example, with respect to inhibition there are reports that normal ageing is accompanied by larger Stroop effects, (Spieler, Balota, & Faust, 1996), even though the strategy is clear to all participants.[1] Similarly, older and younger adults are equally likely to comply with imagery strategies in a paired-associates memory task (Dunlosky & Hertzog, 1998), and older adults can also spontaneously adopt more effective strategies (Taconnat *et al*., 2009). Age differences when trying to inhibit spatial information are also often observed, even after controlling for age-related response slowing (Golob, & Mock, 2019; Rey-Mermet & Gade, 2018).

The executive function processes just described may be particularly vulnerable to changes within normal ageing (Luszcz, & Lane, 2008) and may precede conversion to abnormal ageing in some cases (Harrington *et al*., 2013). That is, clinical and neuropsychological evidence indicates that impairments of executive function may be associated with the conversion from mild cognitive impairment (MCI) to probable Alzheimer's disease (Albert, Moss, Tanzi, & Jones, 2001; Kirova, Bays, & Lagalwar, 2015). Despite its importance to adult cognition, relatively few studies have examined the role that executive functions may play in episodic memory among heathy older adults (Bouazzaoui *et al*., 2014; Bryan, Luszcz, & Pointer, 1999; Bunce & Macready, 2005). Additionally, it has been demonstrated that 'executive function' is a broad term that can encompass many abilities and that individuals in particular sub-fields of psychology such as clinical versus cognitive psychologists may use different measures to assess similar

[1] *Note that an age-related increase in the Stroop effect is often not evident after controlling for overall slower responding in older participants (Verhaeghen & Cerella, 2002).*

constructs. For example, research has indicated that measures of executive functioning on the one hand, and WM capacity on the other, have high levels of shared variance (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). Thus, in the current paper, we conceptualized executive functioning broadly and assessed this construct via multiple measures of WM.

The relationships among age, WM capacity, and executive functioning were recently evaluated in work by Zuber *et al*. (2019). The authors contrasted a group of younger adults ($N = 175$), who ranged in age from 18 to 39 years, with a group of older adults ($N = 107$), who ranged in age from 57 to 77 years. Two measures of each construct were included, which permitted multiple analyses to determine the best predictors of performance. The findings supported the executive attention framework of memory ageing (Engle & Kane, 2004; McCabe *et al*., 2010). The best prediction of WM capacity arose from a model that did not include age (a continuous variable), but did include the measures of updating and inhibition. Measures of shifting did not significantly predict WM capacity scores. The positive results for the updating and inhibition components have both theoretical and applied implications. Theoretically, their findings are consistent with the executive attention framework of memory ageing in that they highlight the role of these two processes in 'active memory maintenance and inhibitory control' (Zuber *et al*., 2019, p. 201) and suggest that future research on these particular executive functions in relation to WM capacity would be valuable. With respect to applied implications, Zuber et al.'s findings have applications for maintaining cognitive function and independent living, which is often the goal of focused WM training studies with older adults.

Encoding and retrieval strategies in older adults

Evidence of age declines in spontaneously adopting a deep level of encoding is well documented in the cognitive ageing literature (Craik & Rose, 2012) and may reflect age-related decreases in executive control. Moreover, at least in women, declines in executive function may antedate memory declines and contribute to memory impairment (Carlson, Xue, Zhou, & Fried, 2009; see Kirova, Bays, & Lagalwar, 2015 for review). Executive function may also impact memory retrieval strategies. Memory retrieval strategies are commonly assessed by varying the level of support to aid retrieval, from low support levels when participants must freely recall information without external cues to higher support levels such as in cued recall or recognition tasks (Bouazzaoui *et al*., 2014; Craik & McDowd, 1987; Craik & Rose, 2012). Other evidence has shown that older adults employ retrieval strategies less often than do younger adults, which has consequences for everyday memory performance (for review, see Touron, 2015).

Although there are differences in the way that older adults may spontaneously employ retrieval strategies, Kuhlmann and Touron (2016) provided evidence that direct instruction of a clustering technique in a free recall task can improve older adults' performance. An important manipulation within their research was the presentation format of the items, and in a whole-list presentation format, direct instruction to use a clustering strategy not only led to increased performance, but also to significant correlations with measures of working memory capacity. These correlations were stronger in magnitude for the older adult group, who ranged in age from 60 to 84 years. The findings from this study provide key evidence regarding both strategic retrieval in older adults and the importance of working memory capacity when older adults utilized a specific retrieval strategy.

Age-related differences in executive function may be pronounced in the oldest-old (85+ years) relative to younger reference groups, yet relatively few studies have focused on the cognitive capabilities of those oldest-old adults who show no signs of dementia or other substantial neurological impairments (Cherry *et al.*, 2008, 2012; Bäckman & Wahlin, 1995; Elliott *et al.*, 2011). For instance, Cherry *et al.* (2008) found clear evidence of a pictorial superiority effect in free recall and recognition of simple line drawings and matching words in the Louisiana Healthy Aging Study (LHAS), which had participants who ranged in age from 45 to over 90 years. In a later study, Cherry *et al.* (2012) examined the role of a semantic processing strategy during acquisition on recall and recognition of pictures and words. Participants were given a semantic orienting task or standard intentional learning instructions. Results confirmed a pictorial advantage in recall and recognition that was comparable in size for all age groups. The magnitude of the benefit was larger for those with the semantic orienting task, relative to the control condition, indicating that the memorial advantage of semantic encoding was confined to pictorial stimuli. The finding that nonagenarians, defined as people 90 years of age and older, recalled and recognized more pictures than words as well as did their younger counterparts was remarkable, although Cherry et al. did not directly address the role of executive functions in episodic memory performance, which motivated the present research.

The current study

The present study used an analysis of individual differences to address the role of executive control in encoding and retrieval strategies in verbal recall using original data from our earlier reports (Cherry *et al.*, 2008, 2012). Previous work has defined the utility of examining variation across individuals to test general theories of cognition (Kosslyn *et al.*, 2002; Salthouse, 2017; Underwood, 1975). A sample of 237 adults was created by combining data (control conditions, words only) from Cherry *et al.* (2008, 2012). We examined associations between free recall and a set of cognitive variables assumed to vary in executive function involvement from the most (e.g., working memory) to the least (e.g., vocabulary). Supporting the assumption that WM and vocabulary involve different levels of executive function, McCabe *et al.* (2010) demonstrated a correlation between the latent variables of executive functioning and WM capacity to be .96, while the correlation between the latent variable of vocabulary and executive functioning was .45. Importantly, the correlation between the latent variable of vocabulary and WM capacity was the smallest of these relationships, at .27, indicating discriminant validity among these constructs.

Within the current study, to-be-remembered items were simple words that were exemplars of four taxonomic categories (e.g., peacock, a type of bird; corn, a vegetable). Strategic encoding and retrieval processes were inferred based on two indices of clustering in free recall: (1) the average number of words recalled per category as an index of strategic encoding, and (2) the number of categories among correctly recalled items, which is presumed to reflect strategic retrieval. The former metric arguably reflects the extent to which participants may organize to-be-remembered items into categories during acquisition, whereas the latter metric may reflect participants' retrieval plan (Bäckman & Larsson, 1992; Bäckman & Wahlin, 1995). Prior work shows that during recall older adults have somewhat longer times shifting between categories, even on trials when accuracy is equal to young adults (Wingfield & Kahana, 2002). This was not an issue in the present study, because recall continued until the participant decided to stop.

One line of thinking would suggest that strategic encoding may be more resource demanding, with greater reliance on executive control processes relative to strategic retrieval. On the assumption that semantic activation during encoding remains age invariant in late life (Hartman & Warren, 2005; McCabe & Hartman, 2008), we expected that the taxonomic categories from which these items were drawn would be activated and available to guide retrieval at test. Thus, free recall of a given memory item would be facilitated by referencing the category that had been activated when the item was encoded. One might speculate that memory span measures with presumed executive function involvement would be more strongly associated with strategic encoding than retrieval, while vocabulary (a proxy for verbal intelligence) would show associations of similar magnitude across indices of strategic encoding and retrieval. However, another line of thinking would suggest that both encoding and retrieval processes will rely upon executive functions, such as WM, because both require strategic effort and controlled attention (Unsworth, 2016; Zuber *et al.*, 2019). Given the lack of research in older adults, especially with the inclusion of individuals above the age of 85, the current work can provide new evidence concerning encoding and retrieval dynamics in episodic memory and also has important applied implications for cognitive health in later life.

Methods

Participants

A sample of 237 middle-aged and older individuals was created by combining datasets from two previously published studies (*M* age = 72.7 years, *SD* = 15.9 years, range 44–97 years; see Cherry *et al.*, 2008, 2012). All were enrolled in the Louisiana Healthy Aging Study (LHAS), a multidisciplinary study of the determinants of longevity and healthy ageing. LHAS participants were sampled randomly from the Voters Registration 2000 files for those age 20–64 years old and from the Medicare Beneficiary Enrollment Data file of the Center for Medicare and Medicaid Services (CMS) for those age 65 years and older living in the greater Baton Rouge area. Informed consent was obtained for all participants according to protocols approved by the respective Institutional Review Boards. All were visually capable and free of known neurological impairment due to stroke or dementia.

Cognitive status measures

The Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was used to assess cognitive status. All participants who were retained in the final analyses scored at least a 25 or higher on the MMSE. Participants also completed a measure of vocabulary knowledge (Jastak & Jastak, 1964) which served as a proxy for verbal intelligence. The majority of participants had at least a high school diploma or GED equivalent (92%). Their responses to a demographic questionnaire indicated that most rated their health as good to excellent (82.1%), that health considerations prevent activities ’a little’ or ’not at all’ (88.9%), and that their health was the same or better than their age mates (97.4%). Further information on LHAS participants’ social activity and health-related characteristics is reported elsewhere (Cherry *et al.*, 2013).

Three memory span measures were administered where participants simultaneously held and processed auditorily presented information. Two of the measures were the forward digit span (FDS) and backward digit span (BDS) tests from the WAIS (Wechsler, 1981). Digit span tests were administered according to the established protocol (1-s per item presentation rate with immediate recall) and were scored by giving full (set size) credit for sequences where both of the two trials were correct and half credit if only one trial per set size was correct. The third measure, the size judgement span (SJS) test (Cherry, Elliott, & Reese, 2007) required the manipulation of visuospatial information. Participants heard progressively longer sequences of individual words whose referents could be easily visualized (e.g., frog–piano–hairpin) and repeated the sequence of words in order of the referents' relative physical size, from the smallest item to the largest item (e.g., hairpin–frog–piano). SJS words were presented at a 1-s rate. Immediate recall followed. Two practice trials were given (two item sequences). After practice, participants were given three trials of two, three trials of three, and so forth, until they missed three consecutive trials within a sequence length. The SJS test was scored by giving full credit to sequence levels where at least two out of three trials were correct and half credit (0.5) if only one of three trials was correct (Cherry *et al.*, 2007).

Materials and procedure

Stimulus items used in the original studies (Cherry *et al.*, 2008, 2012) for the episodic memory task were simple, black and white line drawings and matching words taken from a standard corpus, and were matched for image and name agreement (Snodgrass & Vanderwart, 1980). The to-be-remembered items were presented individually on 6 × 9 inch index cards, as reported in Cherry *et al.* (2008, 2012). Participants were tested individually using standard intentional learning instructions, where a memory test was expected. An example card was shown first, followed by a 3-item practice encoding and free recall task to familiarize participants with the procedure. During acquisition, participants studied a list of 16 items presented for study (5 s rate) followed by a 2-min distractor task. Acquisition items were presented in a uniform order across participants, although categorical membership of the stimuli was random. Participants orally recalled these items, and the experimenter recorded their answers verbatim on a prepared sheet. A second acquisition and test sequence followed, where the stimulus type (picture or word) was changed relative to the first sequence, counterbalanced across participants. The analyses reported here are confined to free recall of words only, however, consistent with the goals of this investigation. Lastly, the memory span and vocabulary measures were administered and debriefing followed.

Results

Overview of scoring and analyses

For each participant, the three memory span measures were scored as described previously. Free recall was scored as the proportion of items correctly recalled (out of 16). Clustering analyses were conducted using the Scoring Options for Recall Tests (SORT) program, version 2.0 (Elie & Payne, 1999). Two dependent measures were calculated separately for each participant: the average number of words recalled per taxonomic category (out of 4) and the average number of taxonomic categories accessed, after Cherry *et al.* (2008, 2012). After preliminary analyses were completed, these data were examined for outliers and missing data. Two participants had WM scores with z-scores ±3, three participants were missing data on the vocabulary measure, and one participant scored a 23 on the MMSE (see Appendix for histogram of ages for the final sample,

$N = 231$). To improve interpretability, these participants were removed from the analyses reported next.

These data were analysed according to the following plan. Correlations among age (treated as a continuous variable) and the cognitive performance measures were carried out (see Table 1). The relationship between the two measures of memory span that included a manipulation or processing component, BDS and SJS, were examined for the suitability of creating a WM composite variable. We then calculated correlations among the composite measure of WM and vocabulary with the strategic encoding and retrieval variables, with and without holding age constant (see Table 2). Furthermore, given our interest in the relationships among strategic encoding and retrieval processes with measures of WM, we utilized a set of simultaneous regressions that allowed us to partial out the unique and shared variance among the multiple predictors (see Tables 3–5). Using Venn diagrams along with the regression analyses can provide a view of the shared variance among predictors that other methods could not provide (see Chuah & Mayberry, 1999; Cowan *et al.*, 2005 for a similar analysis approach in child development). Given our specific interest in the relationships among the measures of WM, vocabulary, and age in their prediction of the encoding and retrieval variables, the method of using regression and Venn diagrams provided indications of shared and unique variance in different combinations (e.g., all three predictors of WM, vocabulary, and age; pairs of predictors; and finally unique variance from individual predictors).

Correlations

Inspection of Table 1 indicates that age was negatively correlated with all of the cognitive variables, as expected. BDS and SJS were also significantly and positively correlated, as expected based on prior literature (Cherry *et al.*, 2008; Cherry *et al.*, 2007). These two measures were converted to z-scores and were averaged together to create a WM composite variable. Scores on the MMSE were positively correlated with vocabulary; however, the MMSE was used as a screening measure in this research, so range restriction prohibits further meaningful analysis of the MMSE scores. Vocabulary was positively correlated with the recall metrics as expected (r's ranging from .34 to .39). Of greater interest are the correlations among performance on the cognitive variables assumed to vary in executive function involvement and overall verbal recall (the total number of items correctly free-recalled), strategic encoding (the average number of words recalled within categories), and strategic retrieval (the number of categories accessed) presented in the first through the third columns of Table 2, respectively.

The results in Table 2 (upper panel) indicate that vocabulary was associated with both strategic encoding and retrieval and had similar r values,[2] which is in line with expectations. Because chronological age was significantly correlated with all of the cognitive variables (Table 1), we calculated partial correlations to statistically control for age effects (see Table 2 lower panel). Note that the ability to control for age effects was facilitated by having a large age range in the present sample (44–97 years). Importantly, the same pattern of outcomes was mostly observed, although r values were smaller after statistically controlling for the variance associated with age. Additionally, the correlation

[2] *We utilized the method of Fisher's* r *to* z *transformation (Lee & Preacher, 2013) and determined that these correlations were not statistically significantly different (*$r = .36$ *and* $r = .34$, $z = 0.357$, $p = .721$*).*

Table 1. Means, standard deviations, and correlation coefficients

	M	*SD*	1	2	3	4	5	6	7	8	9
Age (1)	72.8	15.7	–								
FDS[a] (2)	5.7	1.1	−.33**,a	–							
BDS[a] (3)	4.2	1.0	−.22**,a	.53**,a	–						
SJS[b] (4)	4.1	0.9	−.44**,a	.50**,a	.46**,a	–					
MMSE[c] (5)	28.6	1.4	−.46**,a	.25**,a	.30**,a	.36**,a	–				
Vocabulary[d] (6)	24.5	7.3	−.17**,a	.33**,a	.42**,a	.34**,a	.40**,a	–			
Verbal recall[e] (7)	6.0	3.4	−.54**,a	.36**,a	.29**,a	.48**,a	.48**,a	.39**,a	–		
Strategic encoding[f] (8)	1.9	0.8	−.46**,a	.35**,a	.29**,a	.44**,a	.41**,a	.36**,a	.88**,a	–	
Strategic retrieval[g] (9)	2.9	1.1	−.51**,a	.24**,a	.24**,a	.38**,a	.43**,a	.34**,a	.81**,a	.57**,a	–

Note. [a]Digit span tests (FDS and BDS) from the Wechsler Adult Intelligence Scale (Wechsler, 1981).; [b]Size judgement span (SJS; Cherry *et al.*, 2007).; [c]Mini-Mental State Examination (MMSE; Folstein *et al.*, 1975).; [d]Vocabulary (Jastak & Jastak, 1964).; [e]Verbal recall = the total number of words recalled.; [f]Strategic encoding is based on the mean number of words recalled per taxonomic category.; [g]Strategic retrieval is based on the mean number of categories accessed during free recall.; $^{**}p < .01$.

Table 2. Correlations among cognitive variables and recall metrics

	Verbal recall	Strategic encoding	Strategic retrieval
FDS	.36**	.35**	.24**
WM	.46**	.43**	.37**
Vocabulary*,[a]	.39**	.36**	.34**
r values with age partialed out			
FDS	.23**	.24**	.10
WM	.32**	.30**	.22**
Vocabulary*,[a]	.36**	.32**	.29**

Note. Entries are Pearson's correlation coefficients. Verbal recall reflects the total number of words recalled. Strategic encoding is inferred from the mean number of words recalled per category. Strategic retrieval is inferred based on the mean number of categories accessed. FDS indicates the forward digit span measure, and WM indicates the working memory composite created from backward digit span and size judgement span.
[a]Vocabulary (Jastak & Jastak, 1964).; $^{**}p < .01$.

Table 3. Simultaneous regression analysis for strategic encoding metric

	B	*T*	sr^2	R^2	*F*
Age	−0.02	−5.75**	.10		
WM	0.19	3.05**	.03		
Vocab	0.02	3.46**	.04	.32	35.22**

Note. $^{**}p < .01$; WM stands for the working memory composite variable (average of z-scores of BDS and SJS).

Table 4. The R^2 values produced from variance-partitioning regression analyses predicting strategic encoding and retrieval

	Encoding		Retrieval	
Variables	R^2	*F*	R^2	*F*
Age, WM, Vocab	.32	35.22**	.33	37.16**
Age, WM	.28	44.67**	.29	46.94**
Age, Vocab	.29	46.47**	.32	54.05**
WM, Vocab	.22	31.83**	.17	23.86**
Age	.21	60.19**	.26	79.33**
WM	.18	50.98**	.14	35.81**
Vocab	.13	34.13**	.11	29.49**

Note. $^{**}p < .01$. WM stands for the working memory composite variable (average of z-scores of BDS and SJS).

between FDS and the strategic retrieval measure was no longer significant, possibly due to the minimal concurrent processing demands associated with the present FDS measure.

We then conducted a simultaneous regression predicting performance on the average number of words recalled to investigate strategic encoding (see Table 3). Age, the WM composite, and vocabulary scores were entered into the analysis as predictors, which

Table 5. The simultaneous regression analysis predicting strategic retrieval

Variables	*B*	*t*	sr^2	R^2	*F*
Age	−0.03	−7.27**	.16		
WM	0.14	1.62	.01		
Vocab	0.03	3.57**	.04	.33	37.16**

Note. **$p < .01$; WM stands for the working memory composite variable (average of *z*-scores of BDS and SJS).

resulted in a significant outcome, $F(3, 227) = 35.22$, $p < .01$. Following this significant finding, the three predictors were then entered into a series of simultaneous regressions, with each of the three predictors entered in seven possible orders (such as ABC, AB, AC, BC, and A, B, and C), after Chuah and Mayberry's (1999) and Cowan *et al*'s (2005) procedure. Using subtraction can then lead to the calculation of the unique variance in one predictor at a time; for example, using the regression with variables ABC and finding the R^2 and then using the regression with variables BC to subtract the R^2 value provide the unique variance in A. The outcome of the regressions presented in Table 4 was summarized in Figure 1, illustrating the proportion of unique and shared variance among the predictors in strategic encoding.

The same method was employed when analysing the contribution of these three predictors to the number of categories recalled, our measure of strategic retrieval. The simultaneous regression was also significant, $F(3, 227) = 37.16$, $p < .01$ (see Table 5). The subsequent simultaneous regressions and the R^2 values are also shown in Table 4, and these values were used to create the Venn diagrams depicted in Figure 2.

Examination of Figures 1 and 2 revealed that the unique variance accounted for the WM composite was 3% for strategic encoding, and 1% for strategic retrieval, while the shared variance was 15% and 13%, respectively. Additionally, the shared variance between WM and age was 6% for strategic encoding, and 5% for strategic retrieval. In both cases, the relationships between age and vocabulary were effectively at 0%. Chronological age was responsible for 10% of the unique variance in strategic encoding and 16% for strategic

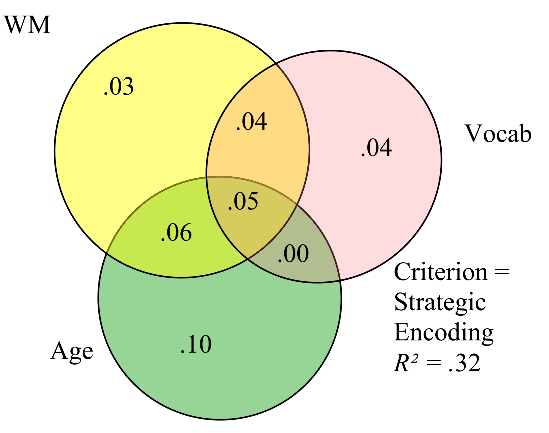

Figure 1. Unique and shared variance from age, the working memory composite variable, and vocabulary scores predicting strategic encoding. This diagram is based upon the regressions carried out in Table 4. Overlapping circles indicate portions of shared variance in strategic encoding.

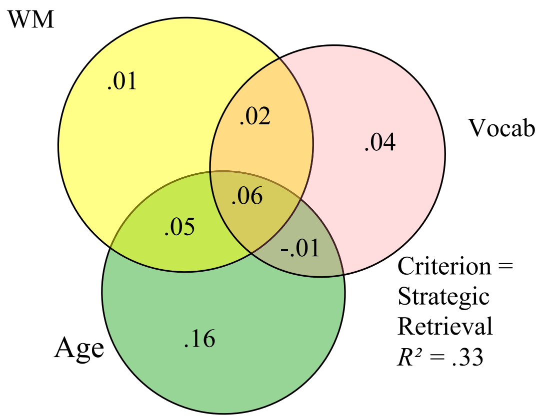

Figure 2. Unique and shared variance from age, the working memory composite variable, and vocabulary scores predicting strategic retrieval.

retrieval, while the shared variance was 21% and 26% respectively. Finally, vocabulary accounted for smaller amounts of overall variance, and a total of 13% and 11% of variance were accounted for the unique and shared variance in strategic encoding and retrieval. Thus, the patterns of variance indicated by the series of simultaneous regressions for the two dependent variables were very similar.

Discussion

In the present investigation, an individual differences approach was used to examine the role of executive control in verbal recall in a sample of middle-aged and older community-dwelling adults which included many cognitively healthy nonagenarians from the LHAS. The wide age range (44–97 years) and the inclusion of multiple cognitive measures are strengths of this study. Original data from two prior reports (Cherry *et al*., 2008, 2012) were combined to create a larger dataset here, which allowed us to test hypotheses about strategic encoding and retrieval processes in verbal recall. Two main findings emerged from the analyses. First, WM was roughly equally associated with strategic encoding and retrieval, providing additional evidence supporting the notion that executive control contributes to successful encoding and retrieval in older adults as well as in young adults (Kuhlmann & Touron, 2016; Unsworth, 2016; Zuber *et al*., 2019; see Figures 1 and 2). Second, vocabulary had effectively no shared variance with chronological age in the prediction of either strategic encoding or retrieval, which differed from the pattern described above with WM and chronological age. These findings and their theoretical and clinical implications are discussed in turn next.

These data represent an important addition to the literature on individual differences in older adults' cognitive abilities because of the very large age range of the participants included here. Furthermore, the use of the Venn diagrams to illustrate the unique and shared variance allowed us to understand the relative contributions of executive function to strategic encoding and retrieval in long-term memory, as measured by a WM composite, separate from age and from a proxy for verbal intelligence, vocabulary scores.

We found that WM was associated with strategic encoding and retrieval. This pattern of results extends our prior work where episodic memory for words and simple line drawings was compared by age group to establish the pictorial superiority effect in nonagenarians (Cherry *et al*., 2008, 2012). Additionally, the current study extends beyond prior work on individual differences in older adults by including a large group of nonagenarians. The present results support the view that executive control is involved in the implementation of organizational strategies at encoding based on the to-be-remembered words' taxonomic categories. We suspect that participants were aware of the categorical membership of the words during encoding; in turn, categorical cuing may have guided participants' retrieval plan at test (Bäckman & Larsson, 1992; Bäckman & Wahlin, 1995). Indeed, participants' responses to a post-test strategy assessment are consistent with this speculation (see Cherry *et al*., 2012), although further research using more sensitive indices of metacognitive awareness than verbal report would be desirable (see also work by Kuhlmann & Touron, 2016). Our findings extend Bäckman and colleagues' work, pointing to the potentially critical role of executive functions during encoding (Craik & Rose, 2012) and retrieval (Kuhlmann & Touron, 2016). The current data add to the body of literature on the relationship of WM to LTM recall in young adults (Unsworth, 2016, 2017) and support the prior findings in young adults that WM and LTM recall share critical variance at both encoding and retrieval. These findings also join others in the literature where multiple cognitive tests have been linked to episodic memory in later life (Cherry & LeCompte, 1999; Cherry & Park, 1993; Head, Rodrigue, Kennedy, & Raz, 2008).

On a broader note, the use of individual differences in various cognitive domains to dissect processes underlying memory performance can have applications to clinical studies. One approach is to more precisely define normal ageing effects on interactions among executive function strategies and memory performance, which could improve clinical test sensitivity. Control of memory strategies has been used to successfully increase sensitivity in distinguishing healthy older controls from MCI patients (Bennett *et al*., 2006). Examining individual differences in WM, or more broadly construed as executive function, could also be used to examine memory function in subtypes of frontotemporal dementia (FTD). The behavioural variant of FTD loads more strongly on executive function, while primary progressive aphasia, the other main FTD subtype, is more reflective of crystalized knowledge (Bang, Spina, & Miller, 2015). It may be fruitful to consider relations among strategic encoding and retrieval that differentially reflect executive function, and explore the impact of these strategies on episodic memory in these populations.

Our findings and their implications should be considered in light of at least three methodological limitations. First, the LHAS participants included in this sample were physically active, socially engaged, and psychologically capable at the time of testing, which raises concerns about the representativeness of the sample and possible selection bias in the direction of vitality. Second, these are cross-sectional data so causal inferences based on the relationships observed here are not warranted. Most would agree that executive control and strategy use are dynamic processes that vary over time for healthy older adults as well as persons with cognitive dysfunction secondary to dementia or other neuropathological conditions. Future research that includes longitudinal comparisons with two points of temporal reference (at minimum) is needed to track potential changes in responses over time. Third, we did not include clinical measures of executive function in the original LHAS test battery, which would have permitted more precise inferences on the neurocognitive mechanisms underlying strategic encoding and retrieval, an exciting direction for future research.

In closing, the present data underscore the value of an individual differences approach to understanding encoding and retrieval dynamics in verbal recall. Future research to explore the generality of these findings seems warranted so that explicit connections between the young adult and older adult literatures can be made.

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Conflicts of interest

All authors declare no conflict of interest.

Author contribution

Katie Cherry, PhD (Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Writing – original draft; Writing – review & editing). Emily M. Elliott (Conceptualization; Formal analysis; Writing – original draft; Writing – review & editing) Edward J. Golob (Conceptualization; Methodology; Writing – original draft; Writing – review & editing) Jennifer Silva Brown (Data curation; Project administration; Writing – original draft; Writing – review & editing). Sangkyu Kim (Investigation; Project administration; Resources). S. Michal Jazwinski (Data curation; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Writing – review & editing).

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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Appendix :

Histogram of the chronological age variable