The role of memory traces quality in directed forgetting: A comparison of young and older participants using the list procedure

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Titre courant: Directed forgetting and memory in aging

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Abstract

Background. Discrepant results are observed about the Directed Forgetting (DF) effect in healthy aging when the list method is used. The present study aimed at investigating if preserved DF effect is due to a decline in the ability to self-initiate efficient encoding strategies, or efficient retrieval-inhibition processes. We predicted that increasing the strength of memory traces by favoring deep information encoding would be associated with attenuation of DF effects in older participants by comparison to younger ones, due to the increased inhibitory difficulty. **Method.** Forty young and 40 older participants were submitted to a list-based directed forgetting paradigm, with two encoding conditions: standard and enriched (longer presentation time and proposal of mnemotechnic strategies). **Results.** We observed the expected effects of age, encoding condition and item type ($p<0.05$). When directly comparing performance of older participants in the enriched encoding condition to that of younger participants in the standard one, the results were very similar between groups, which is in contradiction with our initial hypothesis. **Discussion.** These results do not argue in favor of a reduction of inhibitory mechanisms underlying DF with age but are better explained by between-groups episodic memory differences.

Résumé

Contexte. Des résultats divergents sont observés concernant la préservation de l'effet d'Oubli Dirigé (OD) dans le vieillissement normal lorsque la méthode liste est utilisée. La présente étude vise à examiner si les effets préservés d'oubli dirigé (OD) viennent de difficultés à mettre en place spontanément des stratégies d'encodage efficaces, ou peuvent être attribuées à des capacités d'inhibition à la récupération préservées. Nous prédisons qu'augmenter la force des traces mnésiques en favorisant un encodage profond de l'information sera associée à une atténuation des effets d'OD chez les personnes âgées par rapport à des participants jeunes, en lien avec leurs difficultés d'inhibition. **Méthode.** Quarante participants jeunes et 40 participants âgés ont été soumis à un paradigme d'oubli dirigé de type liste, avec deux conditions d'encodage : standard et enrichi (temps de présentation plus long et proposition de stratégies mnémotechniques). **Résultats**. Les effets attendus de l'âge, de la condition d'encodage et du type d'item ont été observés ($p<0.05$). Lorsque les performances des participants âgés dans la condition d'encodage enrichi sont comparées à celles des jeunes dans la condition standard, les résultats sont très similaires entre les groupes, ce qui est en contradiction avec notre hypothèse initiale. **Discussion**. Ces résultats ne plaident pas en faveur d'une réduction des mécanismes inhibiteurs associés à l'OD chez les personnes âgées mais s'interprètent plutôt en lien avec les différences de mémoire épisodique entre les groupes.

Introduction

Forgetting of information, often conceptualized and perceived as a memory failure, can nevertheless, in some circumstances, be adaptive and lead to a better memory functioning. More specifically, forgetting permits us to update our memory content, by processing current information without interference from no longer relevant information or by inhibiting closely related incorrect information (Bjork, Bjork, & Anderson, 1998; Bjork, 1989). The active suppression of information from memory is classically explored using directed forgetting paradigms.

Directed forgetting (DF) refers to a deliberate attempt to limit the future expression of specific memory contents (Johnson, 1994). DF has traditionally been investigated by two distinct paradigms: the item and the list methods. In the item method, participants learn a list of items (study phase), with the instruction to remember every item followed by a "remember" cue (to-be-remembered items, TBR) and to forget items followed by a "forget" cue (to-be-forgotten items, TBF). Typically, in the subsequent test phase, TBR items are better recalled by comparison to TBF items (Basden & Basden, 1998; MacLeod, 1975, 1998). In the list-method, the cue to forget or remember is presented after a block of items rather than on an item-by-item basis. More specifically, a first list of items is presented, followed by a cue to either forget or remember that list (list 1), and then a second list to study is presented, always followed by a cue to remember (list 2). In this paradigm, costs of directed forgetting corresponds to impaired recall for list 1 when followed by a "to forget" instruction by comparison to a "to remember" instruction. These costs are sometimes, but not systematically, accompanied by an enhanced recall for the second list (list 2) in the "to forget" condition (list 1 followed by a TBF cue) by comparison to the "to remember" condition (list 1 followed by a TBR cue). This enhanced recall for list 2 in the "to forget" condition is called the benefits of directed forgetting (Geiselman et al., 1983; MacLeod, 1998; Sahakyan, Delaney, & Goodmon, 2008; Zellner & Bäuml, 2006).

Different cognitive mechanisms, either affecting encoding or retrieval of information have been discussed to explain the DF effects observed with the list method (e.g., Basden & Basden, 1996). A traditional account is retrieval-inhibition (Bjork, 1989; Geiselman et al., 1983). Retrieval-inhibition assumes that, following the forget cue, active inhibitory processes are engaged to reduce access to list 1 items. Reduced access to items from list 1 will therefore facilitate memory for list 2 items, due to the suppression of list 1 proactive interference (Bjork, 1989; Geiselman et al., 1983) and the reset of encoding processes (Bäuml, Hanslmayr, Pastötter, & Klimesch, 2008; Pastötter & Bäuml, 2010). This view is supported by the fact that DF costs for this procedure are typically not observed in recognition: the re-presentation of TBF information during recognition test would release their inhibition, in such a way that they would become as accessible as TBR information (for a review, see MacLeod, 1998). Other accounts (selective rehearsal and context-change) have however attributed a role of encoding in the DF costs and benefits. For selective rehearsal, after the presentation of forget cue associated with the first list, participants only rehearse list 2 during list 2 encoding, whereas they rehearse both lists during list 2 encoding when there was a remember cue after list 1 (Benjamin, 2006; Sheard & MacLeod, 2005). The context-change account (Sahakyan & Kelley, 2002) argues that the presentation of the forget cue initiates a mental context change in participants, which would impair list 1 recall (DF cost) because of a mismatch between encoding and retrieval contexts. Consequently, the improved list 2 recall (DF benefit) would originate from reduced interference of list 1 and improved encoding strategies following a forget cue (i.e., adaptation of study strategies with more elaborate encoding after forget cue presentation; Sahakyan & Delaney, 2003, 2010; Sahakyan et al., 2008).

A series of studies explored directed forgetting in aging (for a review, see Titz & Verhaeghen, 2010). However, the majority of studies that evidenced an age-related decline used the item method (e.g., Collette, Germain, et al., 2009; Dulaney et al., 2004; Hogge, Adam & Collette, 2008a; Sego et al., 2006; Zacks, Radvansky & Hasher, 1996). With the list method, a relative preservation of DF abilities in older participants was observed in some studies (Jantz, Festini & Reuter-Lorenz, 2021; Sego et al., 2006; Zellner & Bäuml, 2006) but not all (Aguirre et al., 2014; Collette et al., 2009; Pitarque et al., 2018: Zacks et al., 1996). For example, Zellner and Bäuml (2006) reported a DF effect of similar amplitude for both age groups in a series of experiments that do not propose strategies to perform the task. Sahakyan et al. (2008) also evidenced preserved ability to forget unwanted memories in aging but underlined the important role of tasks instructions (i.e., when forgetting strategies were provided or not to the participants). Finally, Sego et al. (2006) did not find any significant DF costs on a recognition task for older participants, as previously observed in young ones (MacLeod, 1998 for a review). Overall, these results seem to indicate a preservation of DF abilities with the advance in age when using the list procedure.

Gamboz and Russo (2002) suggested that the smaller DF effect observed in older participants with the item method "may reflect larger age-related differences in recall of words processed extensively (the TBR words) compared to recall of words processed only superficially (the TBF words), occurring as a consequence of the well documented age-related episodic memory deficit" (Gamboz & Russo, 2002, p. 367). In contrast, older people would not be impaired with the list procedure because of the similar processing applied to all items (participants do not know when the forget cue will be presented and thus process equally all the presented items), despite their globally lower recall (due to episodic memory deficit). Hence, for the authors, age-related inhibitory deficit is not the best candidate to explain the smaller DF effect of older compared to younger participants. To test if episodic memory rather than inhibitory deficits is responsible of reduced DF effect in aging, they implemented a level-of-processing manipulation with the item procedure (shallow processing: to count the number of letters in the word; deep processing to judge the pleasantness of each word; control: no instructions). They observed larger DF effects for younger in the shallow and control conditions, but an equivalent DF effect in younger and older participant in the deep encoding condition, although older recalled overall fewer TBR and TBF words. The authors argued that when both TBR and TBF words were processed extensively (i.e. in the deep encoding condition), both groups manifested equivalent DF effect, and consequently earlier reports of smaller DF in aging are likely to reflect age-related episodic memory deficit. Similarly, Kurkela et al. (2021) showed that increased processing time improved performance both in young and older adults. However, contrary to Gamboz & Russi (2002), Dulaney et al. (2004) failed to evidence any effect of level-of-processing manipulation on DF performance of young and older groups. More recently, Collette, Grandjean, Lorant & Bastin (2014) manipulated in a classical item-method DF paradigm the depth of encoding by increasing presentation times and providing mnemonic strategies at encoding in an enriched condition (by comparison to a shorter condition without suggested strategies).[1] They observed that, when the quality of memory traces are equated between groups (comparison of performance in the enriched condition in older participants with the standard condition in younger ones), DF effects observed with the recall, recognition and RKG procedures are of similar amplitude in both groups. On this basis, they suggested that DF in normal aging does not crucially depend on inhibitory abilities, but mainly depends on the selective processing of TBR information (e.g., through rehearsal and elaborated encoding). Indeed, when efficient processing is favored in the older group, the presence of smaller DF effect previously attributed to inhibitory difficulties is no more observed.

Aim

To replicate the results obtained by Collette et al. (2014), the present study investigated the role of age-related differences in memory traces quality on the magnitude of DF effects using the list method paradigm. More specifically, we argue that, due to a decline in the ability to self-

[1] We consider that favoring deep encoding with these manipulations will increase the quality of memory traces in the older group.

initiate spontaneously deep and elaborate encoding strategies (Bouazzaoui et al., 2010; Craik & Rose, 2012; Saczynski, Rebok, Whitfield, & Plude, 2007), older participants would present weaker memory traces for the information they just encoded compared to younger adults. Therefore, inhibitory processes, supposed to apply on some of those memory traces (i.e., TBF information), will require less effort, favoring the DF effect. To test that hypothesis, we compared DF effects in young and older participants in standard and enriched/strong encoding conditions. We predicted that increasing the quality of memory traces with a deeper encoding should be associated with attenuated DF effects in older if they encounter difficulties to actively inhibit that information. However, the manipulation of the encoding condition would not affect DF effects in younger subjects, as their inhibition abilities are sufficient to suppress the TBF information whatever the condition.

Methods

Participants

Forty young and 40 older adults participated in this experiment, and were naive about its purpose. The younger group had a mean age of 23.18 years (range: 18–30 years; SD = 4.02; 20 females and 20 males) and the older group had a mean age of 70.55 years (range: 65–78 years; SD = 3.76; 20 females and 20 males). This study was performed in accordance with the ethical standards described in the Declaration of Helsinki (1964) and approved by the Ethics Committee of the Faculty of Psychology at the University of Liège. All participants signed an informed consent form. All participants, native French speakers, did not report any history of medical, neurological or psychiatric disorders, and were not under any medical treatment that could affect cognition. In addition, all had normal (or corrected-to-normal) hearing and vision. The cognitive status of the older group was evaluated with the Mattis Dementia Rating Scale (Mattis, 1976). All had a total score (M = 142.20; SD = 1.42; range 137-144) superior to the cut-off score of 130 (Monsch et al., 1995). Both groups of participants did no differ in terms of education level (young participants: M = 14.68 years; SD = 2.20; older participants: M = 15.33 years; SD = 2.19; t (78) = -1.32; p = .19) but differed in terms of vocabulary level on the French adaptation of the Mill Hill test (Deltour, 1993; young participants: M = 23.20; SD = 3.50; elderly participants: M = 30.08; SD = 3.02; t (78) = -9.41; $p < .0001$).

Materials

The materials consisted of eight lists of 8 unrelated words each, which were concrete nouns and verbs of six letters selected from the Brulex French database (Content et al., 1990). The assignment of words to lists and the presentation order during the learning phase were constant for all participants. Those eight lists, equivalent in terms of word frequency [F (7, 56) = 0.80; p = .59], were split in two sets of 4 lists; one for the remember condition and one for the forget condition. For each condition, four versions of the task were created, counterbalanced across participants, in such a way that each list served one time as list 1 in one version, and one time as list 2 in another version. In addition, within each version, the two lists of words that were not presented during the learning phase served as distracters for the recognition phase. Finally, presentation order of the forget and the remember conditions was counterbalanced in such a way that half of the participants performed the forget condition first, and half performed the remember condition first.

Design

We used a 2 (Group: young vs. older) x 2 (Condition: forget vs. remember) x 2 (List: list 1 [TBR or TBF] vs. list 2 [TBR only]) x 2 (Encoding: standard vs. enriched) design, with group and encoding as between-participant factors, whereas condition and list were within-participant factors.

Procedure

Participants were informed that they would have to learn some lists of words, and that their memory for those words would then be tested. They were told that in some cases an instruction to forget the list can be provided after its presentation. Moreover, after the recall step of the forget condition, they were assured that no more lists to forget would be presented. Indeed, knowing that to-be-forgotten items had to be recalled could have a different impact on memory strategies during the remember condition for participants who received the forget condition first (for a similar within-participants design, see Zellner & Bäuml, 2006).

During the study phase, two lists of 8 words were presented. Each item was on screen for a duration of 3 s in the standard encoding condition (7 s in the strong encoding condition), and was followed by a black screen for 1 s. A fixation cross was displayed before each word for a duration of 1500 ms. In addition, participants in the strong encoding condition were provided three possible mnemonic strategies (repetition, sentence generation, and mental imagery). They were additionally informed that they could use any other strategy. As we had no a priori hypothesis about the most effective strategy, we decided to let the participant choose the one that seemed most appropriate to the task. After the presentation of the first list, an instruction to either forget or remember depending on the condition appeared on the screen, and was accompanied by oral instructions from the experimenter. In the remember condition, participants were told to continue to remember the previously presented items and in addition to learn another new list of items. In the forget condition, they were told that the so far presented items would not be tested later. Thus, they were told to forget that list and, instead, to learn a new list of items. After memory instruction, list 2 was presented, always followed by the instruction to remember that list. Once both lists were presented, participants performed an arithmetic task during 30 s in which they had to count backward in steps of 3. Then, participants were asked to recall and then recognize a maximum of the words presented during the study phase; even those that were in the list to forget (forget condition).

For the recall task, participants gave, for each list, their responses orally in any order, which were noted by the experimenter. We controlled for possible output interference effect (Golding and Gottlob, 2005) by asking half of the participants to recall list 1 words (TBF or TBR instruction) first, and the other half list 2 words (TBR instruction only) first (Zellner & Bäuml, 2006)[2]. In the recognition task, the 16 target words (8 from list 1 and 8 from list 2) were presented individually on the screen intermixed with 16 distracter words in a random fashion. Each word was presented until the participant made his/her recognition judgment orally (yes/no), and the experimenter pressed the corresponding key on the keyboard. In addition, for each recognized word, participants performed a RKG judgment. Finally, there was a break of 5 minutes between the administration of the remember (TBR instruction for list 1 and 2) and the forget (TBF instruction for list 1 and TBR instruction for list 2) conditions.

Statistical analyses

We computed a sensitivity analysis to get an indication of the minimum detectable effect size in our main analyses given our sample size. According to G*Power 3 (version 3.1.9.4) (Paul et al., 2009) taking into account a power of .8, an error rate α of .05, a sample size of 80 allowed us to detect effect sizes f > .15.

All statistical analyses were conducted with a *p* level set at .05. Concerning the mean percentages of word recall and recognition, we first performed a 2 (Group: young vs. older) x 2 (Encoding: standard vs. strong) x 2 (Condition: forget vs. remember) repeated measures ANOVA for list 1 (TBR or TBF instruction) and list 2 (TBR instruction only) separately. Moreover, we also directly compared performance of older participants in the strong encoding condition to that of younger in the standard encoding condition by means of a 2 (Group: young

[2] The statistical analysis showed no evidence that output interference effect could affect DF results detailed here (see supplemental Material)

vs. older) x 2 (Condition: forget vs. remember) repeated measures ANOVA for list 1 and list 2 separately, assuming that younger participants implement strategies spontaneously (Bouazzaoui et al., 2010). Finally, separate 2 (Group: young vs. older) x 2 (Condition: forget vs. remember) repeated measures ANOVAs were performed on the mean proportion of RKG judgments separately in the standard encoding condition, and for list 1 and list 2 separately. The same ANOVAs were also performed when considering RKG judgments of the older group in the strong encoding versus those of the younger group in the standard encoding condition. Planned comparisons were performed to specifically assess directed forgetting costs and benefits. The analyses that compared DF effects in young in the standard encoding condition and older participants in the enriched encoding condition have allowed to determine if increasing the quality of memory traces is associated with attenuated DF effects in older due to their inhibitory difficulties.

Results

Recall data

Mean percentages of recall are presented in Table 1 and Figure Ia. Concerning list 1, the analysis showed a main effect of group [F (1, 76) = 18.67; $p < .0001$, η_P^2= .20; younger > older], encoding [F (1, 76) = 19.35; $p < .0001$, η_P^2= .20; enriched > standard], and condition [F (1, 76) = 22.97; $p < .0001$, η_P^2= .23; remember > forget]. None of the interactions was significant. Post-hoc planned comparisons first showed that the costs of DF (i.e., better recall for List 1 in the remember than forget condition) were significant for the younger group in the two encoding conditions [standard: F (1, 76) = 5.09; p = .03; enriched: F (1, 76) = 15.58; $p < .001$] while in the older group only a tendency is observed for the enriched condition [standard: F (1, 76) = 2.15; p = .15; enriched: F (1, 76) = 3.67; p = .06].

[Insert Table 1 and Figure I here]

For list 2 data, the ANOVA showed main effects of group [F (1, 76) = 42.72; $p < .0001$, η_P^2= .36, young > older], encoding [F (1, 76) = 21.44; $p < .0001$, η_P^2= .22, strong > standard], and condition [F (1, 76) = 5.56; p = .02, η_P^2= .07, forget > remember]. In addition, as for list 1 analysis, none of the interactions reached significance. Planned comparisons showed that the benefits of DF (i.e., the better recall of list 2 in the forget condition than in the remember condition) were significant for older adults in the standard encoding condition only [*F* (1, 76) = 6.57; *p* = .01].

Next, the pattern of results of older participants in the strong encoding condition was compared to that of younger participants in the standard condition for both lists separately. We observed that the main effect of group disappeared for both List 1 [*F* (1, 38) = 0.03; *p* = .96, η_P^2< .0001] and List 2 [*F* (1, 38) = 1.56; *p* = .22, η_P^2= .04]. A better recall in the remember condition for list 1 was also observed [*F* (1, 38) = 8.10; *p* = .007, η_P^2= .18]. Planned comparisons showed DF costs (list 1) for both groups, although this difference was only marginally significant for older [young: *F* (1, 38) = 4.73; *p* = .04; elderly: *F* (1, 38) = 3.42; *p* = .07]. However, the DF benefits (list 2) were absent for both groups [young: *F* (1, 38) = 1.06; *p* = .31; elderly: *F* (1, 38) = 0.56; *p* = .46].

The main results from the recall task can be summarized as follow: (1) we observed DF costs only in young participants while the older group showed DF benefits, but only in the standard encoding condition; (2) memory traces manipulation did globally increase memory performance for the two groups of subjects; (3) when memory trace quality is equated, no between group differences were observed .

Recognition data

Recognition data of younger in the strong encoding condition were excluded from the analyses, given the very high recognition rate for both lists (see Table 2). Therefore, analyses focused on comparing performance of older and younger participants in the standard encoding condition, and on comparing performance of older participants in the strong encoding condition to the one of younger participants in the standard encoding condition. As for recall data, results of list 1 and list 2 were analyzed separately. Mean percentages of recognition (hits - false alarms) are presented in Table 2 and Figure Ib.

[Insert Table 2 here]

In the standard encoding condition, list 1 analysis did not bring any significant results [group: *F* (1, 38) = 3.44; *p* = .07, η_P^2= .08, condition: *F* (1, 38) = 1.03; *p* = .32, η_P^2= .03 group x condition: *F* (1, 38) = 3.23; *p* = .08, η_P^2= .08]. Planned comparisons showed that both groups did not manifest the DF costs, although close to significance for the older group [younger: *F* (1, 38) = 0.31; *p* = .59; elderly: *F* (1, 38) = 3.96; *p* = .05]. Results for list 2 analysis did not reveal any significant effect [group: *F* (1, 38) = 0.64; *p* = .43, η_P^2= .02, condition: *F* (1, 38) =

0.09; p = .76, η_P^2< .01, group x condition: F (1, 38) = 0.21; p = .65, η_P^2< .01]. Both groups recognized as many words in both conditions. Overall, analyses in the standard encoding condition showed a globally equivalent memory performance for both groups. In addition, none of the groups did evidence any significant DF costs or benefits.

The direct comparison of younger participants in the standard encoding condition and older participants in the strong encoding condition showed no significant effect in list 1 analysis [group: F (1, 38) = 0.69; p = .41, η_P^2= .02, condition: F (1, 38) = 0.62; p = .44, η_P^2= .02, group x condition: F (1, 38) = 0.01; p = .93, η_P^2< .001]. Similarly, list 2 analysis showed no main effect of group [F (1, 38) = 0.59; p = .45, η_P^2= .02], condition [F (1, 38) = 0.25; p = .62, η_P^2< .01], and no significant interaction [F (1, 38) = 0.44; p = .51, η_P^2=.01]. In sum, these analyses did not reveal any DF costs or benefits in both groups, and did not evidence any age-related effect on memory performance.

RKG judgments

RKG judgments associated with hits and false alarms are presented in Table 3. In the standard encoding condition, analyses on R judgments only revealed a significant age group x condition interaction [F (1, 38) = 6.15; p = .02, η_P^2= .14] for list 1 data. Planned comparisons showed that younger participants used more R judgments in the forget than in the remember condition [F (1, 38) = 4.43; p = .04], and used more R judgments than older participants in the forget condition [F (1, 38) = 10.51; p < .01], while older participants did use R judgments in a similar extent for both conditions [F (1, 38) = 1.97; p = .17]. Concerning K and G judgments, analyses for both list 1 and list 2 did not yield any significant main effect or interaction. Thus, both groups used K and G judgments in a similar extent in both the forget and the remember conditions.

[Insert Table 3 here]

Finally, comparison of older group performance in the strong encoding condition to the one of younger in the standard encoding condition only revealed significant results for list 1, with a significant group x condition interaction for R judgements [F (1, 38) = 8.10; p < .01, η_P^2= .18]. This interaction originated from (1) the trend for younger to use more R judgments in the forget than in the remember condition [F (1, 38) = 3.87; p = .06], and (2) the significantly higher rate of R judgments for older participants in the remember than in the forget condition

[F (1, 38) = 4.24; $p < .05$], while the proportion of R judgments did not differ between younger and older for the forget [F (1, 38) = 3.11; $p = .09$] and the remember condition [F (1, 38) = 2.14; $p = .15$], respectively. Analyses for list 1 data on K and G judgments did not evidence any significant main effect or interaction. Hence, despite both groups were matched for memory performance in the remember condition (as attested by recall and recognition data), RKG judgments analyses for list 1 indicated more R judgments for younger in the forget than in the remember condition, and inversely for older participants.

Discussion

In this study, we compared young and older adult performance on a directed forgetting (DF) task using the list method. We expected older participants to manifest a DF of similar magnitude to that of younger in the standard encoding condition, given the repeatedly reported preservation of DF abilities with the advance in age in the literature on the list method procedure (Sego et al., 2006; Zellner & Bäuml, 2006). However, results failed to show any DF costs (i.e., better recall of list 1 items in the remember than the forget condition) for older, contrary to younger participants. Second, list 2 analyses showed that only older participants manifested the DF benefits (i.e., better recall of list 2 in the forget than in the remember condition). As a matter of fact, DF benefits have not been systematically reported in the literature (e.g., Conway, Harries, Noyes, Racsmány, & Frankish, 2000; Sego et al., 2006; Zellner & Bäuml, 2006), and seem thus to be a less robust phenomenon that DF costs. In that line, we consider that the DF benefits in older participants may be mainly due to their particularly low memory performance for list 2 in the remember condition rather than to a disproportionately better encoding (compared to younger) of list 2 words in the forget condition (see Table 1). Concerning recognition data, we observed no significant DF costs and benefits. This finding is in agreement with a large body of data that showed that the list method procedure of DF does not affect recognition memory (for a review, see MacLeod, 1998). This has classically been interpreted as a support for retrieval-based mechanisms as responsible of the effect (i.e., retrieval inhibition). More specifically, the lack of directed forgetting in recognition test is supposed to reflect a release of inhibition due to the presentation of the items to forget (e.g., Bjork & Bjork, 1996, 2003).

Our main hypothesis was that matching memory performance between both groups in the remember condition would be associated with smaller DF effects (mainly DF costs) in the older group. In that line, the comparison of memory performance of older participants in the strong encoding condition to the one of younger participants in the standard encoding condition brought some interesting results. First, as expected, the strong encoding condition did equalize memory traces between groups. Second, both groups manifested the costs of DF, although marginally in the older group (p = .07), and no DF benefits were observed. Finally, recognition performance was very similar for both groups, with no significant DF costs and benefits. However, R judgements were more used by older people in the remember than forget condition, and the reverse was observed for young participants. Consequently, boosting memory of older participants by providing an enriched encoding environment made their pattern of performance close to the one of younger participants. However, the results need replication to exclude the possibility of an absence of effect due to a low statistical power, for example by using a Bayesian statistical approach (Keysers, Gazzola & Wagenmakers, 2020).

These results are contrary to our hypothesis that older people would evidence a decreased DF ability in this condition due to their inhibitory difficulties. Hence, inhibitory abilities in list method DF paradigm seem relatively independent of initial memory capacity. In a previous study using the item method, we also observed DF effects of similar amplitude for recall, recognition and RKG tasks when memory traces are equated between groups (Collette, et al, 2014). This study also showed that inhibitory abilities does not influence the magnitude of DF effects in aging. An absence of association between recall for TBF words and memory performance was also observed by Collette, Germain, et al. (2009).

As a whole, these results support the hypothesis that smaller DF effect (e.g., Collette, Germain, et al., 2009; Dulaney et al., 2004; Salthouse, Siedlecki, & Krueger, 2006; Sego et al., 2006; Zacks et al., 1996) or the lack of significant DF (Sego et al., 2006; Zellner & Bäuml, 2006) previously observed in older participants by comparison to younger ones may reflect age-related differences in episodic memory rather than age-related differences in inhibitory mechanisms (Gamboz & Russo, 2002). In that line, our results agree with the proposal of Gamboz and Russo (2002), that older people would be particularly impaired in the recall of words processed extensively (i.e., TBR information) in comparison to the recall of words processed more superficially (i.e., TBF words), due to their episodic memory deficits. As a consequence, memory traces quality of the TBR words would be disproportionately impaired for older participants compared to younger ones. Our study did not control for the type of strategy used by participants to improve their memory trace. It would be particularly interesting to determine in future work the processes leading to this improvement (semantic processing or sensorimotor content, duration of encoding, mental imagery...).

Recognition data also support the proposition that age-related differences in DF may better be explained in reference to episodic memory rather than inhibitory functioning differences. Indeed, older participants in the enriched encoding condition presented a pattern of recognition identical to that of younger participants in the standard encoding condition. This is not a pattern of results one would have expected if age-related differences in DF were due to inhibitory abilities. Moreover, results from the RKG procedure (Tulving, 1985) suggests that there may be age-related differences in source memory between both groups, more particularly in binding information to contextual details (Kliegl & Lindenberger, 1993; Naveh-Benjamin, Brav, & Levy, 2007; Old & Naveh-Benjamin, 2008). For the younger group, the forget cue may have constituted a salient contextual information leading to a better memory trace. On the contrary, the higher rate of R judgments for older participants in the remember than in the forget condition would be a consequence of the better memory trace for TBR words (absence of inhibition on these items contrary to TBF words), and would not necessarily mean that they did effectively remember that those items were cued to remember (for a discussion on the subjective experience associated to recognition decision for TBR and TBF information, see Basden and Basden, 1996; Racsmány, Conway, Garab, & Nagymáté, 2008). A main involvement of episodic memory processes in DF also comes from Kurkela et al. (2021) that reported that increasing processing time modulates primarily intentional encoding associated to the TBR condition. Finally, Jantz et al. (2021) manipulated indirect measures of forgetting efficacy in working memory and suggested that age-related lower control of working memory may also contribute to DF impairment in older adults.

Conclusion

Overall, the results of the present study do not argue in favor of a reduction of inhibitory mechanisms underlying DF in the list procedure with the advance in age. Rather, our differences between young and older participants were better explained by episodic memory differences between both groups that may account for their differential pattern of results in the standard encoding condition. Collette et al. (2014) proposed a similar interpretation for the item method DF paradigm. In that line, our results agreed with the proposition of Gamboz and Russo (2002) that age-related differences with the item procedure may mainly reflect age-related differences in the recall of words processed extensively at encoding (i.e., TBR words) rather than differences in inhibition. As a whole, the present study showed the importance of equalizing memory performance between groups for TBR information when investigating directed forgetting.

Conflicts of interest

None

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Table 1. Mean percentages of recall of both groups as a function of list and encoding condition in the forget and in the remember conditions.

	Standard				Strong			
	Younger		Older		Younger		Older	
	Forget	Remember	Forget	Remember	Forget	Remember	Forget	Remember
List 1	31,25 (26,75)	43,75 (18,80)	20,63 (17,81)	28,75 (21,88)	48,75 (27,18)	70,63 (16,86)	32,5 (23,79)	43,13 (18,79)
List 2	55 (27,63)	48,13 (21,18)	39,38 (21,94)	23,75 (16,67)	70,63 (17,80)	69,38 (17,43)	47,5 (18,41)	42,5 (21,23)

Forget = forget condition, Remember = remember condition, List 1 = first list presented during the study phase, List 2 = second list presented during the study phase. In the forget condition, list 1 was cued to forget and list 2 was cued to remember. In the remember condition, both list 1 and list 2 were cued to remember. Numbers in parentheses correspond to standard deviations.

Table 2. Mean percentages of recognition (hits - false alarms) of both groups as a function of list and encoding condition in the forget and in the remember conditions

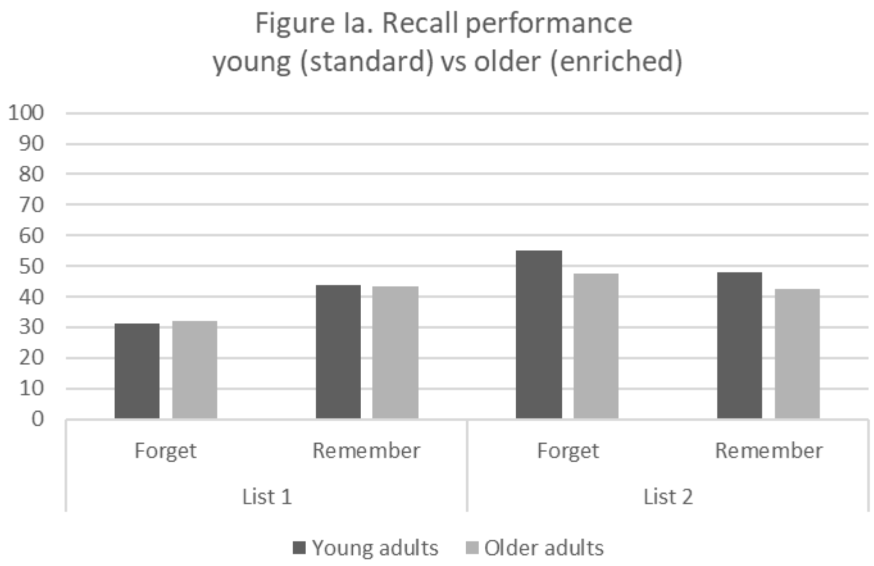
	Standard				Strong			
	Younger		Older		Younger		Older	
	Forget	Remember	Forget	Remember	Forget	Remember	Forget	Remember
List 1	79.38 (24.01)	76.25 (15.52)	62.81 (20.33)	74.06 (20.71)	88.44 (14.52)	91.56 (10.97)	82.5 (17.40)	80 (8.75)
List 2	75.63 (21.55)	75.63 (19.75)	72.19 (24.71)	69.06 (24.79)	95.31 (8.57)	92.81 (11.87)	81.25 (16.47)	76.88 (20.69)

Forget = forget condition, Remember = remember condition, List 1 = first list presented during the study phase, List 2 = second list presented during the study phase. In the forget condition, list 1 was cued to forget and list 2 was cued to remember. In the remember condition, both list 1 and list 2 were cued to remember. Numbers in parentheses correspond to standard deviations.

Table 3. Mean proportions of RKG judgments of both groups as a function of list and encoding condition in the forget and in the remember conditions. The sum of RKG percentages corresponds to the mean percentage of recognition.

		Standard				Strong			
		Younger		Elderly		Younger		Elderly	
		Forget	Remember	Forget	Remember	Forget	Remember	Forget	Remember
List 1	*R*	56.25 (22.40)	43.13 (26.74)	34.38 (20.23)	43.13 (24.16)	63.75 (22.18)	73.13 (19.57)	41.88 (28.76)	55.63 (27.35)
	K	26.25 (20.64)	32.5 (24.13)	24.38 (20.06)	30 (20.84)	23.13 (21.94)	15 (15.50)	35 (25.84)	26.25 (20.24)
	G	6.88 (10.26)	7.5 (10.26)	12.5 (10.73)	8.75 (11.54)	3.75 (9.16)	4.38 (8.39)	10 (10.42)	3.13 (5.55)
List 2	*R*	47.5 (26.47)	35 (22.06)	43.75 (26.13)	37.5 (26.90)	66.25 (26)	66.88 (28.47)	50.63 (26.12)	41.88 (26.99)
	K	31.25 (25.16)	38.75 (17.63)	27.5 (24.20)	29.38 (25.74)	27.5 (22.43)	21.88 (22.17)	29.38 (21.57)	33.75 (20.32)
	G	6.88 (15.43)	8.75 (10.81)	9.38 (8.95)	10 (14.96)	3.75 (9.16)	5 (13.69)	5.63 (8.58)	6.25 (10.34)
False alarms	*R*	0.94 (2.29)	0	0.31 (1.40)	0.63 (1.92)	0.94 (4.19)	0	0	0.63 (2.80)
	K	3.75 (7.42)	3.13 (6.25)	2.19 (5.08)	1.88 (3.57)	0	0	1.25 (3.85)	0.94 (3.06)
	G	5.31 (8.18)	3.75 (7.69)	5.94 (7.98)	5.31 (6.81)	1.25 (3.27)	0.94 (2.29)	3.13 (7.98)	3.13 (6.25)

Forget = forget condition, Remember = remember condition, List 1 = first list presented during the study phase, List 2 = second list presented during the study phase, false alarms = recognition of words not presented during the study phase, R = remember judgment, K = know judgment, G = guess judgment. In the forget condition, list 1 was cued to forget and list 2 was cued to remember. In the remember condition, both list 1 and list 2 were cued to remember. Numbers in parentheses correspond to standard deviations.



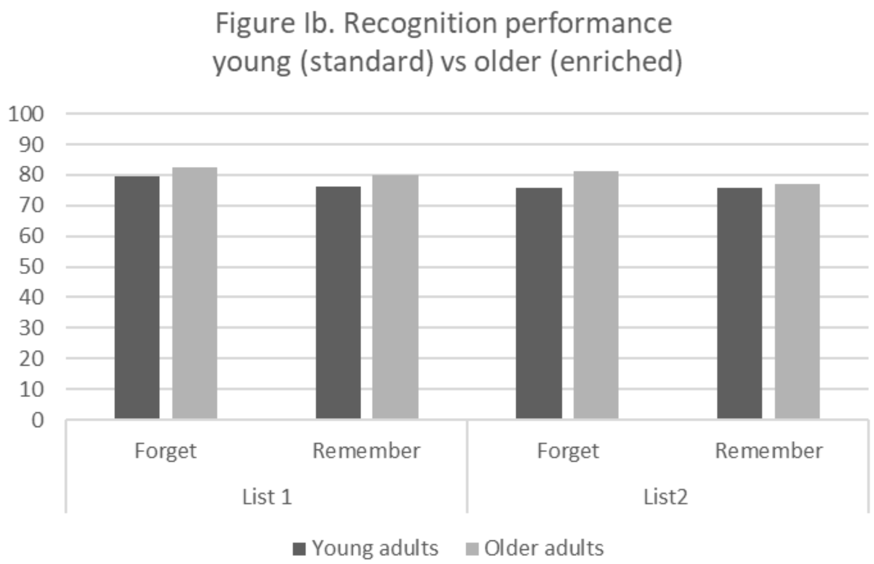


Figure I. Mean percentages of recall (Figure Ia) and recognition (hits - false alarms ; Figure Ib) performance of young (standard encoding) and older (enriched encoding) participants. Forget = forget condition, Remember = remember condition, List 1 = first list presented during the study phase, List 2 = second list presented during the study phase. In the forget condition, list 1 was cued to forget and list 2 was cued to remember. In the remember condition, both list 1 and list 2 were cued to remember.

Supplementary material

Effect of recall order

To ensure that an output interference effect did not influence our DF results, we performed 2 (Group: young vs. older) x 2 (List: list 1 vs. list 2) x 2 (Recall order: list 1 first vs. list 2 first) repeated measures ANOVAs for the forget and the remember conditions separately, and for the standard and the strong encoding conditions separately. In the forget condition, the analysis for the standard encoding condition was the only one who revealed a main effect of recall order [F (1, 36) = 5.05; p = .03, η_p^2= .12]. However, planned comparisons showed a surprising pattern of results, which did not correspond to the output interference effect as described by Golding and Gottlob (2005). Indeed, only a better memory performance for list 1 (to forget) was observed for younger when this list was recalled after the second list [F (1, 36) = 5.34; p = .03], which was the list cued to remember..