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Controlled processes account for age-related decrease in episodic memory

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Abstract

A decrease in controlled processes has been proposed to be responsible for age-related episodic memory decline. We used the Process Dissociation Procedure, a method that attempts to estimate the contribution of controlled and automatic processes to cognitive performance, and entered both estimates in regression analyses. Results indicate that only controlled processes explained a great part of the age-related variance in a word recall task, especially when little environmental support was offered.

PsycINFO classification: 2343; 2860

Keywords: Learning & Memory; Gerontology

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1. Introduction

Automatic memory processes, also called "ecphoric" processes, allow the activation of a memory trace from a cue without intention or conscious effort, at least if there is overlap between this cue and the memory trace. On the contrary, controlled processes are not supported by environmental support and do not depend on habits (Bialystok, Craik, Klein, & Viswanathan, 2004). They are involved in the rejection of irrelevant stimuli, the orienting of attention to the relevant ones, the conscious mental manipulation of information, etc. They also allow intentional and active memory search of a past event; in the memory context, they are called "recollection" and are assumed to be independent of the automatic use of memory (Jacoby, Bishara, Hessels, & Toth, 2005).

It is now well known that elderly adults, compared with younger adults, are typically disadvantaged in their performance on direct or explicit tests of memory (such as free recall, recognition, and cued recall), in which participants are asked to recollect a previous study episode (for reviews, see Craik, Anderson, Kerr, & Li, 1995; Craik & Jennings, 1992). For the last 15 years, much work has focused on the possible causes of such a decline. One interesting hypothesis stems from the convergence of two sets of data. Studies on brain-damaged patients and studies using brain imaging, have shown that the frontal lobes play an important role in memory tasks requiring controlled processes such as initiation, planning, reorganisation, spatial and temporal contextual details retrieval or in dual task memory situations (Craik & Grady, 2002; Moscovitch, 1994a; Norman & Schacter, 1996; Shimamura, Janowsy, & Squire, 1990). Moreover, age-related physiological brain changes are particularly visible in those cerebral structures (Grady & Haxby, 1995; Martin, 1998; Prull, Gabrieli, & Bunge, 2000) and could therefore disrupt controlled processes in aging people (Buckner & Koutstaal, 1998).

Age effects on tasks implying control and effortful strategies have indeed been frequently described. Craik (1986, 2002) noted that aging persons obtained lower memory performances than young adults, especially when strategic demands were high, and that giving the participants environmental support reduced these age-related differences. For instance, telling people in advance the best way to encode the to-be-presented words reduced differences in memory performance between young and elderly adults (Bäckman & Karlsson, 1986; Bäckman & Larsson, 1992). In the same way, giving them semantic cues at retrieval reduced the gap between elderly and young people (Bäckman & Karlsson, 1986; Bäckman & Larsson, 1992; Craik, Byrd, & Swanson, 1987) because retrieval cues allowed them to recover information from memory even if specification of some retrieval cues (attributed to controlled processes) was deficient (Burgess & Shallice, 1996). As also noted by Moscovitch (1992), free recall implies strategic processes to retrieve information (since no cues are given) while cued recall can be based on more automatic processes. However, strategic processes can also be implied in cued recall tasks in order to consciously retrieve encoded information (free and cued recall tasks being explicit tasks). It is therefore difficult, with these manipulations (e.g. giving cues), to distinguish the contribution of automatic and controlled processes to memory performance.

In contrast to the age-related decline in tasks of direct or explicit memory, some studies have proposed that performance of older and younger adults do not differ on indirect or implicit memory tests (e.g. Ergis, Van der Linden, & Deweer, 1995; Light, La Voie, & Kennison, 1995; Winocur, Moscovitch, & Stuss, 1996). Implicit tasks, such as word fragment completion, in which no conscious recall of a prior learning episode is necessary, should involve automatic processes that are not conscious, rapidly performed, difficult to control, with minimal effort or with automatic allocation of attention (Hasher & Zacks, 1979; Schneider & Shiffrin, 1977). Although these findings suggest that implicit memory does not change with age, there has been contradictory evidence showing the presence of a small age-related difference in performance on indirect tests (La Voie & Light, 1994). Moreover, Fleischman and Gabrieli (1998) pointed out that, although 85% of the studies reviewed reported age invariance in priming, almost half of these studies showed a 10% reduction in priming magnitude in elderly participants compared with young subjects. One factor often considered to explain these diverging results is the possibility that performance on indirect tests may be contaminated by consciously controlled use of memory and vice versa (performance on direct memory tests would be contaminated by automatic processes). For instance, in a comparative study between word recognition, cued recall and stem-completion, responses to a questionnaire showed that almost half of the participants used active retrieval strategies in the completion task (Gooding, Mayes, Van Eijk, Meudell, & McDonald, 1999). To summarise, one of the problems associated with explicit and implicit memory tasks is that they do not provide a pure measure of automatic and controlled processes since performance in one task is not solely supported by one kind of process (Jacoby, Toth, & Yonelinas, 1993).

As both automatic and controlled processes play a role in all cognitive tasks, a procedure that could separate them in the same task seems necessary. Jacoby (1991, 1998) developed a paradigm, the "process-dissociation procedure", that enables one to quantify properly and separately contributions of automatic and consciously controlled memory processes in the same task (familiarity versus recollection). For example, in a word-stem version of the procedure, subjects perform two tasks: one involving inclusion, the other exclusion. In the inclusion task, subjects are asked to complete a stem with a previously studied word and, if they are unable to do so, to use the first word which comes to mind. In the exclusion task, they are asked to complete a stem with a new word that was not encountered during the earlier study phase and to avoid (exclude) old studied words. It is then possible to insert performance of the two conditions in equations representing the logical relation between automatic (A) and controlled (C) memory processes. So, in the inclusion condition, a subject may complete correctly a stem with an earlier studied word either because they consciously recollect having seen the word before (C), or because it was the first word that came to mind automatically (A), when there is a failure of conscious recollection ($1 - C$). Thus, $\text{Inclusion} = C + A(1 - C)$. On the other hand, in the exclusion condition, a subject may complete incorrectly an earlier studied word only if the word comes automatically to mind (A), without any controlled recollection that the word was presented earlier ($1 - C$): $\text{Exclusion} = A(1 - C)$. Using these two equations and considering the subject's performance on the two conditions, it is then possible to derive estimated contributions of automatic and controlled memory processes. Controlled processes can be estimated by subtracting the probability of responding with a studied word in the exclusion task from the probability of responding with an old word in the inclusion task [$C = \text{Inclusion} - \text{Exclusion}$]. Once an estimate of controlled processes has been obtained, the contribution of automatic processes corresponds to the probability of completing a stem with the studied word in the exclusion condition divided by one minus the estimate of controlled processes [$A = \text{Exclusion}/(1 - C)$].

This procedure was adapted for several kinds of memory evaluations and in various psychopathological states (Hay & Jacoby, 1999; Jacoby, 1999; Jennings & Jacoby, 1993, 1997; Jermann, Van der linden, Adam, Ceschi, & Perroud, 2005; Smith & Knight, 2002; Titov & Knight, 1997; Zelazo, Craik, & Booth, 2004) as well as for non-memory performances (Spieler, Balota, & Faust, 1996). All these studies presented converging data showing an age-related decline in controlled processes along with age constancy in automatic processes.

However, it should be noted that the process-dissociation procedure is not without its critics. The most controversial aspect is the assumption that controlled and automatic processes contribute independently to memory performance (from which the formulas proposed by Jacoby are derived). Alternative hypotheses are Redundancy and Exclusivity (however, see Jacoby, Yonelinas, & Jennings, 1997 for a refutation of these hypotheses). The major argument put forward by Jacoby and colleagues in favour of the independence assumption is that several studies identified variables that produce dissociate effects on the estimates of controlled and automatic processes (e.g. Debner & Jacoby, 1994; Hay & Jacoby, 1996; Jacoby, 1991, 1998, 1999; Jacoby et al., 1993; Jennings & Jacoby, 1993, 1997; Kelley & Jacoby, 2000; Yonelinas & Jacoby, 1995). As Jacoby has noted (Jacoby, 1998; Jacoby & Hay, 1998), the inclusion/exclusion tests instructions are critical in order for controlled and automatic processes to independently influence task performance. Another criticism to the PDP procedure is that A and C estimated in a memory task could reflect non-mnesic controlled or automatic processes, for instance inhibitory processes (Nigg, 2001; however see Hay & Jacoby, 1999 who demonstrated that C and A evaluated with the PDP effectively reflects memory processes).

Assuming that the Process Dissociation Procedure is adequate to obtain correct estimates of automatic and controlled processes, the A and C estimates can then be used in regression analyses in order to verify the hypothesis that age-related decreases in episodic memory tasks are mediated by age-related decreases in controlled processes but not in automatic processes. However, many studies based on regression analyses use raw scores obtained in tasks that are multi-compound. For instance, to evaluate how speed processing can explain age-related decrease in memory, speed is defined as time to solve tasks such as Digit-Symbol or perceptive comparisons. Time measures are then entered in regression analyses to evaluate how they are able to reduce age effect on an independent memory task (Bryan, Luszcz, & Pointer, 1999; Earles, Connor, Smith, & Park, 1997; Earles et al., 1997; Salthouse, Fristoe, & Rhee, 1996; Salthouse et al., 1996; Sliwinski & Buschke, 1997). Unfortunately, the tasks used to evaluate processing speed imply other variables in addition to the strict speed component, in other words, they are not “pure”, for instance working memory plays a role in the Digit-Symbol task and strategic processes are involved in perceptive tasks. Moreover, it is often difficult to determine if the observed relationships are due to one, several or all factors involved in the tasks.

As noted by Salthouse, Toth, Hancock, and Woodard (1997), it is important to have tasks providing a pure evaluation of the suspected factors. They studied the influence of several factors on age-related decrease (from 18 years to 78 years) in a word learning task. These factors were perceptual speed, executive functions evaluated with Verbal Fluency tests and the Trail Making Test, spatial abilities, and controlled and automatic processes engaged in a stem-completion task and in a spatial attention task. In this spatial task, left or right directed arrows appeared on the left or on the right side of a screen.

Location on the screen and arrow's direction did or did not correspond (both were left, both were right, or one was left and the other was right). Subjects had to respond to the arrow's direction only and ignore its position on the screen. The stem-completion task was similar to the ones used by Jacoby and colleagues (Jacoby, 1998; Jacoby et al., 1993). Perceptual speed was the best explanatory factor of the age-related decline in the word learning task. *C* obtained with the spatial attention task also accounted for a great part of the age-related variance (78%). However, *C* obtained with the PDP on the stem-completion task only explained 18% of this variance. This result was rather unexpected since the material involved is this task was closer to the words to be learned than was the spatial task. Moreover, *C* for stem-completion did not significantly correlate with age,[3] which is in contradiction with results frequently described (e.g. Hay & Jacoby, 1999; Jacoby, 1999). These results could be due to the fact that, in the stem-completion task, word encoding was incidental. This encoding procedure, which differs from the procedure generally used in studies of stem completion, could render the task more difficult. Indeed, *C* estimates were relatively low (respectively 31% and 24% for young and old participants).

In this context, the major aim of our study was to re-evaluate how age effect on controlled processes could explain age-related memory decrease in "classical" memory tasks such as learning words lists. To obtain a more valid measure and to avoid floor effects (as suspected in Salthouse et al., 1997' stem completion task), we modified somewhat the procedure proposed by Salthouse et al. Automatic and controlled processes were also evaluated with the Process Dissociation Procedure, as this procedure appears to give pure measures of *C* and *A* processes (in contrast with procedures where a variable is directly evaluated by the score obtained in the task), but we proposed an intentional encoding of the words (Jacoby et al., 1993). As noted, since retrieval and encoding are not independent (Craik, 2002), the fact of enhancing strategic memory processes thanks to intentional encoding should increase performance and controlled processes at retrieval, avoiding both floor performances and too small *C* values. Using regression analyses, we then correlated *C* and *A* estimates derived from the PDP task with memory scores obtained on "independent" words learning tasks (items in the PDP task and in the learning lists were different). In our study, the learning words lists varied in modality (they were orally or visually presented), in speed presentation (either fast or slow) and in support given at encoding (by using a list where words were organised in semantic clusters) or at retrieval (by providing semantic cues at retrieval). We manipulated these variables in order to evaluate the *C* involvement in several memory tasks: we expected that the *C* decrease would be a better explanatory factor than *A* changes in tasks requiring controlled and effortful processes (for instance when no support is given, or with faster presentation), but not necessarily in tasks where support is giving at encoding or, at least, in retrieval, given that support is supposed to reduce the intervention of controlled processes (Craik, 2002). Therefore, variables manipulated in the word recall tasks should be susceptible to modify the contribution of controlled processes and particularly the possibility of *C* to explain age effects on memory performance (Bäckman & Karlsson, 1986; Bäckman & Larsson, 1992; Craik et al., 1987).

[3] Note however that *C* correlated significantly with age when vocabulary was statistically controlled for.

2. Method

2.1. Participants

Forty-seven French-speaking participants were divided into two groups. The young group consisted of 25 undergraduate students from the University of Brussels, aged between 18 and 23 years (11 males and 14 females with mean age = 19.1 years). The older group included 22 volunteers aged between 60 and 77 years (10 males and 12 females with mean age = 69.9) and recruited in various Belgian associations. All the elderly participants were retired; none of them had obtained a university degree, but all had attended at least secondary school. Both groups were equally educated, with respectively 13.1 and 13.2 years of schooling ($t(45) = .119$, $p = .906$). All subjects were administered the second part of the Mill-Hill Vocabulary Scale (adaptation for spoken French, Deltour, 1993). The young participants performed as well as the older ones ($t(45) = 1.544$, $p = .130$, with a mean score = 28.0 for the younger group, and 29.1 for the older group). Participants did not suffer either from any neurological pathology or from any major auditory or visual problems.

2.2. Material and procedure

Participants were tested individually at the University in two sessions lasting approximately one hour and half an hour, respectively. Sessions were separated by an interval of one to three weeks.

In session 1, the participants were first presented with a questionnaire about health, education level, memory difficulties in everyday life, etc. Then they were presented word lists to learn and recall (lists one to four, described below) and other tasks which will not be described here either because they were not relevant to the present purpose. Finally there was a vocabulary test. In session 2, the Process Dissociation Procedure (PDP with other words than those used in the word recall task) was presented. The Inclusion and the Exclusion tests were separated by the presentation of a fifth word list and by its recall. Exclusion did not directly follow the Inclusion test in order to avoid confusion between inclusion and exclusion instructions.

2.2.1. Word recall

Participants had to learn word lists in which some manipulations were introduced because we supposed that different age effects would be obtained in some conditions (for instance, age effects could be smaller for words presented slowly or with support at encoding or at retrieval). Each list contained 20 French words from 5 semantic categories, with 4 words per category. The participants were informed that five lists with twenty words from five semantic categories would be presented and that they had to memorise them for a subsequent memory test. No other information was given (for instance, speed or modality information, if cues would be given at retrieval or if items would be intermixed or semantically organised). Between each list presentation and its recall, participants had to count backwards from 400 during 20 s, in order to avoid word maintenance in short-term memory. Responses were orally given.

List 1(base list): words were presented orally, in a quasi-random order, with a 1.25 s interval between consecutive words onsets. Categories were vegetables, illnesses, weapons, professions and organs.

List 2(retrieval cues): the main difference from list 1 is that semantic cues were given at retrieval. Before giving any answer, the first category label was orally presented ("colour") and participants had to retrieve as many items as possible from the category. Then, the second category was provided ("gems") and so on for all categories. Categories were colours, gems, animals, furniture, and means of transport.
List 3(slow presentation): compared with lists 1, 2, and 4, words were presented more slowly (a word every 2.25 s). Categories were fish, spices, clothes, kitchen utensils, and aggressions.
List 4(semantic organisation): the difference from list 1 (base list) is that words were presented in a semantically organised way. More specifically, the four words from a same category were presented successively. Participants did not know anything about this list organisation. Categories were insects, time measures, family members, vessels and spirits.
List 5(visual presentation): contrary to the other lists, words were presented visually on a computer screen. The rate was a word onset each 2.25 s. Categories were fruits, mammals, sports, flowers and musical instruments.

Except for the organised list (in which the four words from a category were presented successively), the words were quasi-randomly mixed: no more than two words from the same category were presented successively. In each category, selected words were neither prototypes, nor rare (Battig & Montague, 1969; Dubois, 1982). Orally presented words were recorded on a CD. Visually presented words were displayed in the centre of a 14-inch computer screen with the program MEL in the MEL-FONTS prints. The lists were presented always in the same order as described here over but a pilot experiment in which all these lists were presented in the same order as in the present study revealed that the lists had the same difficulty level.

2.2.2. PDP

The stem-completion test included three sets of stimuli: a baseline condition, an Inclusion condition, and an Exclusion condition.

The stimuli consisted of 68 six-letter words of high (>2000) and low (<500) frequency[4] of occurrence in the French language (determined with Brulex: Content, Mousty, & Radeau, 1990), presented in lowercase letters in the centre of a computer screen. Each word stem (i.e. the first three letters of each word) was unique within the test and could be completed by at least four other six-letter words. Stimuli were divided into three sets: 16 words for the baseline condition, 26 for the Inclusion condition and 26 for the Exclusion condition. The three distinct conditions were administered in the same order for all subjects: baseline condition, followed by Inclusion condition, followed by Exclusion condition.[5] Each set contained 50% of high frequency words and 50% of low frequency words, had an equal mean probability of having stems completed with its target word without prior pre-

[4] Values indicate the number occurrences out of a total of 100 millions.

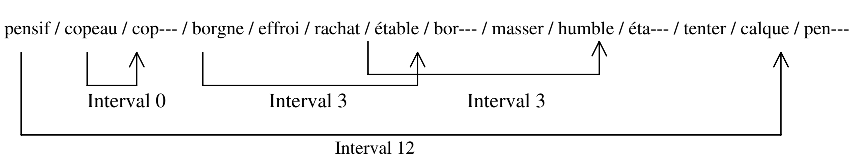
[5] However, we have used recently a new version of this stem completion task in which the order of Inclusion and Exclusion conditions was counterbalanced, and in which stimuli sets were rotated through each lag and condition (see Adam, Gouvarts, & Van der Linden, in preparation). Analyses comparing the two versions of this task (counterbalanced or not) showed no effects of the version and no interaction between version and condition (Inclusion and Exclusion).

sentation (i.e. base rate probability of completion), and an equal mean number of possibilities to complete stems with another six-letter word.

The objective of the baseline condition was to determine the probability to complete a stem by the chosen target word when the latter had not been presented before the completion. Participants were asked to complete the stems with the first six-letter word coming to mind. This chance rate was compared with the estimate of automatic processes that was supposed to be higher because of the influence of the earlier words' presentation.

In the Inclusion and Exclusion conditions, words were presented during 5 s. Participants were asked to read aloud the words (e.g. "pensif") and to memorise them in order to retrieve them when their stem (e.g. "pen—") would appear later in the test. In the Inclusion condition, participants were then asked to complete the stem with the corresponding studied word and, if they could not remember it, to give another six-letter word coming to mind to complete the stem (e.g. "pen—" has to be completed with "pensif"). In the Exclusion condition, participants were asked to remember the studied word but to complete the stem with a new word, which means that they had to reject the studied word to give another six-letter word completing the stem (e.g. "pen—" can be completed with "pendre"). If they could not remember the learned word, they had to give an adequate six-letter word coming to mind and complete the stem. In all conditions, participants had 15 s to complete orally the stem with a word according to the following rules: six-letter French words, no plurals, no proper names and no conjugated verbs except past participles. If the response did not meet the rules, negative feedback was given and the participant was encouraged to give a better answer.

Phases of items presentation and completion were intermixed. Entire words and their stems to complete were separated by different lag intervals: either 0, 3 or 12 items. These lags corresponded to the number of items intervening between the presentation of a word and its stem (see Fig. 1). The manipulation of lag may help to determine the severity of the deficit. Indeed, the deficit of *C* is greater if observed at shorter intervals (Jermann et al., 2005). For each condition, there were respectively 6 word-stem for the lag 0, 10 for the lag 3, and 10 for the lag 12. Completion failure with interval 0 could indicate problems in instruction comprehension or faulty encoding or attentional aptitudes, particularly in the Exclusion condition. Each test list order (i.e. succession of words and stems in Inclusion and Exclusion conditions) was fixed and designed with the restriction that no more than two words of a given lag (0, 3, and 12) could occur consecutively.



English translation of items in the example :

Pensif = thoughtful
Copeau = chip of wood
Borgne = one-eyed
Effroi = terror
Rachat = (re)buy
Etable = stable
Masser = to massage
Humble = modest
Pointe = point
Tenter = to try
Calque = copy

Fig. 1. Illustration of manipulations of intervals between the presentation of a word and the stem to complete in the PDP.

Table 1
Mean scores in% (and standard deviations) for each list, in the young and old groups

Word-lists	Young group	Old group
1. Fast orally presented list	43.00 (9.84)	28.06 (8.86)
2. Fast orally presented list with retrieval cues	51.40 (14.61)	28.63 (14.89)
3. Slow orally presented list	55.00 (16.70)	33.18 (12.10)
4. Fast orally presented organised list	43.80 (11.11)	29.09 (13.50)
5. Slow visually presented list	53.00 (8.16)	35.68 (13.30)

Table 2
Mean scores in% (and standard deviations) in the young and elderly groups

Conditions	Young group	Old group
Baseline	8.76 (5.45)	10.32 (8.08)
Inclusion	89.38 (6.59)	76.40 (11.34)
Exclusion	5.08 (5.17)	11.36 (7.46)

3. Results

3.1. Words recall

We performed a MANOVA analysis with age and list as between- and within-subjects factors, respectively (see Table 1 for mean scores). Young participants displayed better performance for all the lists ($F(1,45) = 53.57$, $p < .001$). A general effect of list manipulation ($F(4,180) = 7.48$, $p < .001$) was also obtained. LSD post-hoc analyses reveal a significant facilitation effect of the retrieval cue ($p = .037$) and of slower presentation speed ($p < .001$) but not of list organisation ($p = .669$)[6] or of presentation modality ($p = .907$). The interaction Age × Manipulation is not significant ($F(4,180) = 1.58$, $p = .182$).

3.2. Word-stem completion and the process dissociation procedure

Scores were first calculated for the baseline, the Inclusion condition and the Exclusion condition. Scores in the Exclusion condition represent the number of words to be rejected that were given in the completion test. Table 2 and t-tests clearly show that young participants outperformed the elderly in the Inclusion ($t(45) = 4.71$, $p < .001$) and Exclusion ($t(45) = 3.39$, $p = .001$) conditions but not in the baseline ($t(45) = .76$, $p = .450$) condition.

To derive estimates of automatic (A) and controlled (C) processes, the equations used by Jacoby and colleagues were applied: $C = \text{Incl.} - \text{Excl.}$ and $A = \text{Excl.}/(1 - C)$. A and C were calculated from performance in Inclusion and Exclusion averaged over intervals 3 and 12 (Table 3). Interval 0 has to be considered as a control condition to verify the understanding of the procedure (moreover, A could not be calculated for interval 0 since C was frequently at 100%). At zero-spacing, near perfect performance in the inclusion task

[6] There were larger clusters of items during the recall of the organised list than during the recall of the base list ($F(1,45) = 57.12$, $p < .001$). However, there were no age difference in clustering ($F(1,45) = 0.38$, $p = .539$) nor Age × List Organisation interaction ($F(1,45) = 0.12$, $p = .729$).

Table 3
C and *A* estimates (and standard deviations) in the young and elderly groups

C and *A* estimates	Young group	Old group
A	31.46 (31.22)	35.18 (24.06)
C	84.32 (7.61)	64.91 (13.41)

(young group: 95% ± 9%; old group: 92% of correct responses ±15%) and, particularly, near zero performance in the exclusion task (young group: 0.7% of incorrect responses ±3.3%; old group: 0.8% ± 3.6%) indicate that both groups understood correctly inclusion and exclusion instructions.

A[7] was higher than the baseline for the young adults ($t(23) = 3.766$, $p = .001$) and the elderly ($t(21) = 4.994$, $p < .001$) participants. *A* was thus influenced by memory traces and by instructions.

Age had no effect on *A* ($t(44) = .461$, $p = .647$). Power analyses were performed on *A* in order to obtain the effect size. Its value (.13) indicates that the effect was really small,[8] We also calculated *A* after elimination of participants having either 100% in Inclusion or 0% in Exclusion. Thirteen young and 19 old participants were maintained. The conclusion was the same: *A* was not affected by age ($t(30) = .924$, $p = .363$). On the contrary, *C* was influenced by age ($t(45) = 6.198$, $p < .001$).

As noted by Salthouse et al. (1997), age could have no effect on *A* because *A* would be less reliable than *C*. Reliability was evaluated through the correlation between two sets of items randomly selected in each test. Reliability estimates are significant for both *C* (.52, $p < .001$) and *A* (.46, $p = .004$).

Nevertheless, we also analysed the Interval effect. As noted above, the lag manipulation should inform us about severity of *C* decrease with age (Jermann et al., 2005). Interval did not affect *A* but affected *C* with smaller values for greater intervals ($F(2.45) = 47.02$, $p < .001$). Moreover, a significant interaction Age × Interval ($F(2.45) = 5.43$, $p = .006$) and post-hoc analyses indicated an age related effect on *C* with small interval: the age effect on *C* appeared especially between interval 0 and interval 3.

3.3. Regression analyses

Table 4 shows, for each list, the proportion of variance associated with age when age was the only predictor in the regression analysis and when estimates of either controlled or automatic processes were entered before age in the hierarchical analyses (column "R^2"). It also shows the percentage of reduction of the age-related variance after control of automatic or controlled processes estimates (column "% reduction"). It can be seen that age alone explains a significant part of the variance for all the learned lists. When *A* was taken into account before entering age in the equations, the age-related variance was not or only very slightly reduced (from 0% to 3.33%) and remains highly significant. On the contrary, controlling *C* before entering age in the equations greatly reduced the age-related variance in all lists (by 56.92% to 74.38%). Moreover, it can be noted that, even if age-related

[7] A could not be calculated for one young participant who, having performed perfectly in both conditions, obtained an estimate of *C* at 100%. Therefore, he was excluded from the analysis.
[8] As noted by Cohen (1988), value <.2 refer to effect that can be considered as small.

Table 4
Age-related variance in the learned word lists

Word-lists		R^2	% reduction
Fast orally presented lists	Age alone	.396**	–
	Age after *C*	.114**	71.21
	Age after *A*	.387**	2.28
Fast orally presented organised lists	Age alone	.271**	–
	Age after *C*	.104*	61.62
	Age after *A*	.262**	3.33
Fast orally presented lists with retrieval cues	Age alone	.383**	–
	Age after *C*	.165**	56.92
	Age after *A*	.383**	0
Slow orally presented lists	Age alone	.363**	–
	Age after *C*	.093*	74.38
	Age after *A*	.363**	0
Slow visually presented lists	Age alone	.398**	–
	Age after *C*	.102**	74.37
	Age after *A*	.391**	1.76

* R^2 sign. at .05.
** R^2 sign. at .001.

variance is greatly reduced after *C*, age still accounted for a significant portion of the variance in word-recall after *C* was entered into the hierarchical regression.

4. Discussion

4.1. Applying the process dissociation procedure

In the present study, elderly adults performed more poorly than the young in Inclusion (less correct responses) and Exclusion (more errors) stem-completion tasks. Applying equations used by Jacoby and colleagues (Jacoby, 1991, 1998, 1999; Jacoby et al., 1993) revealed that these differences in performance were due to an age-related decrease in controlled processes but not in automatic processes. This result confirms those already reported in the literature (Hay & Jacoby, 1999; Jacoby, 1999; Jacoby & Hay, 1998; Spieler et al., 1996; Titov & Knight, 1997; Zelazo et al., 2004).

Moreover, we found, like Jennings and Jacoby (1997), that the interval between an item presentation and its recall did not affect *A* but affected *C*, with smaller values for greater intervals. A significant interaction Age × Interval and post-hoc analyses indicated an age related effect on *C* when information was stocked for short periods. As noted by Jermann et al. (2005), the decrease of *C* with small intervals proves particularly well the age effect on *C*.

4.2. Manipulation effects on word recall

In the word lists learning task, elderly participants produced lower performance than the young, regardless of whether the lists were presented orally or visually, rapidly or slowly, with or without support at encoding or at retrieval. Some manipulation effects also correspond to what is generally described. For instance, slowing presentation speed or giving retrieval cues increased performance. Indeed, to develop complex encoding strategies seems to be easier when the material is presented slowly (Hartley, 1993; Vakil, Malamed, & Even, 1996; Verhaeghen, Marcoen, & Goossens, 1993). Similarly, since a difficulty in free recall is to initiate memory search by specifying cues (Burgess & Shallice, 1996), external semantic cues generally facilitate retrieval, contributing to improve performance. These manipulations were supposed to affect old and young participants differentially, with a reduction in the age-related effect with slower presentation and retrieval cues (Bäckman & Karlsson, 1986; Bäckman & Larsson, 1992; Craik et al., 1987; Smith, 1977; Verhaeghen, Vandenbroucke, & Dierckx, 1998), but this frequently observed pattern of results was not obtained. An explanation of the last result could be that providing cues at retrieval is not as useful for elderly adults as for the young because words had not been sufficiently processed at encoding. Bäckman and Karlsson (1986), Rabinowitz, Craik, and Ackerman (1982) and Smith (1977) showed that semantic retrieval cues reduced age effects only if instructions at encoding specified the semantic organisation of the material or if the same cues were also present during encoding. The absence of an Age × Speed interaction can be understood in terms of Salthouse's (1996b) theory. In spite of the fact than older participants have slowed processes, giving more time at encoding could help young participants more than old ones whose working memory is less efficient. Therefore, the old participants could not benefit as well as the young reducing presentation speed (Verhaeghen et al., 1998).

Presentation modality had no effect on scores. Frieske and Park (1999) found similar results with facts presented orally or visually (either text alone or both text and pictures).

The absence of a list-organisation effect replicates the result found by Morrow, Leirer, Carver, and Tanke (1998) who asked their participants to memorise organised and non-organised messages. Nevertheless, this outcome is surprising since semantic organisation at encoding is supposed to offer considerable support. An explanation could be found in the instructions. Indeed, Bäckman and Karlsson (1986) found that age-related differences disappeared when information about semantic organisation of the material was given. In the present experiment, participants were not informed about the list organisation. Again, these results suggest that processes at encoding and at retrieval are not independent.

4.3. Age-related memory decrease and mediation by controlled processes

As the Process Dissociation Procedure seems to provide process-pure estimates of automatic and controlled processes, these estimates can be used in hierarchical regression analyses to evaluate how they mediate age-related effects in memory tasks. Entering *C* before age in hierarchical regression analyses greatly reduced the age-related variance observed for all word lists, while entering *A* did not reduce this age-related variance. *C* obtained in the stem completion task reduced the age related variance in independent word list memory tasks to a much greater extent than in the study of Salthouse et al. (1997). In our study, higher performance in our Inclusion and Exclusion conditions than in those from the Salthouse's,[9] probably due to intentional encoding study, seems to be related to a higher intervention of *C* processes in our task: *C* estimates were about 84% and 64%, respectively for young and old participants in our study, and for respectively 31% and 24% in Salthouse's

[9] In the Inclusion condition, performances were about 90% and 76%, respectively for young and for old participants while they were about 54% and 46% in Salthouse study. In the Exclusion condition, errors were about 5% and 11% for young and old participants while they were about 23% and 25% for Salthouse's participants.

study, while *A* was almost about 30% in both studies (31% and 35% in our study, 30% and 28% in Salthouse's study). For Jacoby, the *C* estimate reflects controlled (voluntary and strategic) processes at retrieval. However, processes at encoding and at retrieval are not independent. As noted by Craik (2002), many studies have shown influences either of encoding strategies or of encoding manipulation effects on retrieval performance. Differences of *C* involvement in incidental encoding (presumed low level of controlled processes at encoding in the stem-completion task of Salthouse et al., 1997) and intentional encoding (presumed higher level of controlled processes at encoding in the target memory task of the same authors) could reduce the amount of overlap between the two tasks.

In addition, even with environmental support given either at encoding or at retrieval, entering *C* could still reduce the age-related variance for more than 50%. This shows that controlled processes are still playing an important role in memory tasks in which support is given.

The reduction of the age-related variance in memory tasks after control of *C* processes could be related to the changes in frontal structures accompanying aging. Indeed, because of the role of these structures in organisation, integration and manipulation of information, Moscovitch (1994b) described them as "working-with memory" structures. If these structures are deficient in aging people, memory tasks involving them could be disrupted. In contrast, automatic memory processes, more related to medial temporal lobes, would be better preserved.

It is also worth noting that inhibitory processes play a role in the stem-completion task. Indeed, errors could reveal inadequate cues specification and, particularly in the Exclusion task, they could also reveal an inadequate inhibition of activated memory traces. It is now well known that the inhibition capacity decreases with age (Connelly, Hasher, & Zacks, 1991; McDowd & Filion, 1992; Salthouse & Meinz, 1995) and that this age-related inhibition decrease could explain some part of the age effect on memory tasks (Hay & Jacoby, 1999; Zacks, Radvansky, & Hasher, 1996). As reported by Jacoby et al. (2005), an inhibitory deficit can prevent recollection processes by inducing errors in cues specification (called capture errors). These authors also reported some studies that have shown relations between control in recollection and control in inhibitory tasks or in prevention of perseverative errors. Nevertheless, it was shown that an age related decrease in controlled processes could not be resumed to a decrease in inhibitory processes (Hay & Jacoby, 1999).

Even if the age-related variance was reduced after partialling out the contribution of *C*, one needs to account for the fact that it remained significant. Factors other than those included in the evaluated controlled processes should thus be also responsible for the memory decline with age. Several factors have been identified such as a reduction in processing speed or in keenness of eyesight and hearing (Baltes & Lindenberger, 1997; Frieske & Park, 1999; Lindenberger, Mayr, & Kliegl, 1993; Park et al., 1996; Salthouse, 1993, 1994, 1996a). According to Salthouse et al. (1997), the slowing down of processing could be a better explanatory factor than the reduction in controlled processes. Therefore, the speed with which processes are carried out could be responsible for some memory decline. Nevertheless, to date, there seems to be no pure measure of the concept of processing speed. As noted in the Introduction, tasks used to evaluate speed are not pure and thus involve other processes than speed. The keenness of eyesight and of hearing (Baltes & Lindenberger, 1997; Frieske & Park, 1999) could also be involved but it is implausible that this kind of factor would not influence the estimates of automatic processes. Indeed, if the stimuli were not as well perceived by older than by young people, the automatic influence of these stimuli traces should be less important in older persons. However, our results are in the sense of slightly (though not significantly) greater automatic processes in the elderly group.

Finally, in a study conducted with the same objective, Salthouse et al. (1997) separated automatic and controlled influences in a stem-completion task and in an attentional task (the Arrow Task described earlier). They found a correlation between both estimates of controlled processes but no correlation between evaluations of automaticity. Hence, if automatic attentional processes played a role in age memory decrease, these automatic influences would be task-specific. Moreover, Salthouse et al. (1997) also showed that estimates of automatic attentional processes accounted for a small part of the age-related variance in a word learning task. It is thus unlikely that, in our study, any other estimate of *A* could better explain the age effect on memory than *A* evaluated on the stem-completion task. Furthermore, controlled attentional processes estimated with the Arrow Task explained a great part of the age-related variance in the word learning task, but were also strongly related to controlled processes evaluated in the stem completion task. For this reason, it is unlikely that partialling out controlled processes assessed with another task, such as the Arrow Task, would add much to the estimates of controlled processes obtained in our study.

In summary, it was found that controlled processes could explain a great part of the age-related variance in word list memory, even in tasks where environmental support is given. Nevertheless, as the age-related variance remained significant, other factors should also be considered. Further work is still necessary to identify those factors not included in automatic and controlled processes estimates that are responsible for the age-related memory decrease.

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