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The protective effect of educational level varies as a function of the difficulty of the memory task in ageing

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Competing interests

We declare no competing interests.

Abstract

This study aimed to explore the effects of age and educational level on recall performance and organisational strategies used during recall as a function of the level of memory task difficulty. Younger (*n* = 55, age range = 20 - 39 years) and older (*n* = 45, age range = 65 – 75 years) adults learned a word list where the words were either already semantically grouped (easy) or presented in pseudo-random order (hard), and then recalled the words. The number of words recalled was calculated, and an index of clustering was computed to assess organisational strategies. Older adults recalled less words than the younger ones. Older adults with a higher educational level recalled more words than their counter-parts with a lower educational level when the memory task was easier, but they all performed similarly on the harder memory task. Moreover, we noted a strong positive association between educational level and semantic organisation in older adults when the memory task was easy. Regardless of educational level, older adults used semantic organisation as much as younger adults when the memory task was easy. However, when the memory task was harder, older adults showed significantly less organisational strategies than younger adults, the latter using semantic organisation to boost their recall performance. In sum, the protective effect of educational level seems to be restricted on recall performance, but not organisational strategies, in easy memory tasks providing sufficient external information about the most efficient mnemonic strategy to use.

Key words: episodic memory, semantic organisation, ageing, educational level

Introduction

One of the main explanations of the age-related decline in episodic memory is that older adults have difficulties in recalling information and selecting and using efficient strategies at the encoding and/or retrieval stages of memory tasks (Craik & Rose, 2012; Guerrero-Sastoque et al., 2019; Taconnat et al., 2009, Taconnat et al., 2020). However, individual factors such as level of education may decrease or slow the age-related decline in memory (e.g., Angel et al., 2010; Foubert-Samier et al., 2012). The main objective of this study was to explore the effects of age and of educational level on recall performance and the readiness to use semantic organisation according to variations in episodic memory task difficulty.

Bousfield (1953) showed that when presented with a randomly-ordered list of words belonging to several categories, individuals recalled the words by organising them into semantic categories during a free recall task. These results have since been replicated, revealing that those who spontaneously use this semantic organisation retrieve more words (Denney, 1974; Puff, 1979). Interestingly, although older adults always show lower recall performance than younger adults, some studies have reported that older adults do use semantic organisation spontaneously with a gain in performance, whereas other research has reported deficits regarding the use of this strategy (e.g., Howard & Kahana, 1999; Taconnat et al., 2009, Taconnat et al., 2020; West & Thorn, 2001). Although the use of semantic organisation may be spared in older adults (Golomb et al., 2008), a recent eye-tracking study by Taconnat et al. (2020) showed that older adults at least try to semantically organise the words during encoding, but fail to use this strategy at recall as compared to younger adults. In an environmental support model, Craik (1990) posited that even though older adults fail to efficiently use processes or strategies to assist better memorisation, they can do so when given appropriate directing tasks. This model has been empirically validated by several studies showing that giving enough environmental support information during encoding makes older adults use various memory strategies to improve performance as much as younger adults (e.g., Dunlosky et al., 2005; Froger et al., 2009; Guerrero-Salstoque et al., 2019; Naveh-Benjamin et al., 2007; Taconnat et al., 2007). However, it is also unknown whether increasing the amount of environmental support during encoding (e.g., presenting the items already semantically organised) would make older adults use more semantic organisation during recall with improved subsequent performance.

Critically, older adults show great variability in terms of how ageing is impacting brain regions and associated behavioural performance decline, with some keeping a high level of cognitive functioning as compared to others (Raz et al., 2010). To account for this variability, Stern (2002) has proposed the cognitive reserve hypothesis referring to the maintenance of high levels of cognitive performance, despite the natural age-related changes within the brain, by accessing intact neurocognitive processes or by compensatory processes (see also Stern, 2021). This cognitive reserve is modulated by intrinsic factors (e.g., intelligence) and extrinsic factors (e.g., educational level, leisure activities). Of particular interest here, among other socio-demographic factors, higher educational level provides a strong proxy of cognitive reserve (Jefferson et al., 2011; Josefsson et al., 2012). Indeed, recent meta-analyses have highlighted the protective effect of educational level on performance on various cognitive measures, including episodic memory (e.g., Lövdén et al., 2020). Importantly, empirical studies on episodic memory using paired-associates or cued-recall paradigms have shown that more educated older adults outperform their less educated counterparts (Angel et al., 2010; Guerrero-Sastoque et al., 2021; Shimamura et al., 1995). Moreover, recent studies showed that educational level is positively associated to self-reported strategy use and a variety of cognitive strategy use (Frankenmolen et al., 2018; Guerrerro et al., 2021). However, using other material than semantically related words on both item (i.e., hands performing an action) and associative (i.e., a particular person performing an action) memory tasks, Peterson et al. (2017) observed similar item/associative memory performance in older adults regardless of their educational level. This suggests that in order to benefit of a higher level of education, more explicit incentives given by the task itself (e.g., words semantically related) may be necessary to successfully recall words and implement strategic processes (e.g., semantic organisation).

As such, in the present study, the overall objective was to investigate whether educational level would modulate age-related differences in episodic memory performance in free-recall tasks with different levels of semantic organisation implementation difficulties. More specifically, we compared how younger and older individuals with various levels of education recalled and efficiently semantically organised words at recall. Two levels of task difficulty were constructed: an easier memory task where the words were already organised in semantic clusters when presented to the participants (organised word-list) and a harder memory task, where the semantically-related words were presented in a random fashion (organisable word-list). Overall, we first predicted classical age-related differences, which should be evidenced by younger adults recalling more words and showing better organisational processes than older adults. However, we expected this overall pattern to be attenuated in the easier task as compared harder task. More importantly, regarding the effect of educational level on recall and semantic organisation, we had no firm hypotheses given that while some research seems to indicate that more external support might be needed to benefit from higher educational level (Peterson et al., 2017), other previous research has reported that when the task demand increases in a working memory task, the benefit of being highly educated increases as well in older adults (Bherer et al., 2001). As such, we predicted educational level to modulate recall and semantic organisation performance as a function of the task difficulty, but it was unclear how precisely it would do so.

Methods

Participants

Fifty-five younger adults (age range = 20 years – 39 years, 27 females) and forty-five older adults (age range = 65 years – 75 years, 29 females; see Table 1 for characteristics) were recruited. Younger and older adults were matched regarding formal education level, self-reported health score (measured by using a 5-point scale from 0 (‘‘bad health’’) to 5 (‘‘very good health’’) and anxiety and depression scores of the HADS (Hospital Anxiety and Depression Scale; Zigmond & Snaith, 1983). Older adults had better vocabulary performance to the Mill-Hill vocabulary test (Raven, Raven, & Court, 1989) than younger adults. The older adults were screened with the Mini-Mental State Examination (MMSE; Folstein et al., 1975) and none had a score inferior to 27 (M = 29.02, SD = .94), reducing the risk of including participants with a risk of neuro-degenerative diseases.

Table 1. Participant characteristics in each age group (Mean and Standard Deviation)

	Age Group		
	Younger adults (*n*=55)	Older adults (*n*=45)	
	M (*SD*)	*M* (*SD*)	t(98)
Age (in years)	27.29 (5.87)	69.29 (3.05)	
Educational level (in years)	11.54 (2.06)	11.24 (2.36)	.67, p = .503
Vocabulary (Mill-Hill)	22.69 (4.21)	26.42 (3.79)	**-4.65, p < .001**

Self-reported health	3.79 (.80)	3.83 (.87)	-.25, p = .802
Anxiety (HADS)	6.71 (2.54)	6.42 (4.14)	.40, p = .686
Depression (HADS)	6.25 (2.50)	6.69 (2.26)	-.91, p = .364

Ethics approval for this research was obtained from the Local Ethics Committee of the University of [XXX], and all participants signed consent forms.

Material and procedure

All participants were individually tested in a quiet room in the laboratory by a trained experimenter. Two free-recall memory tasks were administered. In each task, participants were shown two 20 word-lists comprising five categories of four words, with each word presented one-by-one once on a computer screen at a pace of 5 seconds each, and were instructed to learn these words for a subsequent free-recall task. Critically, for one of the lists the presented words were already organised into semantic categories (so-called *organised word list*; easier memory task) so that four words of the same category were sequentially presented before four other words from another category and so on. The other memory task, the more difficult task, used the so-called *organisable word list*, where words were arranged and presented in pseudo-random order so that two words from the same semantic category were never presented sequentially. Importantly, in each task, participants were not informed about the possible structuring of lists and the conditions were counterbalanced across participants and the word lists were counterbalanced across conditions. The words in each of the ten categories were selected from Marchal & Nicolas (2003). The categories were matched with respect to word length, and word frequency (Brulex database: Content et al., 1990). The words were 5 to 8 letters long, with 2 to 3 syllables, and were all concrete nouns. The presentation was immediately followed by a letter-comparison task (XO; Salthouse, 1996) for forty-five seconds to avoid any recency effect on the recall task. Then participants had to recall the words in the order the words came in mind. The number of words correctly recalled in each task and the Adjusted Ratio Clustering score (ARC) were used as dependent variables for these memory tasks. ARC was developed by Roenker et al. (1971), as a measure of categorical organisation at recall. It ranges from 0 to 1; a score of 0 indicates chance clustering, and a score of 1 indicates perfect clustering. It is computed using the following formula:

$$ARC = \frac{R - E(R)}{maxR - E(R)}$$

“…where R is the total number of category repetitions, max R is the maximum possible number of category repetitions, and E(R) is the expected (chance) number of category repetitions” (Roenker et al., 1971, p. 46).

It adjusts for the differences in total number of items recalled. Thus, ARC scores are relatively independent of the recall score, inasmuch as a low score at recall may lead to a high ARC score, if the few words are recalled in an organised fashion.

Data analyses

Data analyses were performed using R version 4.0.2 (R Core Team, 2020). We first investigated the effect of age group (younger adults *vs.* older adults; between-subjects factor), word list (organised *vs.* organisable; within-subject factor) and educational level (scaled centered continuous factor) on the variable recall using a Generalised Linear Mixed Model (GLMM) with a Gaussian distribution fit with the *lme4* package (Bates et al., 2015). We then examined the effects of these factors on semantic organisation using the variable ARC as dependent variable. As this variable comprises scores from 0 and 1 and included 0 and/or 1, this was not suitable to be fit using a GLMM with a Binomial distribution. As such, we used a Beta Regression (Ferrari & Cribari-Neto, 2010) and to account for 0 and 1 values, we applied the following transformation:

$$\frac{(y \times (n-1) + 0.5)}{n}$$

where n is the sample size (Smithson & Verkuilen, 2006) .

This Beta Regression was fit using the *betareg* package (Cribari-Neto & Zeileis, 2010).

If education was involved in any interactions, we conducted further investigations using a similar GLMM and Beta Regression, but with education as a categorical variable (low *vs.* high). To do so, we split each age group into two groups with individuals considered as highly educated when their educational level was above the median (11 years). This resulted into four distinct groups: lower educated younger adults (*N* = 31, *M* = 28.68 years, *SD* = 6.58 years, age range = 20 years – 39 years), higher educated younger adults (*N* = 25, *M* = 25.36 years, *SD* = 4.25 years, age range = 22 years – 34 years), lower educated older adults (*N* = 27, *M* = 69.93 years, *SD* = 2.95 years, age range = 65 years – 75 years) and higher educated older adults (*N* = 18, *M* = 68.33 years, *SD* = 3.03 years, age range = 65 years – 75 years).

Pairwise comparisons were used with Tukey's adjustments when there were multiplicity issues using the *emmeans* package (Lenth, 2020) and the function *lstrends* from *lsmeans* package to deal with continuous factors; estimated marginal means (EMMs) from the models are re-ported. Plots of the results were obtained using the *ggplot2* package (Wickham, 2016) and error bars represent standard errors.

Finally, we conducted Pearson correlation analyses with the Benjamini and Hochberg correction (Benjamini & Hochberg, 1995) to account for both false positives and false negatives, to investigate the relation between recall and ARC within each memory task with educational level, separately in younger adults and older adults using a correlation matrix with the *Hmisc* package (Harrel, 2020).

Results

Recall as a function of age group, word list and education

On recall, there were main effects of age group, $\chi^2 = 20.11$, $p < .001$, word list, $\chi^2 = 6.08$, $p = .014$, and educational level, $\chi^2 = 11.27$, $p < .001$. Overall, younger adults recalled more words than older adults ($M_{\text{younger adults}} = 12.5$ *vs*. $M_{\text{older adults}} = 11$), participants recalled more words when the word list was organised than organisable ($M_{\text{organised}} = 12.1$ *vs.* $M_{\text{organisable}} = 11.3$), and participants with higher educational level recalled more words than participants with lower educational level (trend = .257). These effects were qualified by a three-way interaction between age group, word list and educational level, $\chi^2 = 4.36$, $p = .036$, revealing there was no difference regarding the educational level trend between the organised and organisable word lists in younger adults (trend = .167 *vs.* trend = .245, respectively; $p = .660$), whereas the trend was significantly higher for the organised word list than for the organisable word list in older adults (trend = .528 *vs.* trend = .086; $p = .013$; see Figure 1). Other interactions were not significant, *ps* > .128.

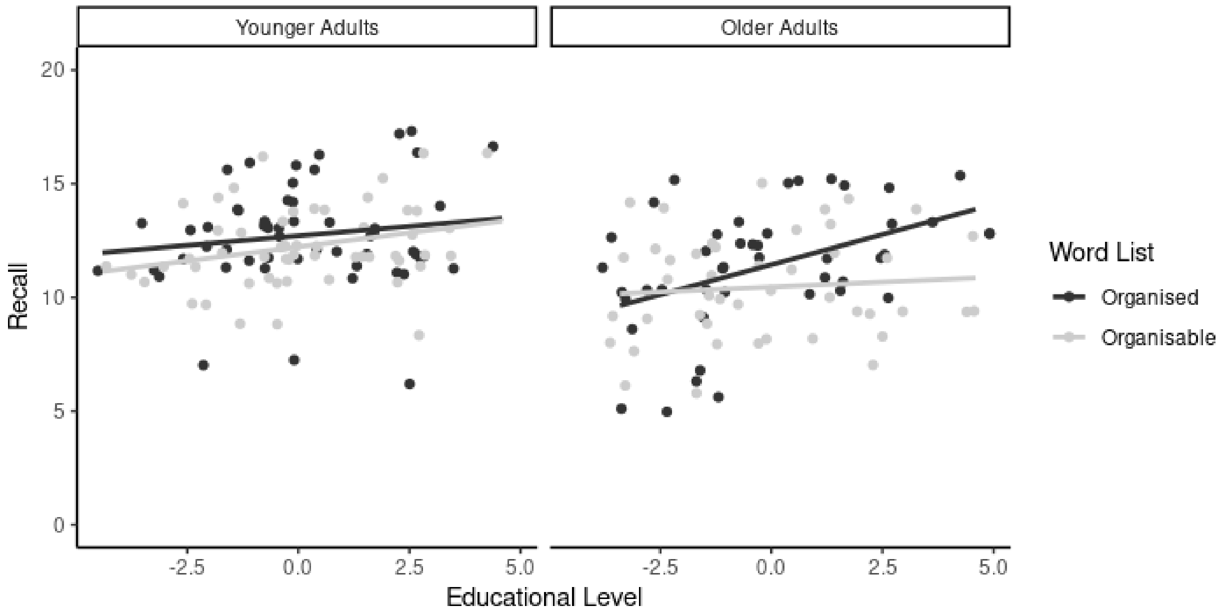

Figure 1. Recall as a function of age group (younger *vs.* older), word list (organised *vs.* organisable) and educational level (continuous).

Given that educational level was involved in a three-way interaction when considered as a continuous variable, we conducted the same analysis with this variable as categorical. This analysis yielded similar results with main effects of both age group, $\chi^2 = 20.91$, $p < .001$, word list, $\chi^2 = 5.99$, $p = .014$, and educational level, $\chi^2 = 7.95$, $p = .005$ as well as a significant three-way interaction between these factors $\chi^2 = 4.18$, $p = .041$. Pairwise comparisons revealed that when the word list was organised, younger adults with lower educational level recalled more words than older adults with similar educational level ($M_{\text{younger adults}} = 12.6$ *vs.* $M_{\text{older adults}} = 10.4$; $p < .001$), but no such difference was observed between the two age groups for individuals with higher educational level ($M_{\text{younger adults}} = 12.9$ *vs.* $M_{\text{older adults}} = 12.8$; $p = .838$; Figure 2). When the words were organisable, younger adults recalled more than older adults independently of the educational level (lower educational individuals: $M_{\text{younger adults}} = 11.9$ *vs.* $M_{\text{older adults}} = 10.2$; higher educational level: $M_{\text{younger adults}} = 12.7$ *vs.* $M_{\text{older adults}} = 10.8$; *ps* < .005). Finally, consistent with the analysis using educational level as a continuous variable, we reported no difference between younger adults with lower educational level and with higher educational level when the words were both organised and organisable, *ps* < .571. Conversely, when no difference was observed between educational levels for older adults when the words were organisable, $p = .402$, older adults with higher educational level recalled more words than their counter-parts with lower educational level, $p < .001$.

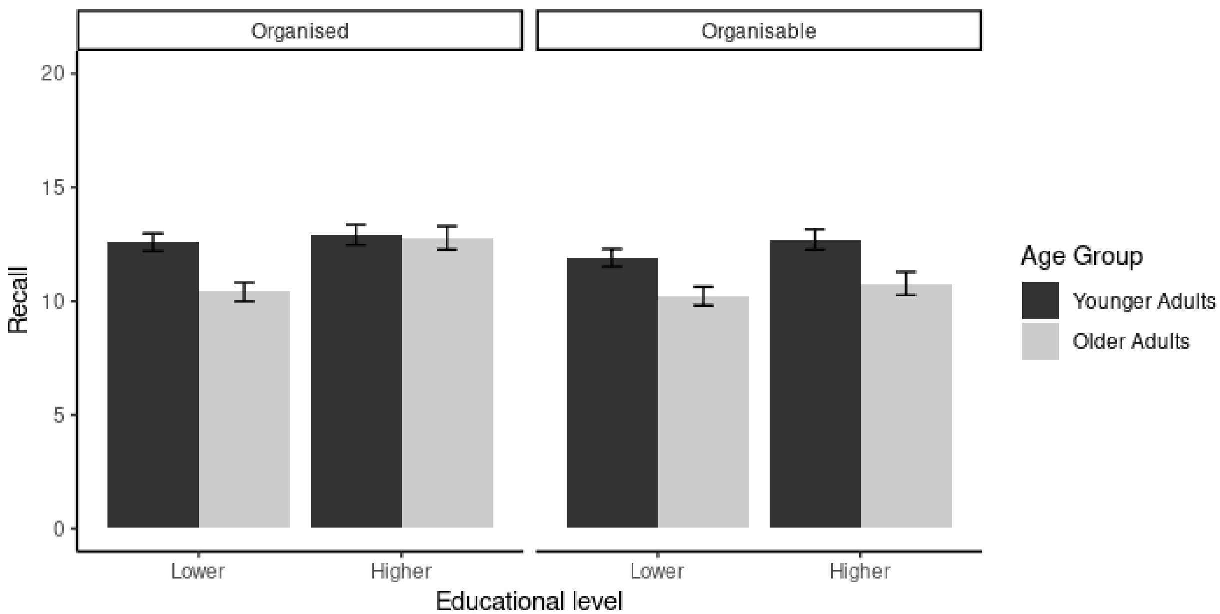

Figure 2. Recall as a function of age group (younger adults *vs.* older adults), word list (organised *vs.* organisable) and educational level (lower *vs.* higher).

ARC as a function of age group, word list and educational level

On ARC, there were main effects of age group, $\chi^2 = 19.51$, $p < .001$, word list, $\chi^2 = 34.47$, $p < .001$, and education, $\chi^2 = 4.23$, $p = .040$. Overall, younger adults showed higher semantic organisation than older adults ($M_{\text{younger adults}} = .80$ *vs*. $M_{\text{older adults}} = .64$), participants better organised the words when the word list was organised than organisable ($M_{organised}$ = .82 *vs.* $M_{organisable}$ = .61), and participants with higher educational level slightly better organised the words than participants with lower educational level (trend = .011). Age group and word list significantly interacted, $\chi^2 = 19.66$, $p < .001$, revealing that whereas younger and older adults showed similar semantic organisation when the word list was organised ($M_{younger\ adults}$ = .82 *vs*. $M_{older\ adults}$ = .82, p = .919), younger adults showed significantly better organisational processes than older adults when the word list was organisable ($M_{younger\ adults}$ = .77 *vs*. $M_{older\ adults}$ = .45; $p < .001$; Figure 3). Other interactions were not significant, *ps* > .131.

Given that educational level was not involved in any interactions, we did not conduct further analyses.

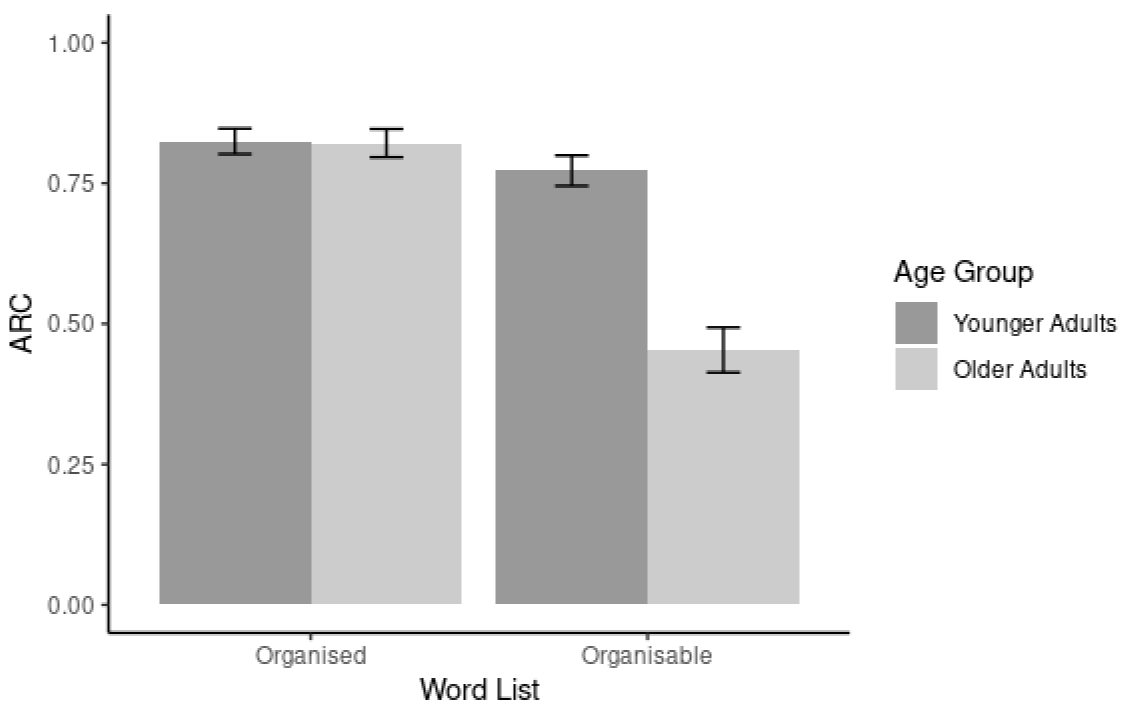

Figure 3. ARC as a function of age group (younger *vs.* older) and word list (organised *vs.* organisable).

Relation between recall and ARC in organised and organisable word lists, and education in young and older adults

Results of the correlation analyses for each age group are presented in Table 2. In younger adults, we observed that ARC was positively associated with recall in the same task. In older adults, education was positively correlated with both ARC and recall in the organised word list. Finally, ARCs in the two memory tasks were positively associated for this age group.

Table 2. Correlations (Pearson's *r*) with Benjamini and Hochberg corrections between education, recall and ARC (words organised and words organisable) per age group

Younger adults (n =55)				
	Recall organised	Education	ARC organised	Recall organisable
Education	.15	-		
ARC organised	-.11	.17	-	
Recall organisable	.21	.30	.09	-
ARC organisable	.18	.16	-.30	**.43 (*p* = .011)***
Older adults (n = 45)				
	Recall organised	Education	ARC organised	Recall organisable
Education	**.47 (*p* = .012)***	-		
ARC organised	.14	**.39 (*p* = .027)***	-	
Recall organisable	.26	.09	.05	-
ARC organisable	-.003	.08	**.42 (*p* = .022)***	.16

Discussion

The present study investigated whether educational level modulated recall performance and semantic organisation strategy in free-recall tasks with different levels of difficulty in younger and older adults.

Firstly, consistent with our overall prediction, we observed globally that older adults recalled less words and organise them less into semantic clusters to boost performance as compared to younger adults (e.g., Deney, 1974; Taconnat et al., 2009). Whereas older adults recalled less words than younger adults in both word lists (no significant age group x word list interaction), we reported interesting differences between older and younger adults regarding semantic organisation as a function of the word list difficulty. Indeed, older adults showed a similar semantic organisation index to younger adults in the easier task (organised word list). This finding is in accord with the environmental support model (Craik, 1990) and with studies showing that given enough environmental support, older adults use mnemonic strategies as efficiently as younger adults (e.g., Dunlosky et al., 2005; Froger et al., 2009; Naveh-Benjamin et al., 2007; Taconnat et al., 2007). However, organisation did not boost performance in both age groups as suggested by the lack of correlation between recall and ARC in this easy task. C**Erreur ! Signet non défini.**onversely, we reported that older adults used this semantic organisational strategy significantly less than younger adults when the memory task was harder (i.e., organisable word-list). In this condition, only younger adults benefited from using this strategy as evidenced by the positive association between the ARC score and recall. These results are in line with a wide literature showing that older adults have difficulties to spontaneously implement semantic organisation during recall and that when implemented, the strategies are less efficient for memory than for younger adults (Denney, 1974; Taconnat et al., 2009, Taconnat et al., 2020), but also other mnemonic strategies in diverse memory tasks (e.g., Burger et al., 2017). Although we did not test for any cognitive control abilities, there is growing evidence that one reason why older individual fail to implement semantic organisation in a memory task where the words as organisable but not organised is due to lower working memory capacities (e.g., Cherry et al., 2021; Kuhlmann & Touron, 2016).

Crucially, the present study sheds new light on our understanding of the protective effect of education in older adults' episodic memory performance. Our findings support the notion that educational level is such an extrinsic factor and can serve as a main proxy variable that may modulate cognitive reserve (Mungas et al., 2021), aligning with Jefferson et al. (2011, 2012), particularly in episodic memory, again, corresponding with insights from Lövdén et al. (2020), suggesting that education may permit some individuals have greater resilience in tasks than those with fewer years of education. Research contrasting between higher and lower educated older individuals has reported that the former group recalled more words than the latter. However, the memory tasks used in these studies were easier than a free-recall task (e.g., paired-associated and cued-recall tasks; Angel et al., 2010; Shimamura et al., 1995). In a recent study requiring associative strategy, Peterson et al. (2017) suggested that in order to find a similar pattern (i.e., a protective role of prolonged education) with a difficult memory task such as a free-recall task, it might be necessary providing explicit instructions to highly educated older adults for them to recall more words and to employ efficient mnemonic strategies. In line with this, we found that whereas recall performance did not vary as a function of task difficulty and educational level in younger adults, the older adults with higher level of education recalled more words than those with lower level of education when the words were already organised (easier task), even performing equivalently to the younger adults. However, no difference was observed as a function of educational level in the harder memory task in older adults. It is possible that the harder task was not explicit enough to generate effects. Though it is interesting to note that episodic memory is reportedly less associated with life-exposure variables such as educational level (Early et al., 2013), whilst Mungas et al. (2021) note this socio-demographic factor to be weakly associated with baseline episodic memory, and more strongly linked to executive function, and semantic memory. As we show educational level to modulate the decline in episodic memory for the easier task only, this may go some way in explaining why this research highlights a low association between educational level and episodic memory. As such, it might be possible that educational level should be perhaps more associated with semantic memory, as these memories are strongly encoded in tasks that resemble easy episodic memory tasks more closely than harder episodic memory tasks.

In agreement with this notion, we also observed that education slightly predicted better semantic organisation. Correlational analyses in each age group indicated that semantic organisation was positively associated with education only in older adults when the word list was organised. As such, older adults with higher educational level were more likely to use this strategy when the memory task was easy. Interestingly, for older adults, semantic organisation and recall were not associated in this memory task, potentially due to the difference between higher educated individuals using more organisation and recalling more words and lower educated individuals using less this strategy and recalling less words. This was in sharp contrast with what was observed for younger adults where the use of semantic organisation was strongly associated with better recall in the words organisable memory task, meaning that for a difficult task, this strategy appears efficient in boosting performance. Note that we observed that educational level was slightly positively associated with recall in the organisable word list condition in younger adults, but this association failed to turn into a prediction when the analyses were performed in the whole sample.

Overall, it is possible that despite a high level of education, some effective strategic processes are not available or not implemented to support the organisational strategy, resulting in an age-related organisational deficit. This suggests that educational level has a protective effect on memory in older adults only when the memory task or the memory strategies are supported by cues or specific instructions. The lack of spontaneous organisational strategy implementation appears in the present study, as well as in Peterson et al.'s (2017), with an associative strategy. However, previous studies showed that strategy use and educational level were positively related in older adults (Guerrero-Sastoque et al. 2021; Frankenmolen et al., 2018), but these studies examined self-reported (subjective) strategy use, not direct objective strategy use as in the present study, and did not compare groups with matched educational level. Therefore, there is a discrepancy between the positive effect of educational level on the self-reported strategy use and the lack of this effect on the use of self-initiated strategies (i.e., when there is no environmental support to guide them) during a memory task. It is possible that older adults with a high level of education, who generally have better memory performance and intellectual resources, have been accustomed to the point they have the feeling of using memory strategies often, as reported in questionnaires. However, these divergent results can also be the results of methodological differences such as the use of matched groups in terms of educational level in our study but not in the other mentioned studies (Guerrero-Sastoque et al., 2021; Frankenmolen et al., 2018).

Our study has nevertheless some limitations that deserve future investigations. First, we did not measure cognitive control capacities whereas such measures could have also shed lights on the underlying mechanisms of the implementation of semantic organisation. Indeed, the use of semantic organisation requires keep both words and semantic categories in memory and eventually reattribute the remembered words in the appropriate categories in mind. As such, some studies have reported that older individuals with lower cognitive control (Taconnat et al., 2009), and more especially working memory capacities (Cherry et al., 2021), organised less information into semantic clusters. However, when manipulating the format presentation to disentangle spontaneous and instructed semantic organisation, Kuhlmann and Touron (2016) observed that whereas instructed semantic organisation was linked to working memory, spontaneous semantic organisation was linked to metacognition. Therefore, a measure of metacognition and metamemory would have allowed us to investigate how these beliefs may affect the strategy affordability of our task, potentially leading (particularly educated) older adults to engage well in the easier task, but poorly engage in the harder task. Moreover, individual preferences or experiences regarding strategy use could have also played a role. For instance, some individuals might have grouped the items in terms of familiarity groups (e.g., if in the kitchen there is apples on the table next to a photograph, the participant might have grouped the items apple, table and face together) and not in terms of semantic groups (e.g., grouping bananas, leeks, apples and so on). As such, future studies should examine the respective contribution of working memory and metacognition when the difficulty of the memory tasks is varied as well as providing explicit measures of which strategy the participants report to have used to convey a better understanding of the underlying processes of semantic organisation. Another potential limitation relates to the use of a short interval between words. Many studies used an interval of presentation between words comprised between three to five seconds (e.g., Cherry et al., 2008; Kuhlmann & Touron, 2016; Moutoussamy et al., 2022; Taconnat et al., 2009 Uittenhove et al., 2015), and so we aligned with them by using an interval between words of five seconds. However, one could argue that if a longer interval was used, individuals would have more time to memorise and potentially grouping words into semantic clusters. Indeed, there is evidence that giving more time to participants in a working memory task improves their later episodic memory traces (Souza & Oberauer, 2017; Mizrak & Oberauer, 2021). As such, we encourage future studies to test whether giving more time to participants, and especially older adults, would be beneficial for them both in terms of recall performance but also in the engagement of successful semantic organisation. Finally, a last limitation of our study relates to the discrepancy in the age range between younger adults (19 years) and older adults (10 years), which might have impacted our results. Therefore, we ran further analyses by splitting the younger adults group into two sub-samples with about the same age range. These analyses revealed no differences between the two sub-samples in terms of recall and ARC. Moreover, one advantage of having these two sub-samples put together, despite a large age range, was to reduce the difference with the older adults group in terms of educational level, reducing the likelihood that our results might be confounded by educational level difference between younger and older adults (see Supplemental Material).

To conclude, the major contribution of the present study is to report that an important socio-demographic factor, educational level, has a protective effect on recall performance in a free-recall task in older adults only when this task provides sufficient external information about the most efficient mnemonic strategy to use as compared to when it does not. Future research should examine in more detail whether factors other than educational level, such as leisure or physical activities, confer the same protective effect on memory performance.

References

Angel, L., Fay, S., Bouazzaoui, B., Baudouin, A., & Isingrini, M. (2010). Protective role of educational level on episodic memory ageing: An event-related potential study. *Brain and Cognition*, *74*(3), 312–323. https://doi.org/10.1016/j.bandc.2010.08.012

Bates, D., Mächler, M., & Bolker, B. (2015). Fitting Linear Mixed-Effects Models Using (lme4). *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal statistical society: series B (Methodological)*, *57*(1), 289-300. **https://doi.org/10.1111/j.2517-6161.1995.tb02031.x**

Bherer, L., Belleville, S., & Peretz, I. (2001). Education, age, and the Brown-Peterson technique. *Developmental Neuropsychology*, *19*(3), 237-251.

Bousfield, W. A. (1953). The Occurrence of Clustering in the Recall of Randomly Arranged Associates. *The Journal of General Psychology*, *49*(2), 229–240. https://doi.org/10.1080/00221309.1953.9710088

Burger, L., Uittenhove, K., Lemaire, P., & Taconnat, L. (2017). Strategy difficulty effects in young and older adults' episodic memory are modulated by inter-stimulus intervals and executive control processes. *Acta Psychologica*, *175*, 50–59. https://doi.org/10.1016/J.ACTPSY.2017.02.003

Cherry, K. E., Elliott, E. M., Golob, E. J., Brown, J. S., Kim, S., & Jazwinski, S. M. (2021). Strategic encoding and retrieval processes in verbal recall among middle-aged and older adults. *British Journal of Developmental Psychology, 39*(2), 252-268. https://doi.org/10.1111/bjdp.12349

Content, A., Mousty, P., & Radeau, M. (1990). Brulex. Une base de données lexicales informatisée pour le français écrit et parlé. *L'Année Psychologique*, *90*(4), 551–566. https://doi.org/10.3406/PSY.1990.29428

Craik, F. I. M. (1990). Changes with normal ageing: A functional view. In R. J. Wutman, S. Corkin, J. H. Growdon, & E. Ritter-Walker (Eds.), *Advances in neurology, 51: Alzheimer's disease* (pp. 201–205). Raven.

Craik, F. I. M., & Rose, N. S. (2012). Memory encoding and ageing: A neurocognitive perspective. *Neuroscience & Biobehavioral Reviews*, *36*(7), 1729–1739. https://doi.org/10.1016/J.NEUBIOREV.2011.11.007

Cribari-Neto, F., & Zeileis, A. (2010). Beta Regression in R. *Journal of Statistical Software*, *34*(2), 1–24. https://doi.org/10.18637/JSS.V034.I02

Denney, N. W. (1974). Clustering in middle and old age. *Developmental Psychology*, *10*(4), 471–475. https://doi.org/10.1037/H0036604

Dixon, R. A., & Hultsch, D. F. (1983). Structure and Development of Metamemory in Adulthood. *Journal of Gerontology*, *38*(6), 682–688. https://doi.org/10.1093/GERONJ/38.6.682

Dunlosky, J., Hertzog, C., & Powell-Moman, A. (2005). The contribution of mediator-based deficiencies to age differences in associative learning. *Developmental Psychology*, *41*(2), 389–400. https://doi.org/10.1037/0012-1649.41.2.389

Early, D. R., Widaman, K. F., Harvey, D., Beckett, L., Park, L. Q., Farias, S. T., … Mungas, D. (2013). Demographic predictors of cognitive change in ethically diverse older persons. *Psychology and Aging*, *28(3), 633–645.* doi:10.1037/a0031645

Ferrari, S. L. P., & Cribari-Neto, F. (2010). Beta Regression for Modelling Rates and Proportions. *Http://Dx.Doi.Org/10.1080/0266476042000214501*, *31*(7), 799–815. https://doi.org/10.1080/0266476042000214501

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). “Mini-mental state”. A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*(3), 189–198. https://doi.org/10.1016/0022-3956(75)90026-6

Foubert-Samier, A., Catheline, G., Amieva, H., Dilharreguy, B., Helmer, C., Allard, M., & Dartigues, J. F. (2012). Education, occupation, leisure activities, and brain reserve: a population-based study. *Neurobiology of Ageing*, *33*(2), 423.e15-423.e25. https://doi.org/10.1016/J.NEUROBIOLAGEING.2010.09.023

Frankenmolen, N. L., Fasotti, L., Kessels, R. P. C., & Oosterman, J. M. (2018). The influence of cognitive reserve and age on the use of memory strategies. *Https://Doi.Org/10.1080/0361073X.2017.1422472*, *44*(2), 117–134. https://doi.org/10.1080/0361073X.2017.1422472

Froger, C., Taconnat, L., Landré, L., Beigneux, K., & Isingrini, M. (2009). Effects of level of processing at encoding and types of retrieval task in mild cognitive impairment and normal ageing. *Https://Doi.Org/10.1080/13803390802112554*, *31*(3), 312–321. https://doi.org/10.1080/13803390802112554

Golomb, J. D., Peelle, J. E., Addis, K. M., Kahana, M. J., & Wingfield, A. (2008). Effects of adult ageing on utilization of temporal and semantic associations during free and serial recall. *Memory & Cognition*, *36*(5), 947. https://doi.org/10.3758/MC.36.5.947

Guerrero-Sastoque, L., Bouazzaoui, B., Burger, L., & Taconnat, L. (2021). Effet du niveau d'études sur les performances en mémoire épisodique chez des adultes âgés : rôle médiateur de la métamémoire. *Psychologie Française*, *66*(2), 111–126. https://doi.org/10.1016/J.PSFR.2017.05.002

Guerrero-Sastoque, L., Bouazzaoui, B., Burger, L., Froger, C., Isingrini, M., & Taconnat, L. (2019). Optimizing memory strategy use in young and older adults: The role of metamemory and internal strategy use. *Acta Psychologica*, *192*, 73–86. https://doi.org/10.1016/J.ACTPSY.2018.11.002

Harrel, F. E. (2020). *Hmisc: Harrell Miscellaneous*. https://cran.r-project.org/package=Hmisc

Howard, M., & Kahana, M. (1999). Contextual variability and serial position effects in free re-call. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *25*(4), 923–941. https://doi.org/10.1037//0278-7393.25.4.923

Jefferson, A. L., Gibbons, L. E., Rentz, D. M., Carvalho, J. O., Manly, J., Bennett, D. A., & Jones, R. N. (2011). A Life Course Model of Cognitive Activities, Socioeconomic Status, Education, Reading Ability, and Cognition. *Journal of the American Geriatrics Society*, *59*(8), 1403–1411. https://doi.org/10.1111/J.1532-5415.2011.03499.X

Josefsson, M., De Luna, X., Pudas, S., Nilsson, L. G., & Nyberg, L. (2012). Genetic and lifestyle predictors of 15-year longitudinal change in episodic memory. *Journal of the American Geriatrics Society*, *60*(12), 2308–2312. https://doi.org/10.1111/jgs.12000

Kahana, M. J., & Wingfield, A. (2000). A functional relation between learning and organisation in free recall. *Psychonomic Bulletin & Review 2000 7:3*, *7*(3), 516–521. https://doi.org/10.3758/BF03214365

Kuhlmann, B. G., & Touron, D. R. (2016). Ageing and memory improvement through semantic clustering: The role of list-presentation format. *Psychology and Ageing*, *31*(7), 771–785. https://doi.org/10.1037/PAG0000117

Lenth, R. (2020). *emmeans: Estimated Marginal Means, aka Least-Squares Means*.

Lövdén, M., Fratiglion, L., Glymour, M., Lindenberger, U., & Tucker-Drob, E. (2020). Education and Cognitive Functioning Across the Life Span. *Psychological Science in the Public Interest : A Journal of the American Psychological Society*, *21*(1), 6–41. https://doi.org/10.1177/1529100620920576

Marchal, A., & Nicolas, S. (2003). Category generation norms for 38 semantic categories in young and older subjects. *Annee Psychologique*, *103*(2), 313–366. https://doi.org/10.3406/psy.2003.29639

Mızrak, E., & Oberauer, K. (2021). What is time good for in working memory?. *Psychologica Science*, *32*(8), 1325-1337. https://doi.org/10.1177/0956797621996659

Moutoussamy, I., Taconnat, L., Pothier, K., Toussaint, L., & Fay, S. (2022). Episodic memory and aging: Benefits of physical activity depend on the executive resources required for the task. Plos one, 17(2), e0263919. https://doi.org/10.1371/journal.pone.0263919

Mungas, D., Fletcher, E., Gavett, B. E., Widaman, K., Zahodne, L. B., Hohman, T. J., ... & Farias, S. T. (2021). Comparison of education and episodic memory as modifiers of brain atrophy effects on cognitive decline: implications for measuring cognitive reserve. *Journal of the International Neuropsychological Society*, *27*(5), 401-411.

Naveh-Benjamin, M., Brav, T. K., & Levy, O. (2007). The associative memory deficit of older adults: The role of strategy utilization. *Psychology and Ageing*, *22*(1), 202–208. https://doi.org/10.1037/0882-7974.22.1.202

Peterson, D. J., Gargya, S., Kopeikin, K. S., & Naveh-Benjamin, M. (2017). The impact of level of education on age-related deficits in associative memory: Behavioral and neuropsychological perspectives. *Cortex*, *91*, 9–24. https://doi.org/10.1016/J.CORTEX.2016.12.020

Puff, C. R. (1979). Memory organisation research and theory: The state of the art. In C. R. Puff (Ed.), *Memory organisation and structure* (pp. 3–17). Academic Press.

R Core Team. (2020). *R: A Language and Environment for Statistical Computing*.

Raven, J. (2000). The Raven's Progressive Matrices: Change and Stability over Culture and Time. *Cognitive Psychology*, *41*(1), 1–48. https://doi.org/10.1006/COGP.1999.0735

Raz, N., Ghisletta, P., Rodrigue, K. M., Kennedy, K. M., & Lindenberger, U. (2010). Trajectories of brain ageing in middle-aged and older adults: Regional and individual differences. *NeuroImage*, *51*(2), 501–511. https://doi.org/10.1016/J.NEUROIMAGE.2010.03.020

Roenker, D. L., Thompson, C. P., & Brown, S. C. (1971). Comparison of measures for the estimation of clustering in free recall. *Psychological Bulletin*, *76*(1), 45–48. https://doi.org/10.1037/h0031355

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, *103*(3), 403–428.

Sauzéon, H., Claverie, B., & N'Kaoua, B. (2006). Age Differences in the organisation and Acquisition-Forgetting Processes in a Multi-Free-Recall Task. *Http://Journals.Openedition.Org/Cpl*, *18*(18, Vol. 1, 2006), 1–11. https://doi.org/10.4000/CPL.1012

Shimamura, A. P., Mangels, J. A., Jurica, P. J., Berry, J. M., & Rusting, C. L. (1995). Memory and cognitive abilities in university professors: Evidence for successful ageing. *Psychological Science, 6*(5), 271–277. https://doi.org/10.1111/j.1467-9280.1995.tb00510.x

Smithson, M., & Verkuilen, J. (2006). A better lemon squeezer? Maximum-likelihood regression with beta-distributed dependent variables. *Psychological Methods*, *11*(1), 65–71.

Souza, A. S., & Oberauer, K. (2017). Time to process information in working memory improves episodic memory. Journal of Memory and Language, 96, 155-167. https://doi.org/10.1016/j.jml.2017.07.002

Stern, Y. (2002). *What is cognitive reserve? Theory and research application of the reserve concept* (Vol. 8, Issue 3). https://doi.org/10.7916/D8TQ7D3P

Stern, Y. (2021). How Can Cognitive Reserve Promote Cognitive and Neurobehavioral Health? *Archives of Clinical Neuropsychology*, *36*(7), 1291–1295. https://doi.org/10.1093/ARCLIN/ACAB049

Taconnat, L., Clarys, D., Vanneste, S., Bouazzaoui, B., & Isingrini, M. (2007). Ageing and strategic retrieval in a cued-recall test: The role of executive functions and fluid intelligence. *Brain and Cognition*, *64*(1), 1–6. https://doi.org/10.1016/J.BANDC.2006.09.011

Taconnat, L., Morel, S., Sastoque, L. G. –, Frasca, M., & Vibert, N. (2020). What eye movements reveal about strategy encoding of words in younger and older adults. *Https://Doi.Org/10.1080/09658211.2020.1745848*, *28*(4), 537–552. https://doi.org/10.1080/09658211.2020.1745848

Taconnat, L., Raz, N., Toczé, C., Bouazzaoui, B., Sauzéon, H., Fay, S., & Isingrini, M. (2008). Ageing and organisation strategies in free recall: The role of cognitive flexibility. *European Journal of Cognitive Psychology*, *21*(2–3), 347–365. https://doi.org/10.1080/09541440802296413

Uittenhove, K., Burger, L., Taconnat, L., & Lemaire, P. (2015). Sequential difficulty effects during execution of memory strategies in young and older adults. *Memory*, *23*(6), 806-816. https://doi.org/10.1080/09658211.2014.928730

West, R., & Thorn, R. (2001). Goal-setting, self-efficacy, and memory performance in older and younger adults. *Experimental Ageing Research*, *27*(1), 41–65. https://doi.org/10.1080/03610730126109

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. Springer-Verlag.

Zigmond, A. S., & Snaith, R. P. (1983). The Hospital Anxiety and Depression Scale. *Acta Psychiatrica Scandinavica*, *67*(6), 361–370. https://doi.org/10.1111/J.1600-0447.1983.TB09716.X