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Directed Forgetting and Aging: The Role of Retrieval Processes, Processing Speed, and Proactive Interference

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ABSTRACT

The directed forgetting effect obtained with the item method is supposed to depend on both selective rehearsal of to-be-remembered (TBR) items and attentional inhibition of to-be-forgotten (TBF) items. In this study, we investigated the locus of the directed forgetting deficit in older adults by exploring the influence of recollection and familiarity-based retrieval processes on age-related differences in directed forgetting. Moreover, we explored the influence of processing speed, short-term memory capacity, thought suppression tendencies, and sensitivity to proactive interference on performance. The results indicated that older adults' directed forgetting difficulties are due to decreased recollection of TBR items, associated with increased automatic retrieval of TBF items. Moreover, processing speed and proactive interference appeared to be responsible for the decreased recall of TBR items.

Keywords: Directed forgetting; Processing speed; Proactive interference; Dual-process; Cognitive aging.

INTRODUCTION

Directed forgetting (DF) refers to a deliberate attempt to limit the future expression of specific memory contents (Johnson, 1994). This active form of forgetting differs from the simple attenuation of memory contents over time and from proactive or retroactive interference. It is involved in many daily memory activities since it allows one to suppress information that is no longer relevant from one's consciousness or to update outdated information stored in long-term memory. Two methods (the item and list methods) are classically used to study DF effects. Some data support the hypothesis that each method assesses a specific form of voluntary forgetting, or at least depends on partially different processes, such as retrieval inhibition for the list method and selective rehearsal or attentional inhibition for the item method (Basden & Basden, 1996; Basden, Basden, & Gargano, 1993; MacLeod, 1999).

In this study, the item method was used to explore DF processes in normal aging. In the item method, subjects are given a list of words with the instruction to remember every item followed by a 'remember' cue (to-be-remembered items or TBR) and to forget items followed by a 'forget' cue (to-be-forgotten items or TBF). Typically, TBR items are remembered better than TBF items, that is, TBR items are better recalled or recognized when subjects are subsequently tested on all presented words, regardless of study instructions (e.g., Davis & Okada, 1971; MacLeod, 1975).

Two hypotheses have been proposed to explain the DF effect observed with the item method. The first one, the selective rehearsal hypothesis, emphasizes differential encoding and rehearsal of TBR items (Basden et al., 1993; Bjork, 1970; Bjork & Woodward, 1973; Palier, 1990). According to this hypothesis, when an item is followed by a remember cue, subjects typically engage in more elaborated encoding than when items are followed by a forget

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cue, naturally making the TBR items more accessible for later remembering. The main support for the selective rehearsal hypothesis is that the DF effect is reduced (but not systematically suppressed) when subjects are not allowed to rehearse TBR items because of an interpolated task presented just after the cue (Mitchell, Macrae, Schooler, Rowe, & Milne, 2002; Otani, Widner, Kling, & Rubenacker, 1998; Spector, Laughery, & Finkelman, 1973; see, however, Allen & Vokey, 1998). The second hypothesis, the attentional inhibition hypothesis, argues that the item-method DF effect results from the attentional inhibition of TBF items triggered by the forget cue (Zacks & Hasher, 1994; Zacks, Radvansky, & Hasher, 1996). Attentional inhibition refers to the voluntary suppression of irrelevant information that prevents an overload of working memory (Hasher & Zacks, 1988; Zacks & Hasher, 1994). According to this hypothesis, TBF items and/or the rehearsal of these items are assumed to be inhibited just after they are encoded (when the forget cue is displayed), allowing for more successful selective rehearsal (more generally, more elaborated processing) of the TBR items because of the release of working memory resources. In that context, such attentional inhibition is said to be necessary for any voluntary updating of working memory content. This inhibitory hypothesis is supported by psycho-physiological data, which demonstrate that the successful processing of TBF items is associated with specific event-related potential (ERP) activity and that the recognition-related ERPs for TBR and TBF items differ qualitatively and quantitatively, especially in the frontal areas (Paz-Caballero, Menor, & Jiménez, 2004; Ullsperger, Mecklinger, & Müller, 2000; see, however, MacLeod, Dodd, Sheard, Wilson, & Bilbi, 2003, for alternative explanations of the inhibitory account of DF effects).

To sum up, both the selective rehearsal and attentional inhibition hypotheses claim that the item-method DF effect stems from more extensive processing of TBR items during the study phase. However, the attentional inhibition hypothesis assumes that such selective processing of TBR items cannot operate without the active inhibition of the TBF items and of the processing allocated to the irrelevant TBF items prior to the cue presentation, while the selective rehearsal hypothesis does not postulate any inhibitory processing.

According to the selective rehearsal hypothesis, DF instructions should affect explicit (or direct) memory tests but not perceptually based implicit (or indirect) tests because the latter are generally insensitive to variations in encoding processing (see Roediger & McDermott, 1993, for a review). In agreement with this hypothesis, numerous studies have shown that the DF effect only occurs if intentional retrieval of items is required (Basden & Bas-den, 1996; Basden et al., 1993; Gardiner, Gawlik, & Richardson-Klavehn, 1994; McKinney & Woodward, 2004; Paller, 1990; Paz-Caballero & Menor, 1999). However, other studies have shown that the DF effect can occur in implicit memory tasks (Lehman, McKinley-Pace, Wilson, Slavsky, & Woodson, 1997; MacLeod, 1989; MacLeod & Daniels, 2000; Paller, 1990; Russo & Andrade, 1995). These discrepancies among studies probably arise from methodological differences that lead to differential contamination of implicit memory performance by explicit (recollective) memory processes. Indeed, in these studies, only the instructions given to the subjects differentiate implicit and explicit memory tasks. This interpretation was confirmed by studies that have applied the process dissociation procedure (PDP; Jacoby, 1991) in order to dissociate and quantify, within a given memory task, the respective contributions of automatic (familiarity-based) and intentional (recollective-based) retrieval processes (see David & Brown, 2003; Russo & Andrade, 1995). More specifically, the DF effect appears to be due to differences in recollective (intentional) rather than familiarity-based (automatic) retrieval, supporting the idea that explicit contamination is responsible for the earlier finding of a DF effect with indirect (implicit) memory tasks. Although these data support the selective rehearsal hypothesis, selective rehearsal cannot explain the whole DF effect as such since, as discussed earlier, several studies have shown that an interpolated task administered just after cue presentation does not completely eliminate the DF effect (Otani et al., 1998; Spector et al., 1973), and sometimes does not affect it at all (Allen & Vokey, 1998).

The existence of a reduced DF effect in elderly subjects has been demonstrated in several studies with the item method (Earles & Kersten, 2002; Gamboz & Russo, 2002; Sego, Golding, & Gottlob, 2006; Zacks et al., 1996). For example, Zacks et al. (1996) showed that, in comparison to young subjects, older subjects have a reduced DF effect when the instructions are given after word presentation (experiments 1A and 1B). This reduction was found with both recall and recognition tasks. Zacks et al. (1996) interpreted these results as evidence of an inhibitory deficit, consistent with Hasher and Zacks' (1988) more general hypothesis that inhibitory processing is impaired in older adults. Specifically, they believed that elderly subjects' DF impairment was due to difficulties inhibiting the processing of TBF items once the forget instruction was delivered. However, due to the episodic memory problems that are known to develop with age (Chalfonte & Johnson, 1996; Erber, Herman, & Botwinick, 1980; Grady, McIntosh, Horwitz, & Maisog, 1995), a reduction in the DF effect might also be the consequence of age-related differences in the processing of TBR items. To test this hypothesis, Gamboz and Russo (2002) manipulated the level of processing of TBR and TBF items by asking subjects either to judge the pleasantness of each word (deep processing) or to count the number of letters in each word (shallow processing) before the presentation of the cue. They found that the DF effect differed between young and older adults when items were processed superficially but not when deeper processing was induced, confirming that the older subjects' DF deficit may be due to greater age-related differences in the recall of items processed deeply (i.e., TBR items) compared to the recall of items processed superficially (i.e., TBF items), rather than to any inhibitory processing deficit. However, very little time was allowed after the presentation of the cue in their study, which may have reduced the probability of observing, in the deep processing condition, any group differences due to age-related changes in selective retrieval or inhibitory functioning. A recent study by Dulaney, Marks, and Link (2004) also explored the impact of depth of processing on elderly adults' problems with the DF task, but they failed to find any effect of manipulation of the level of processing. However, they found that increasing rehearsal time leads to a disappearance of the DF effect, especially for older adults. Such results again support the role of age-related episodic learning differences in the emergence of DF difficulties in the elderly.

Although the existence of a lesser DF effect in the elderly is now well established, the cognitive processes responsible for this decreased effect are not clearly understood. This pattern of results has been explained by an impairment affecting the selective rehearsal of TBR items (Gamboz & Russo, 2002) or the attentional inhibition of TBF items (Zacks et al., 1996). However, elderly adults' difficulties may also be situated at the retrieval level, consisting in a diminished access to previously presented items (especially for the TBR items, which require explicit learning). So it is possible that elderly adults suffer from DF problems because their memory performance has generally been assessed with intentional retrieval tasks (such as recall or recognition tasks). This assumption is supported by the extensive literature showing that elderly adults are disadvantaged on memory tasks that require self-initiated processes (e.g., Craik, 1986).

The present study was designed to test the hypothesis that the DF effect decline in normal aging is due to the requirement for intentional retrieval processes. For that purpose, DF performance was assessed in two conditions: one in which intentional retrieval processes are the main basis for performance (the inclusion condition), and one in which automatic retrieval processes are the main basis for performance (the exclusion condition). We did this in order to assess on which retrieval processes (intentional or automatic) the DF difficulties of older subjects are observed. Several studies with young subjects have shown that the DF effect tends to emerge only when items are retrieved explicitly, on the basis of recollective processes (David & Brown, 2003; Russo & Andrade, 1995). In this experiment, we examined whether this is also the case for elderly subjects, since the decrease in the DF effect in elderly adults may arise because of greater automatic retrieval of TBF items, associated with decreased intentional retrieval of TBR items. Indeed, previous exposure to an item (even without the explicit instruction to encode it) increases its familiarity and its tendency to be retrieved automatically (Jacoby & Dallas, 1981). Concretely, if TBF items are not subject to more rehearsal than TBR items (as was stressed by the instructions), there may not be sufficient details to allow conscious recollection of these items, which may lead older adults to report many of these items automatically (Jacoby, 1999). We made this prediction on the basis of several studies which have revealed that elderly adults generally show an enhancement of familiarity-based responses when performing memory tasks (e.g., Bastin & Van der Linden, 2003; Parkin & Walter, 1992).

In this experiment, we were also interested in exploring the role of several cognitive factors (short-term memory capacity, processing speed, thought suppression abilities, and proactive interference) that may be potential mediators of the age-related difference in DF performance. Indeed, short-term memory capacity and processing speed are known to be affected in normal aging (Hasher & Zacks, 1988; Hester, Kinsella, & Ong, 2004; Salthouse, 1996; Van der Linden & Hupet, 1994; Verhaeghen & Salthouse, 1997), and these factors also influence episodic memory functioning in both young and older subjects (see, for example, Jacoby, Bartz, & Evans, 1978; Park et al., 1996; Van der Linden et al., 1999; Weaver, 1974), so they could be related to the recall of TBR items. Moreover, these factors are also related to each other (Cowan et al, 1998), and one of them (processing speed) is known to be related to inhibitory functioning in elderly adults (Verhaeghen & De Meersman, 1998). The influence of thought suppression was explored more tentatively because it is possible that daily life thought suppression tendencies involve the same inhibitory processes required in DF tasks, and that subjects who are used to resorting to thought suppression in daily life find it easier to cope with DF tasks. Short-term memory capacity, processing speed, and thought suppression tendencies were assessed after the DF task had been completed. Finally, we were also interested in exploring the influence of proactive interference in the emergence of age-related differences in the DF effect. In DF tasks, a large number of items are presented to the subjects (Dulaney et al., 2004; Zacks et al., 1996), which can lead to poorer performance due to elderly subjects' well-known increased sensitivity to proactive interference (e.g., Hasher, Chung, May, & Foong, 2002; Lustig, May, & Hasher, 2001). To explore this effect, we divided the DF task into two equivalent parts so we could identify any decline in performance resulting from the successive presentation of the items. The rationale was that elderly adults might find it more difficult to process TBR items and/or inhibit TBF items in the second part of the DF task.

Because several studies haves shown that elderly adults' episodic memory deficits are mainly due to recollection problems (e.g., Bastin & Van der Linden, 2003; Craik, 1986; Hay & Jacoby, 1999), whereas automatic (familiarity-based) retrieval abilities appear to be spared (e.g., Hay & Jacoby, 1999; Parkin & Walter, 1992), we hypothesized that the older subjects would recall fewer TBR items in the inclusion condition, but not in the exclusion condition (which is more dependent on automatic retrieval processes). Moreover, because of the enhanced familiarity-based responses frequently observed in elderly adults (Bastin & Van der Linden, 2003; Parkin & Walter, 1992), we expected that these subjects would recall more TBF items in the exclusion condition (and, consequently, in the inclusion condition, which partially relies on automatic retrieval processes), because these items might have a high level of familiarity but were not processed deeply enough to allow conscious recollection. We also wanted to determine whether the expected DF difficulties of elderly adults can be explained by age-related differences in short-term memory, processing speed, and thought suppression, which may influence the processing of TBR and TBF items differently. If these variables are involved in the age-related differences in the recall of TBR and TBF items, the effect of normal aging should no longer be significant when their influence is controlled for with ANCOVA analyses. Finally, if proactive interference is also responsible for elderly adults' DF difficulties, we should observe a reduction in the DF effect in older subjects from the first to the second part of the task as compared to young adults. This reduction in the DF effect due to increased sensitivity to proactive interference could potentially result from decreased recall of TBR items and/or increased recall of TBF items.

MATERIALS AND METHOD

Subjects

Thirty-three young and 27 healthy elderly subjects participated in this experiment. Young participants (age range: 18-34 years old; *M*= 23.6 years old; *SD* = 4.85) were mostly undergraduate students. Older adults aged from 60 to 76 *(M* = 66.04 years old; *SD* = 5.44) were selected to match the younger subjects in terms of education [level of education: young subjects: *M* = 14.06 years; *SD* = 1.82; elderly subjects: *M* = 13.26 years; *SD* = 3.13; $t(58) = 1.24$, $p = .22$) and performance on the Mill Hill vocabulary test (young subjects: *M* = 23.8; *SD* = 3.38, elderly subjects: *M* = 25.7; *SD* = 3.56; $t(58) = -2.03$, $p = .047$]. All elderly subjects had a total score superior to 130 on the Mattis dementia rating scale (Mattis, 1976; *M* = 140; *SD* = 3.24; range: 133-144), which constitutes a cut-off score to discriminate normal aging from dementia (Monsch et al., 1995). All subjects had normal or corrected-to-normal visual acuity.

Materials and Procedure

Directed Forgetting Task

The materials consisted of 80 six-letter words selected from the Brulex French database (Content, Mousty, & Radeau, 1990). These items were organized in five lists of 16 words, matched for word frequency [$F(4, 75) = 0.79$, $p = .53$], the number of words that could be produced from the stem of each item [$F(4, 75) = 0.14$, $p = .97$], and the tendency of the words to be randomly produced from their stems[2] [$F(4, 75) = 0.9$, $p = .47$]. A stem refers to the first three letters of a word; each was original in the present experiment, that is, each stem referred to a specific word. The first four lists were used to create four types of items: (1) TBR items to be recalled through inclusion stem completion (see below), (2) TBF items to be recalled through inclusion stem completion, (3) TBR items to be recalled through exclusion stem completion (see below), and (4) TBF items to be recalled through exclusion stem completion. Allocation of the lists to these types of items was counterbalanced in order to create eight versions of the task, which were administered to subjects randomly. The fifth list was used to assess baseline random stem completion in the test phase of the experiment (see below).

In the learning phase, 64 words were individually presented in the center of a computer screen for 3 s. Each was followed by either a remember ('to remember') or a forget ('to forget') cue that also remained on the screen for 3 s. A fixation cross was presented for a duration of 1.5 s, before the presentation of each word. Subjects were asked to read each word aloud and to remember only the words followed by a remember cue (while attempting

[2]Base rate probability of completion was determined for each six-letter target word by asking a group of 40 undergraduates to complete each stem with the first six-letter word that came to mind. Subjects had 15 s to orally complete the stem with a word (see Adam, Van der Linden, Collette, Lemauvais, & Salmon, 2005).

to forget words followed by a forget cue). TBR and TBF items were presented pseudo-randomly, with the constraint that each type of item could not be presented more than three times consecutively. Before the beginning of the task, we emphasized that the memory test would be based only on the TBR words. After the learning phase, subjects were asked to perform a distraction task that consisted of counting backward in steps of 3 for 30 s; this was intended to suppress any recency effect.

The 64 stems of all the words used in the learning phase were presented to subjects accompanied by the cue 'old' or 'new' (half with each cue), pseudo-randomly. When the cue 'old' was presented (inclusion stem completion), the task was to complete each stem by giving a word that had previously been presented, regardless of the prior study instructions (i.e., TBR or TBF). When subjects could not remember the target word, they were asked to complete the stem by giving the first six-letter word that came to mind. Thus, in the inclusion stem completion task, intentional and automatic processes converge to retrieve the target word since subjects might correctly complete a stem with a word they had studied earlier either because they consciously recollected having seen the word before, or because it was the first word that came to mind automatically, without any recollection that the word had been presented earlier. Following the presentation of the cue 'new' (exclusion stem completion), subjects were asked to complete each stem by giving a six-letter word that had not been presented in the learning phase. Consequently, in the exclusion stem completion task, intentional and automatic processes have opposing effects on performance since subjects might incorrectly complete the stem with a word that had been studied earlier only if that word came automatically to mind, without any controlled recollection that it had been presented earlier. Subjects had 15 s to complete each stem, and several practice trials were performed for both learning and test phases. The stems of 16 words (list 5) not seen during the learning phase were also randomly presented with cues, either 'new' or 'old,' to assess baseline stem completion.

Finally, it is important to note that the first 32 words (16 TBR and 16 TBF items) presented during the learning task corresponded to the first 32 words of the stem completion task. However, they were randomly presented across these two parts of the task. This manipulation was done in order to divide the whole task into two blocks that were not obvious to the subjects but that allowed us to assess the proactive interference effect by comparing their performance on the two parts. In comparison to Gamboz and Russo's (2002) study, the display time for cues was increased from 1 to 3 s, which should allow any age differences in inhibitory processing or selective rehearsal to emerge during the DF performance. After completing the DF task, subjects performed the short-term memory and processing speed tasks, and then completed the WBSI (see below).

Short-term Memory Task

A word span task was used to measure verbal short-term memory capacity. Concrete words were orally presented at a rate of one word per second, starting with strings of two words. The length of the strings progressively increased. Subjects were asked to repeat the words in the same order as they had been presented. Three attempts were allowed for each word string length and the span level for each subject was the longest string of words that he or she could repeat correctly on at least two of the three attempts. We used a short-term memory task instead of a complex working memory task (e.g., reading span) because performance on these more complex tasks is affected by the ability to resist to proactive interference, especially in elderly adults (Lustig et al., 2001; May, Hasher, & Kane, 1999). The presence of proactive interference in our control span task appeared to be a confounding factor in this experiment since its effect on DF performance was assessed directly.

Processing Speed Task

The processing speed task was a choice reaction time task in which subjects simply had to press one button if two letters printed on the screen were the same and another button if they were different, working as quickly and accurately as possible (see Salthouse & Babcock, 1991). This task was composed of 60 trials (30 with the same letters and 30 with different letters) randomly presented. The processing speed measure we used was the mean reaction time for the same-letter trials that were correctly detected.

The White Bear Suppression Inventory (WBSI)

The WBSI questionnaire consists of a set of 15 questions that assess thought suppression tendencies (Wegner & Zanakos, 1994). Each item is presented as a statement for which subjects have to give their degree of agreement on a 5-point Likert scale (from 'completely agree' to 'completely disagree'). As a recent factorial analysis has shown that a 3-factor model can be extracted from this questionnaire, we also split the global score for each subject into three subscores referred to as 'unwanted intrusive thoughts,' 'thought suppression,' and 'self-distraction' before running the correlation analysis (Blumberg, 2000). High scores on the WBSI reflect high reported thought suppression tendencies. In the present experiment, we used only the 'thought suppression' subscore, which is theoretically the most closely related to DF.

RESULTS

All effects were assessed for significance at the $p = .05$ level. The effect size of each analysis was reported as eta square (η^2) for the main effects and the interactions, and as Cohen's *D (d)* for planned comparisons. Eta square is generally interpreted as the proportion of variance of the dependent variable that is related to the factor. Traditionally, η^2 values of .01, .06, and .14, and *d* values of .2, .5, and .8 represent small, medium and large effect sizes, respectively (Cohen, 1988). Prior to the analyses, the reliability of the different measures was examined. Reliability of the directed forgetting task was estimated by splitting the task into two equivalent parts (see Salthouse, Siedlecki, & Krueger, 2006) comprising, respectively, odd and even items. The mean scores on the first and second halves of the study trials were then treated as 'items' to compute the coefficient alpha. In the inclusion condition, the estimated reliabilities were .58 for TBR items and .34 for TBF items. In the exclusion condition, the estimated reliabilities were .31 for TBR items and .50 for TBF items. Concerning the processing speed task, the reliability was computed by comparing the even and odd items of the task and by treating each mean as specific 'item'. The estimated reliability was .98 for the whole sample of subjects. The reliability of the span task was not computed since it was not possible to split the task (only three trials at each list length). Nevertheless, a similar version of this task has been found to have good reliability (see, for example, Beckmann, Holling, & Khun, 2007). Finally, the reliability of the WBSI was not assessed since it was previously described as a reliable questionnaire in both its internal consistency and test-retest stability (Muris, Merckelbach, & Horselenberg, 1996).

As expected, older subjects performed worse than younger ones on the word span task [span level; $t(58) = 2.56$, $p < .05$; $\eta^2 = .108$] and on the processing speed task [mean reaction time; $t(58) = -8.14$, $p < .0001$; $\eta^2 = .547$]. Young and older subjects did not differ in terms of their global scores on the WBSI [$t(58) = 1.12$, $p = .27$; $\eta^2 = .023$]. Nor did they differ for the 'unwanted intrusive thoughts' [$t(58) = 1.35$, $p = .18$; $\eta^2 = .033$], 'thought suppression' [$t(58) = 0.5$, $p = .62$; $\eta^2 = .005$], and 'self-distraction' subscores [$t(58) = 0.65$, $p = .52$; $\eta^2 = .008$]. Mean performances of young and older subjects for these three tasks are presented in Table 1.

TABLE 1. Mean performances and scores of young and elderly subjects for the processing speed task, the span task, and the WBSI

	Young	Older
Processing speed (ms)	575(57.21)	865(175.98)
Span	5.27(0.87)	4.8(0.58)
WBSI Global score	50(12.18)	47(11.57)
Unwanted intrusive thoughts	27(7.1)	24 (7.34)
Thought suppression	13(3.16)	12(3.1)
Self-distraction	10 (3.2)	10(3.2)

Note: Numbers in parentheses are standard deviations.

Inclusion Stem Completion

Inclusion stem completion can be considered as a classical DF task since both recollective and familiarity-based processes contribute to the retrieval of TBR and TBF items. The mean proportions of TBR and TBF items retrieved in the inclusion stem completion condition according to age group and part are presented in Table 2. A 2 (young *versus* older) x 2 (TBR *versus* TBF) X 2 (Part 1 vs. Part 2) within-subjects ANOVA was performed on the proportion of completed target stems. There was a significant effect for age group [$F(1, 58) = 11.62$, $p < .005$; $\eta^2 = .057$], which indicated that older subjects recalled fewer items than younger did. There was also an overall significant effect of instruction [$F(1, 58) = 33.16$, $p < .00001$; $\eta^2 = .074$], indicating that more TBR than TBF items were recalled. However, the effect of part was not significant [$F\{1, 58) = 0.004$, $p = .95$; $\eta^2 = < .001$]. There is a significant interaction between group and instruction [$F(1, 58) = 8.45$, $p < .01$; $\eta^2 = .019$], indicating that young subjects displayed a stronger DF effect than older ones. Planned comparisons revealed that elderly adults recalled as many TBF items as younger ones did [$F(l, 58) = 1.51$, $p = .22$; $d= 0.188$], while the two groups differed in their recall of TBR items [$F(1, 58) = 19.12$, $p < .0001$; $d = 0.696$], with an advantage for younger adults. There is also a significant interaction between part and instruction [$F(1, 58) = 4.28$, $p = .043$; $\eta^2 = .011$], indicating that the DF effect was larger in Part 1 than in Part 2. Planned comparisons revealed that this reduction in DF between the two parts was not clearly marked by either a decreased recall of TBR [$F(1, 58) = 1.62$, $p = .21$; $d = 0.207$] or an increased recall of TBF items [$F(1, 58) = 1.42$, $p = .24$; $d = 0.191$]. The three-way interaction was not significant [F(1, 58) = 0.69, p = .41; η^2 = .002]. However, when we compared the DF performance of young and elderly adults for the two parts of the task separately, an effect of normal aging appeared on the second part of the task [F(1, 58) = 5.62, p = .02; η^2 = .03], but not the first [F(1, 58) = 2.32, p = .14; η^2 = .01]. This suggests that elderly adults exhibit normal directed forgetting performance only when relatively few TBF and TBR items are presented. In other words, these results are in agreement with the hypothesis that elderly adults are more sensitive to proactive interference.

TABLE 2. Mean proportions of TBR and TBF items retrieved, according to condition, age group and part

	TBR	TBF	Baseline
Inclusion			
Part 1			
Young adults	.44 (.15)	.27 (.13)	.08 (.09)
Older adults	.32 (.19)	.22 (.13)	.05 (.07)
Part 2			
Young adults	.42 (.16)	.30 (.19)	-
Older adults	.26 (.17)	.27 (.20)	-
Exclusion			
Part 1			
Young adults	.06 (.08)	.12 (.12)	.09 (.09)
Older adults	.14 (.12)	.19 (.13)	.03 (.06)
Part 2			
Young adults	.05 (.07)	.10 (.11)	-
Older adults	.13 (.11)	.13 (.12)	-

Note: Numbers in parentheses are standard deviations.

Exclusion Stem Completion

Exclusion stem completion can be considered as an implicit memory performance in which items are produced automatically. The mean proportions of TBR and TBF items retrieved in the exclusion stem completion task according to age group and part are presented in table 2. A significant effect of group was observed [F(l, 58) = 17.29, p < .0005; η^2 = .083], indicating that older subjects recalled more items than younger ones. Planned comparisons revealed that elderly adults recalled more TBR [F(l, 58) = 19.4, p < .0001; d= 0.69] and more TBF items [F(1, 58) = 4.29, p < .05; d= 0.39] than younger ones. The effect of part was also significant [F(1, 58) = 3.79, p = .05; η^2 = .015]; subjects recalled more items in part 1 than in part 2. The main effect of instruction was also significant [F(l, 58) = 8.82,p < .005; η^2 = .033], revealing an inverse DF effect (more TBF recalled than TBR). However, planned comparisons revealed that this reverse effect was specific to young adults [F(l, 58) = 10.27, p < .01; d= 0.558], since elderly adults failed to show any DF effect [F(l, 58) = 1.23, p = .27; d = 0.21]. This inverse DF effect was probably due to a floor effect since few young subjects made errors in the exclusion condition (see also Russo & Andrade, 1995, for a similar interpretation). The two-way interactions between group and part [F(1, 58) = 0.82, p = .37; η^2 = .003], group and instruction [F(1, 58) = 1.77, p = .19; η^2 = .007], and instruction and part [F(l, 58) = 2.02, p = .16; η^2 = .005] were not significant, nor was the three-way interaction between group, part, and instruction [F(1, 58) = 1.17, p = .28; η^2 = .003]. When we compared the DF performance of young and elderly adults for the two parts of the task separately, there was no effect of normal aging either on the first [F(1, 58) = 0.14, p = .72; η^2 < .001] or on the second part of the task [F(l, 58) = 3.09, p = .084; η^2 = .021], which confirmed the absence of age-related differences due to increased sensitivity to proactive interference in elderly subjects in the exclusion condition.

Baseline stem completion did not differ between the inclusion and exclusion conditions for young subjects [F(1, 58) = *0.32, p* = .57; d = 0.02] or for older adults [F(1, 58) = 0.39, p = .53; d = 0.02], suggesting that they used equivalent criteria in completing the stems in the two conditions (see Table 2). However, a floor effect was confirmed in the exclusion condition for younger subjects, since the recall of TBR and TBF items was no greater than baseline stem completion *(p* = .048 and p = .25, respectively).

The Role of Processing Speed, Short-term Memory, and Thought Suppression

Since the second aim of this study was to determine the influence of several cognitive variables on age-related differences in DF abilities, we first performed covariance analyses (ANCOVA) on the recall of TBR and TBF

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items separately, with short-term memory performance and processing speed as separate covariates. These analyses were conducted because the processes involved in remembering TBR and TBF items are assumed to be different. We did not include thought suppression in the analyses because there were no age-related differences for this cognitive factor (see Table 1). The relation between DF and thought suppression was then explored with correlation analyses (see below). Finally, we performed the same ANCOVAs on the DF effect, which is assumed to neutralize between-subjects variation in memory performance. This DF effect was computed for each subject by simply subtracting the proportion of TBF items from the proportion of TBR items recalled for the inclusion stem completion task, which is the classical method for estimating overall directed forgetting performance (MacLeod, 1998). These analyses were performed for the inclusion condition only, since no significant interaction between group and instruction was found in the exclusion condition.

The results indicate that, when processing speed was used as covariate, the effect of group on the recall of TBR items was no longer significant [$F(1, 58) = 3.44$, $p = .069$; $\eta^2 = .059$], while the group effect remained significant when we controlled for short-term memory [$F(1, 58) = 17.93$, $p < .0001$; $\eta^2 = .245$]. Concerning the recall of TBF items, none of the analyses revealed any age-related differences after controlling for these covariates (all $F < 1.7$ and $\eta^2 < .03$). Further analyses revealed that when we controlled for processing speed, the DF effect no longer differed significantly in the two groups [$F(1, 58) = 0.29$, $p = .59$; $\eta^2 = .005$], while the group effect remained significant when we controlled for short-term memory [$F(1, 58) = 7.42$, $p = .009$; $\eta^2 = .121$].

We performed partial correlation analyses (which controlled for processing speed and short-term memory performance) within each age group between the 'thought suppression' subscore of the WBSI and the recall of TBR and TBF items, as well as the DF effect (see Table 3).

TABLE 3. Partial correlation coefficients between thought suppression (TS) and the directed forgetting effect (DF), TBR and TBF items according to age group, after controlling for processing speed and short-term memory

	TS young	TS older
DF	-.08	.54*
TBR	.22	.25
TBF	.30	-.33

Note: *ρ<.01.

These analyses revealed no significant correlation for young adults (all $p > .10$), but a significant positive correlation between thought suppression and the DF effect for elderly adults ($p < .01$), indicating that subjects with higher thought suppression scores tended to have a higher DF effect. A specific test revealed that the correlation between thought suppression and the DF effect was significantly different for young and elderly adults ($\rho = .015$).

DISCUSSION

The item method DF task is a specific episodic memory task in which subjects are asked to remember target information (TBR) intermixed with information they are asked to forget (TBF). Successful DF in this task is supposed to require both efficient selective processing of TBR items and efficient attentional inhibition of TBF items (Johnson, 1994). In this experiment, we investigated whether the decreased DF effect for elderly adults arises because of an increase in the amount of TBF items retrieved automatically, in addition to the expected decrease in TBR items retrieved intentionally. In order to evaluate this hypothesis, we used a method that allowed us to contrast performance in a classical DF condition (i.e., one in which both automatic and intentional retrieval processes contribute to performance; that is, the inclusion condition) to performance in a condition in which automatic retrieval processes contribute most to performance (the exclusion condition). We also wanted to determine whether the decrease in the DF effect in elderly subjects can be explained by age-related differences in some of the cognitive processes involved in the episodic encoding of TBR items (Gamboz & Russo, 2002) and in the suppression of TBF items (Zacks et al., 1996). For that purpose, four variables supposed to contribute to between-subjects variations in the processing of TBR and TBF items at encoding were examined as potential mediators of age-related differences in DF abilities: short-term memory capacity, processing speed, thought suppression tendencies, and sensitivity to proactive interference.

The results showed that in the classical DF condition (the inclusion stem condition), older adults encountered DF difficulties, characterized by a decrease in the recall of TBR items and a relative increase in the recall of TBF items compared to younger adults (see also Dulaney et al, 2004, Russo & Andrade, 2002; Zacks et al., 1996). Indeed, elderly adults recalled as many TBF items as younger ones did, although one might have expected that they would recall fewer of both TBR and TBF items than younger adults, because of the reduction in their episodic memory capacities. Moreover, elderly subjects' DF performance was affected by proactive interference, since they showed a normal DF effect in the first part of the task, whereas their DF performance was worse than that of younger subjects in the second part of the task. Together, these results are in agreement with both the selective rehearsal and attentional inhibition hypotheses previously proposed to explain the DF difficulties of elderly adults. The poorer recall performance for TBR items supports the hypothesis that these items are encoded in a less elaborated way (Gamboz & Russo, 2002). On the other hand, the increased recall of TBF items supports the attentional inhibition hypothesis (Zacks et al., 1996), since it suggests that these items were not properly inhibited during the task. Importantly, though, it appears that the age-related difference in the directed forgetting effect emerges because of an increase in proactive interference in elderly adults, a result that has never been reported before.

The results for the exclusion condition confirmed that elderly adults' memory performance generally depends more on the use of automatic processes than that of younger adults, probably because of an attempt to compensate for their reduced access to target information due to a deficit affecting explicit recollection processes (Hay & Jacoby, 1999; Jennings & Jacoby, 1997). More specifically, it appears that, in the exclusion condition, elderly adults recalled more TBR and TBF items than younger ones did. This increased recall of TBF items, which is partly responsible for the older adults' poor DF performance, may result from the fact that these items became familiar when they were presented in the encoding phase, but were not processed deeply enough to allow the conscious recollection that is needed under the exclusion instructions. It is therefore possible that the relatively increased recall of TBF items observed in the inclusion condition was also the outcome of a greater contribution of automatic retrieval processes in elderly adults, rather than an inhibitory failure during the encoding phase of the experiment. However, further experiments will be necessary to distinguish between these two potential sources of impairment.

At a theoretical level, the data from this experiment confirm that selective rehearsal is an important determinant of DF performance since, according to the selective rehearsal hypothesis, DF instructions should affect explicit (or direct) memory tests but not perceptually based implicit (or indirect) tests because the latter are generally insensitive to variations in encoding processing (see Roediger & McDermott, 1993, for a review). Indeed, our results replicated those of previous studies showing that the instruction to forget does not affect automatic retrieval, and extended them to an elderly population, since DF was not found in the exclusion condition (see also David & Brown, 2003; Russo & Andrade, 1995). Thus, these results support the idea that the DF effect emerges only with explicit memory tasks, and that any DF effect observed with implicit memory tasks is due to explicit memory contamination (e.g., Basden et al., 1993). However, our results did not totally exclude the possibility that attentional inhibition is involved. Indeed, an absence of DF effect with the exclusion task might also be expected according to the attentional inhibition hypothesis, because the cue (i.e., the stem) used in the retrieval phase of the experiment could have induced a priming effect that competed with the inhibition of the TBF items and was strong enough to release this inhibition. Such a release of the DF effect has actually been observed with recognition or indirect memory tasks when the list method is used (Basden et al., 1993; Bjork & Bjork, 1996; Elmes, Adams, & Roediger, 1970; MacLeod, 1999).

Overall, the data obtained in this experiment indicate that the DF impairment found in elderly subjects is multi-determined. More specifically, it appears that elderly adults' DF problems come from a reduced recall of TBR items (due to recollection difficulties, since DF difficulties were observed only in the inclusion condition) and to increased recall of TBF items (which may be due either to an increased automatic retrieval of TBF items or to an inhibitory failure); this was only obvious in the second part of the task, which suggests that proactive interference also plays a role in the emergence of DF problems.

We were interested in determining whether specific cognitive factors mediated the age-related differences in the recall of TBR and TBF items. For that purpose, processing speed and short-term memory span were introduced into ANCOVAs performed on the recall performance of TBR and TBF items separately, and on the DF effect (which is assumed to neutralize between-subjects variation in memory performance). The ANCOVAs revealed that processing speed and short-term memory span seem not to be responsible for the elderly adults' increased recall of TBF items. However, age-related differences in the DF effect and in the recall of TBR items ceased to be significant once processing speed was controlled as a covariate. These analyses suggest that processing speed plays a role in the DF difficulties of elderly adults, mainly through performance for TBR items; thus, selective rehearsal appears to be another determinant of these problems. Indeed, we can speculate that elderly adults found it difficult to learn TBR items because they processed them more slowly and therefore had fewer opportunities to rehearse them during the task than young adults. A similar direct influence of processing speed on episodic memory performance has recently been demonstrated by Clarys, Insingrini, and Gana (2002), who confirmed that processing speed is an important mediator of episodic learning.

The fact that no relationship was observed between the cognitive factors investigated and the recall of TBF items (except a positive correlation between thought suppression and the DF effect in elderly adults) is quite surprising since several studies have clearly demonstrated the existence of relationships between some of these measures and elderly adults' inhibitory abilities. For example, Verhaeghen and De Meersman (1998) showed in a meta-analysis that elderly adults' inhibitory problems in the Stroop task are due to a general slowing of processing speed. However, the inhibitory abilities solicited by the Stroop task and the DF task appear to be quite different (Nigg, 2000), and we would suggest that not all inhibitory processes are related to processing speed. One would also expect working memory to be involved in elderly adults' DF difficulties since an often postulated function of this system ('the deletion function') is to suppress information that becomes irrelevant because of changes in the task topic (as is the case following the presentation of the 'forget' instruction; Hasher, Tonev, Lustig, & Zacks, 2000). However, our working memory task (a span task) mainly required information storage, with little manipulation of that information. Thus, it could be argued that relationships between processing of TBF items and working memory would be observed with a more 'active' working memory task (such as a reading span task; Daneman & Carpenter, 1980), and especially one that requires resistance to proactive interference from previous trials (see Lustig et al, 2001; May et al., 1999). We would also have expected a relationship between thought suppression and the recall of TBF items, but this was not the case in our data. However, thought suppression appeared to be positively correlated to the global DF performance of elderly adults, suggesting that subjects with higher thought suppression tendencies in daily life tend to cope better with directed forgetting instructions. These results suggest that some inhibitory processes are in fact involved in the DF task. However, additional experiments are necessary to clarify the role of inhibitory functioning in this task. One possibility is that inhibitory processes are involved through resistance to proactive interference, which our study shows to be a critical variable mediating elderly adults' DF performance.

To sum up, this experiment supports, and extends to elderly adults, the results of previous studies indicating that DF instructions affect intentional but not automatic retrieval performance, and confirms that the DF effect observed with implicit memory tasks is due to explicit memory contamination. Our study also provides further evidence that elderly adults' DF difficulties in the inclusion condition are characterized by both a decreased recall of TBR items and an increased recall of TBF items. Otherwise, the comparison of performance in the inclusion and exclusion conditions suggests that their DF difficulties are related to the greater use of automatic retrieval processes (in order to compensate for their deficient intentional processes), which leads to an enhanced recall of TBF items (in both the inclusion and exclusion conditions). We have also demonstrated that elderly adults' DF difficulties are modulated by age-related differences in processing speed and resistance to proactive interference, leading to a reduced recall of TBR items. Taken as a whole, these results indicate that the decreased directed forgetting ability of elderly adults is clearly multi-determined. Further studies are needed for a better understanding of the specific role of the cognitive variables we have identified here.

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