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# False Memories and Normal Aging: Links Between Inhibitory Capacities and Monitoring Processes

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Empirical evidence suggests an increased production of false memories with advancing age. The activation-monitoring theory proposes that strategic monitoring processes influence the probability of false recall in the DRM paradigm. In the present study, we examined the hypothesis that a low level of inhibition may impair the efficient use of monitoring processes during information retrieval and thus increase the production of false memories in aging. Accordingly, we conducted a study in which older adults with low or high levels of inhibition performed a standard DRM task or an inclusion DRM task that disables monitoring processes. The results indicated that low inhibitory capacities were associated with fewer correct recalls and increased production of critical lures (false memories), suggesting difficulties in using monitoring processes at the time of retrieval. Our findings also showed that the relationship between Age and the production of critical lures in a standard DRM task is mediated by Inhibition. These results are interpreted as suggesting that inhibitory abilities may partly be linked to the impairment of monitoring processes in the elderly.

**Keywords:** aging, false memories, DRM, inhibition, monitoring

The reconstructive view (Bartlett, 1932) underlines the malleability of memory and has led researchers to focus on memory errors and false memories (for a review, see Schacter, 1995). A false memory refers to a memory of events that never occurred or that is distorted compared to what was actually experienced (Roediger & McDermott, 1995) and is typically held with a high level of confidence and claims of remembering (Dehon, 2012; De Prince, Allard, Oh, & Freyd, 2004). Many authors have used the DRM paradigm, developed by Roediger and McDermott (1995) and Read (1996) based on the work of Deese (1959), to study the production of false memories in a laboratory setting. The procedure consists of presenting short lists of words thematically linked and all semantically associated with a single word, not presented, called the critical lure (e.g., *bed*, *rest*, or *awake*, for which the nonpresented lure is *sleep*; Roediger & McDermott, 1995). In a free recall or recognition task, results show that the participants falsely recall or recognize many of the critical lures (CLs) while generally being sure that they appeared on the presented lists (for reviews, see Gallo, 2010; Roediger, McDermott, & Robinson, 1998).

Studies on aging have regularly highlighted a reduction in correct recalls associated with an increase in false recalls or

recognitions in older adults compared to young adults (e.g., Balota, Cortese, Duchek, Adams, Roediger, & Yerys, 1999; Dehon, 2006; Dennis, Kim, & Cabeza, 2007; Norman & Schacter, 1997). Note that the literature (for reviews, see Gallo, 2006; Schacter, Koutstaal, & Norman, 1997; Taconnat & Rémy, 2006) is more mixed with respect to DRM recognition performance in which an age-related difference is less pronounced (Gallo, 2006) and that increased intrusions other than CLs, including semantic intrusions, have also been reported (Balota et al., 1999; Waldie & Kwong See, 2003).

The activation-monitoring theory (Roediger, Balota, & Watson, 2001) suggests that the production of CLs occurs via an activation of encoding traces, associated with a failure in the monitoring processes responsible for identifying the acquisition source of the information at the time of retrieval. During encoding, this activation may occur either consciously, following elaborative processing or favoring item distinctiveness (e.g., Brédart, 2000; McDermott & Watson, 2001; Schacter, Israel, & Racine, 1999), or automatically as a result of spreading activation in the associative network (e.g., Hege & Dodson, 2004; McDermott & Watson, 2001; Seamon, Luo, & Gallo, 1998). This theory also questions the reliability of the source monitoring processes (Johnson, Hashtroudi, & Lindsay, 1993), which enables the distinction between real (i.e., belonging to the list) from self-generated information (e.g., CLs). While activation seems preserved with age (e.g., Dehon & Brédart, 2004; Evrard, Colombel, Gilet, & Corson, 2015), studies have regularly reported age-related deficits in source monitoring (e.g., Johnson & Raye, 2000; Johnson et al., 1993). Thus, memory errors or false memories committed by older adults have been often considered as reflecting such a failure to monitor the source (Dehon & Brédart, 2004; Gallo & Roediger, 2003).

Such source monitoring failure has been explained by several hypotheses (referring either to the global or to the analytic per-

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spective) based on the intended contrast of encoding and retrieval processes. Some of these hypotheses focused on the encoding strategy and activation processes (processing speed that causes a less distinctive encoding; e.g., Clarys, Isingrini, & Gana, 2002; Dehon, 2006; Norman & Schacter, 1997) whereas others focused on source monitoring during information retrieval (inhibition deficit hypothesis; e.g., Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; Lustig, Hasher, & Zacks, 2007). Others hypotheses may also include both stages of information processing as suggested by the reduced attentional resources hypothesis (Dehon & Brédart, 2004; Koutstaal, 2003).

Concerning the role of inhibition in the production of false memories, to our knowledge, only two studies (Lövdén, 2003; Sommers & Huff, 2003) have directly questioned this link in the DRM paradigm. Lövdén, using structural equation modeling, indicated an approximately continuous increase in false memories from 20 to 80 years. With regard to inhibition (measured by the percentage of slowing from the congruent trial of the Stroop task), its direct effect on the frequency of false memories was not convincingly confirmed. Lövdén concluded that inhibition affects the frequency of false memories indirectly via episodic memory performance and suggested that his study might have measured inhibitory mechanisms other than those involved in the production of false memories. This result led Lövdén to question the original notion of a unitary inhibitory mechanism in favor of multiple inhibitory mechanisms (Connelly & Hasher, 1993; Feyereisen & Charlot, 2008). Therefore, the model of Hasher et al. (1999), distinguishing three aspects of inhibitory control (access, deletion, and restraint) demonstrated an age-related deficit in inhibition and seems particularly relevant to examine the question of the exact nature of the inhibition processes involved in the production of false memories in the elderly. Sommers and Huff (2003, Exp. 2), using the auditory Stroop interference as an index of inhibitory abilities, found that inhibition accounted for a significant percentage of the variance in false recollection. Although this finding suggested that reduced ability to inhibit activation levels of CLs is one factor contributing to older adults' increased susceptibility to false memories, it must be interpreted cautiously because inhibitory abilities accounted for a relatively small percentage of the total variance suggesting that other factors must, therefore, contribute to the production of CLs.

Inhibition has also been studied in research focusing on the links between executive functions and the production of false memories. An initial report failed to find correlations between tests thought to measure primarily frontal functioning (digit span, word fluency, and mental control tasks) and false recall (Balota et al., 1999). However, the authors suggested these tasks might reflect processing in other cortical areas and might not be sufficiently reliable. Butler, McDaniel, Dornburg, Price, and Roediger (2004) presented a DRM task to younger and older participants whose frontal functioning was assessed using the criteria developed by Glisky, Polster, and Routhieaux (1995). Not surprisingly, the results showed that low executive functioning older participants recalled fewer correct items and more CLs than high executive functioning older adults, who showed the same pattern of results as younger adults. The analyses indicated that age-related increases in false recall depend critically on whether aging impairs frontally mediated processes within a given individual. LaVoie, Willoughby, and Faulkner (2006) compared the false recognition scores of young

adults with those of older adults with no evidence of cognitive impairment or with evident frontal impairment but no other dysfunction, and Alzheimer's patients. Their results, congruent with those of Butler et al. (2004), indicated that false memory susceptibility was highest in the frontally impaired aged group, with the young and older control participants performing similarly. Finally, also using the frontal criteria developed by Glisky et al. (1995), Chan and McDermott (2007) correlated younger and older adults' frontal scores with veridical and false recall probabilities with prose materials. A hierarchical regression analysis showed that, even after frontal functioning had been accounted for, robust age differences in false recall remained. Their results moderated those obtained by Butler et al. (2004) and LaVoie et al. (2006) and suggested that age-related differences in frontal functioning are not sufficient to explain the reduced accurate recall and increased false recall in aging.

Altogether, these studies do not show a clear consensus about the role of inhibition or, more generally, the executive level in the increased production of false memories in older adults. While it is known that inhibition capacity is particularly sensitive to age, its precise connection with the production of false memories and, more particularly, with the effectiveness of the monitoring processes needs to be clarified.

To determine the cognitive processes involved in the production of false memories, some authors suggested adding an inclusion instruction to a classic DRM task (e.g., Brainerd & Reyna, 1998; Brainerd, Wright, Reyna, & Payne, 2002; Hege & Dodson, 2004; Jacoby, 1991). In the inclusion instruction, for each list, participants were asked to recall any studied item they remember having heard, as well as any additional words they thought of during the study or recall phase. Such an inclusion instruction should help remove the contribution of strategic monitoring processes, as there is no need to prevent the recall of the critical lures that come to mind. A comparison of the results from this modified DRM task with those from a standard DRM task makes it possible to identify whether the production of CLs is because of the activation processes at encoding or to the monitoring processes at retrieval. Thus, if the pattern of results between the conditions is identical, then false memories are likely because of activation processes (e.g., Storbeck & Clore, 2005). In contrast, if the pattern is different, then false memory production is because of monitoring processes at retrieval (e.g., Corson, Mahé, Verrier, Colombel, & Jagot, 2011). To our knowledge, this procedure has not been used with an elderly population.

The main objective of the present study was to better understand the mechanisms responsible for the increased production of false memories in the elderly as reported in the literature (e.g., Koutstaal, 2003; Thomas & Sommers, 2005). It has been largely established that older adults have difficulty in identifying the source of information, and are inclined to accept as true information that is self-generated by automatic spread of activation within the semantic network (Roediger et al., 2001). Moreover, research has demonstrated an age-related deficit in inhibition (Hasher et al., 1999, 2007). Hence, in view of the processes involved in the DRM paradigm, we focused on two functions of inhibition identified in the model of Hasher et al., restraint and deletion, and selected three tests (Hayling, Stroop, and a directed forgetting task) and four inhibition indicators. We aimed to explain the rise in the production of false memories in the elderly by highlighting the links

between inhibitory capacities and monitoring processes. More specifically, we suggest that a low level of inhibition could impair the efficient use of monitoring processes during the retrieval of information. However, high inhibition may allow participants to focus on encoding strategies and block out irrelevant information, thereby enhancing correct recall and reducing the number of intrusions.

Using a DRM paradigm including standard and inclusion instruction conditions, we examined correct recalls (CRs), false recalls (i.e., recall of CLs) and semantic intrusions (SIs) of older adults with low or high levels of inhibition. In the standard instruction condition, we proposed that the production of CRs, CLs, and SIs depends on the level of inhibition of the participants. Thus, we expected participants with a low level of inhibition to produce fewer CRs but more CLs and SIs than those with a high level of inhibition. Otherwise, as age-related declines in inhibition are not uniform but vary depending on task-specific characteristics, we expected the functions of restraint and deletion to be negatively correlated to the production of CLs and SIs and positively correlated to the production of CRs.

Then, by comparing the results from the standard and the inclusion conditions, we sought to determine if the inhibitory effect on the production of CLs in older adults is due to the monitoring process at retrieval. Because, in comparison to the standard condition, the inclusion condition disrupts monitoring processes, both high and low inhibition participants should not differ in this condition. However, if high inhibition participants are better at monitoring CLs, they should recall fewer CLs in the standard condition. We expected the differences in CL production between the two instruction conditions to be larger for older adults with high inhibitory capacities than for older adults with low inhibitory capacities.

In addition, in the inclusion condition, we expected the positive correlation between inhibition capacities and CRs to be maintained and the negative correlation between inhibition and CLs or SIs to disappear. Finally, exploratory regression analyses were conducted to determine which inhibition indicators best predict the production of CRs, CLs, and SIs and to test the mediating effect of inhibition on the relationship between age and the production of CLs.

## Method

### Participants

There were 113 older adults between 70 and 90 years ( $M = 76.8$  years,  $SD = 5.70$ , 70% women), all native French speakers, who voluntarily took part in the study. All retired, they were recruited in various clubs and associations in the area of Nantes. All older participants obtained a score equal to or higher than 27 ( $M = 29.11$ ,  $SD = 0.84$ ) on the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975, French version; Derouesné, Poitreneau, Hugonot, Kalafat, Dubois, & Laurent, 1999), confirming the integrity of their global cognitive functioning. The French version of the Geriatric Depression Scale (GDS; Bourque, Blanchard, & Vézina, 1990) revealed no signs of depression ( $M = 6.16$ ,  $SD = 5.00$ ). Their sociocultural levels were measured by the Poitreneau scale (Hugonot-Diener, 2007;  $M = 3.04$ ,  $SD = 0.92$ ). From a few questions about their education and professional status, a score on a 4-point Likert scale was established; the higher the score, the higher the sociocultural level (see Table 1).

Participants were then randomly divided into two groups depending on the instruction (standard or inclusion) they received for the recall task. Thus, 54 older adults were given the standard instruction while 59 other older adults were given the inclusion instruction. Next, participants were contrasted according to their global level of inhibition on the basis of a median split on the composite z-score (four indicators). Raw scores from each inhibition task were transformed into z-scores (using means and  $SD$ s for the whole group). The inhibition test scores were inverted when a lower score indicated a higher performance (in this way, a higher score always corresponded to a higher performance). To obtain a composite score, a mean score was calculated from the z-scores of the inhibition tasks assumed to reflect the component. This global z-score was used to constitute two contrasting groups of older adults. Thus, the performances of 57 high inhibitors ( $M = .52$ ,  $SD = .39$ ) and 56 low inhibitors ( $M = -.54$ ,  $SD = .41$ ) were analyzed.

Overall, no statistical differences were observed between the standard condition and the inclusion condition for Age,  $t(111) = 0.54$ ,  $p = .59$ ,  $d = 0.10$ , Education,  $t(111) = 0.94$ ,  $p = .35$ ,  $d = 0.17$ , MMSE,  $t(111) = 0.40$ ,  $p = .69$ ,  $d = 0.07$ , GDS,  $t(111) = 1.04$ ,  $p = .30$ ,  $d = 0.20$ , or Inhibition global z-score,  $t(111) = 0.29$ ,  $p = .77$ ,  $d = 0.05$ .

Table 1  
Participant Characteristics

Inhibition	Standard condition		Inclusion condition	
	High $n = 27$ $M(SD)$	Low $n = 27$ $M(SD)$	High $n = 30$ $M(SD)$	Low $n = 29$ $M(SD)$
Age	75.07 <sup>a</sup> (4.59)	78.07 <sup>b</sup> (4.52)	75.83 (4.53)	78.38 (5.66)
Education	3.15 (0.90)	3.11 (0.93)	3.13 (0.90)	2.79 (0.94)
MMSE	29.41 <sup>a</sup> (0.75)	28.89 <sup>b</sup> (0.89)	29.10 (0.80)	29.07 (0.88)
GDS (30 items)	5.25 (4.60)	6.11 (4.96)	5.73 (3.98)	7.38 (3.97)
Global Inhibition Score	.51 (0.37)	-.56 (0.36)	.53 (0.42)	-.52 (0.47)

Note. Education = Poitreneau scale; MMSE = Mini-Mental State Exam; GDS = Geriatric Depression Scale; Global Inhibition Score = mean of four indicators in z-score.  $SD$ s are in parentheses. Means with different subscripts differed significantly ( $p < .05$ ) between inhibition groups.



In the standard condition, no statistical differences were observed between high and low inhibitors for Education,  $t(52) = 0.15$ ,  $p = .88$ ,  $d = 0.04$ , and GDS,  $t(52) = 0.65$ ,  $p = .51$ ,  $d = 0.18$ . However, a statistical difference was found for Age,  $t(52) = 2.42$ ,  $p = .02$ ,  $d = 0.66$ , with low inhibitors being older than high inhibitors, and for MMSE,  $t(52) = 2.32$ ,  $p = .02$ ,  $d = 0.63$ , with high inhibitors reporting a higher cognitive efficiency than low inhibitors. Naturally, the high inhibitors had higher inhibition scores than the low inhibitors,  $t(52) = 10.76$ ,  $p < .001$ ,  $d = 2.93$ .

In the inclusion condition, no statistical differences were observed between high and low inhibitors for Age,  $t(57) = 1.91$ ,  $p = .06$ ,  $d = 0.51$ , Education,  $t(57) = 1.42$ ,  $p = .16$ ,  $d = 0.37$ , MMSE,  $t(57) = 0.14$ ,  $p = .89$ ,  $d = 0.04$ , and GDS,  $t(57) = 1.59$ ,  $p = .18$ ,  $d = 0.42$ . Again, the high inhibitors had higher inhibition scores than the low inhibitors,  $t(57) = 9.24$ ,  $p < .001$ ,  $d = 2.44$ .

## Materials

**Stroop** (standardized version; Golden, 1978). The participants had 45 s to study every item on the three cards composed of 100 items. First, on the word card (W), participants had to read the color words (blue, green, or red) printed in black. Second, on the color card (C), participants had to name the color (blue, green, or red) of the crosses. Third, on the color-word card (CW), the color words are printed in conflicting colors (e.g., the color word “green” is printed in blue or red). The participants had to name the printed color, ignoring the color words. The score of inhibition (restraint) was calculated according to the formula proposed by Belleville, Rouleau, and Van der Linden (2006):  $\text{interference} = (\text{Score CW})/[(\text{Score W} + \text{score C})]/2$ .

**Hayling** (Burgess & Shallice, 1997, French adaptation; Belleville et al., 2006). This task consisted of 30 sentences in which the final word was omitted but had a particularly high probability of being one specific response. In the initiation phase (A), the participants had to complete, as fast as possible, 15 sentences, read aloud by the experimenter, with the appropriate word. In the inhibition phase (B), the participants received the instruction to complete the sentences with a word that was not linked to the sentence or to the expected word. Thus, they had to produce a word that made the sentence absurd. The latency (obtained by the formula  $B - A/B + A$ ) and the score of penalties in part B (0 point for an appropriate answer (absurd), 1 point for a wrong answer, 3 points for no answer or an answer giving the expected word) were used as indicators of the inhibition level (restraint).

**Directed forgetting task** (Collette, Germain, Hogge, & Van der Linden, 2009; Sego, Golding, & Gottlob, 2006). Four lists of 12 words created by Gokalsing (2003) were presented orally to participants. After each list of words, the participants were asked to forget or to memorize the items they had just heard. At the end of the presentation, they had to write down all the words they remembered and had to memorize. The indicator of the level of inhibition was obtained by subtracting the number of recalled items to be forgotten from the number of recalled items to be memorized.

**DRM lists.** Six DRM lists of 15 words (Corson et al., 2011; Corson & Verrier, 2007) were selected. Their CLs were: *chaussure* (shoe), *église* (church), *laine* (wool), *diable* (devil), *porte* (door), and *ski* (ski). The indicators used for the memory test were the mean percentage of items correctly recalled (total number of

correct words produced/(15(words)  $\times$  6 (lists))  $\times$  100), the mean percentage of critical lures produced (total number of critical lures produced/(1  $\times$  6)  $\times$  100) and the mean percentage of semantic intrusions produced (total number of semantic intrusions produced/total number of words recalled  $\times$  100).

## Procedure

All the participants gave their informed consent. Two sessions were organized. During the first one, in small groups of five people maximum, they performed the DRM task, filled in the demographic form then took the directed forgetting test. During a second individual session, participants were assessed on their global cognitive functioning with the MMSE, and carried out the Stroop and Hayling tests before completing the GDS. At the end of the session, all the participants were debriefed.

For each DRM list, the items were presented orally with an interval of 2 s between items. To neutralize the order effect, three different orders of presentation of lists were used. The instruction received differed according to the experimental condition: (a) the participants assigned to the standard condition had to write down all the words they could remember from those that were presented; (b) the participants assigned to the inclusion condition had to recall all the items they could think of during the recall and/or that they had thought of during the presentation, including those from the studied lists. Regardless of the instruction, the participants had 90 s for the written free recall test just after the presentation of each list.

## Results

Three separate analyses of variance (ANOVA) were conducted on the mean percentage of correct responses (% CRs), the mean percentage of production of critical lures (% CLs), and the mean percentage of production of semantic intrusions (% SIs) with Inhibition (low, high), and Instruction (standard, inclusion) as between-subjects factors. First, the results associated with these three dependent variables are presented. To refine these results, the planned comparisons specifically related to our hypotheses are given. Second, correlation and multiple hierarchical regression analyses were conducted to examine the relationship of the four indicators selected with the production of CRs, CLs, and SIs. Third, a second set of multiple regressions was computed to determine if the relationship between the production of CLs and Age was mediated by Inhibition.

## Main Analyses

**Correct recalls.** A 2 (Inhibition)  $\times$  2 (Instruction) ANOVA was carried out on the CRs. The results revealed a main effect of Inhibition,  $F(1, 109) = 18.88$ ,  $p < .001$ ,  $\eta_p^2 = .15$ . There was no main effect of Instruction nor an Inhibition  $\times$  Instruction interaction,  $F(1, 109) = 0.57$ ,  $p = .45$ ,  $\eta_p^2 = .005$  and  $F(1, 109) = 0.59$ ,  $p = .44$ ,  $\eta_p^2 = .005$ , respectively. These results suggest that the relationship between inhibition level and CRs did not differ between standard and inclusion instructions (see Table 2).

Focusing only on the results obtained with the standard instruction, planned comparisons showed that older adults with low inhibitory capacities produced fewer CRs than older adults with high inhibitory capacities,  $F(1, 109) = 12.53$ ,  $p < .001$ ,  $d = 1.02$ .

Table 2  
Mean Percentages of Correct Recalls (CRs) and Semantic Intrusions (SIs) for High and Low Inhibition Groups in Standard and Inclusion Conditions

Inhibition	Standard condition		Inclusion condition	
	High <i>M(SD)</i>	Low <i>M(SD)</i>	High <i>M(SD)</i>	Low <i>M(SD)</i>
CRs	56.30 (10.89)	45.80 (9.54)	56.26 (11.13)	48.93 (11.76)
SIs	2.26 (2.51)	3.54 (4.30)	11.74 (8.91)	13.03 (10.72)

Note. SDs are in parentheses.

Finally, planned comparisons showed no differences in the production of CRs between standard and inclusion conditions for the high inhibitors,  $F(1, 109) = 0.00$ ,  $p = .98$ ,  $d = -0.004$ , or for the low inhibitors,  $F(1, 109) = 1.15$ ,  $p = .28$ ,  $d = 0.38$ . Therefore, the monitoring processes at retrieval did not participate in the production of CRs in the elderly. The production of CRs seems to be due mainly to the activation process at encoding. A high level of inhibition could enable older people to encode better items that must be memorized.

**Critical lures.** A 2 (Inhibition)  $\times$  2 (Instruction) ANOVA on the CLs was performed. The analysis indicated a main effect of Instruction,  $F(1, 109) = 14.30$ ,  $p < .001$ ,  $\eta_p^2 = .11$ . There was no main effect of Inhibition nor an Inhibition  $\times$  Instruction interaction,  $F(1, 109) = 1.49$ ,  $p = .22$ ,  $\eta_p^2 = .013$  and  $F(1, 109) = 1.25$ ,  $p = .26$ ,  $\eta_p^2 = .01$ , respectively. This lack of interaction suggests that the relationship between inhibition scores and false recall did not change between the two instructions (see Figure 1). More specifically, in the standard instruction, and contrary to our expectations, there was no significant difference in the production of CLs between the participants with high and low inhibitory capacities,  $F(1, 109) = 2.62$ ,  $p = .11$ ,  $d = 0.45$ . However, planned comparisons showed that the production of CLs in the older adults with high inhibitory capacities was greater in the inclusion instruction condition than in the standard instruction condition,  $F(1, 109) = 12.11$ ,  $p < .001$ ,  $d = 0.87$ . As expected, this was not true for older adults with low inhibitory capacities,  $F(1, 109) = 3.52$ ,

$p = .06$ ,  $d = 0.53$ . The difference being marginally significant, those data may be interpreted with caution.

Although the level of inhibition was not associated with the production of false memories, the instruction condition was linked to high inhibitory capacities only. Those with a high level of inhibition implemented the monitoring process more effectively when it was required for the task. On the contrary, the elderly low inhibitors behaved in the same way whatever the instruction, that is, whether they were asked to call on their monitoring processes or not. These results highlight a difficulty in strategic monitoring processes in the production of CLs at retrieval for elderly low inhibitors.

**Semantic intrusions.** The analysis of the SIs indicated a main effect of Instruction,  $F(1, 109) = 44.84$ ,  $p < .001$ ,  $\eta_p^2 = .29$ . There was no main effect of Inhibition nor an Inhibition  $\times$  Instructions interaction,  $F(1, 109) = 0.82$ ,  $p = .36$ ,  $\eta_p^2 = .007$  and  $F(1, 109) = 0.00$ ,  $p = .99$ ,  $\eta_p^2 = .00$ , respectively (see Table 2).

Here again, the relationship between inhibition scores and SIs did not change between the two instructions. Specifically, in the standard condition, there was no significant difference in the production of SIs between the participants with high and low inhibitory capacities,  $F(1, 109) = 0.39$ ,  $p = .53$ ,  $d = 0.36$ . Moreover, planned comparisons showed that the production of SIs was greater in the inclusion instruction condition than in the standard instruction condition for both high,  $F(1, 109) = 22.56$ ,  $p < .001$ ,  $d = 1.44$ , and low inhibitors,  $F(1, 109) = 22.27$ ,  $p < .001$ ,  $d = 1.16$ .

The level of inhibition was not associated with the production of SIs, which was particularly low, whatever the inhibition level of the participants. The instruction change increased the production of SIs in the same way. The monitoring processes at retrieval did not seem to be involved in the production of intrusion. It is interesting that this pattern of results is different from that obtained for lures.

## Correlations and Regressions Analyses

**Standard condition.** Overall, in agreement with our previous results (see main analyses for CRs), in the standard condition (i.e., classic DRM condition), the global inhibition z-score (GIS) was positively correlated with CRs (see Table 3). This significant

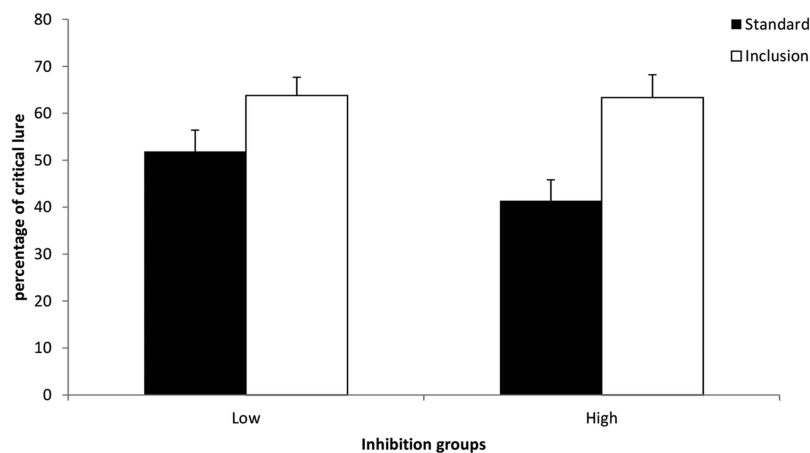


Figure 1. Percentage of critical lure production of older adults according to their level of inhibition and the instruction condition. Errors bars represent SEM.

Table 3

*Pearson Correlations Between Age, Inhibition Indicators, and Percentages of Correct Recalls (CRs), Critical Lures (CLs), and Semantic Intrusions (SIs) in Standard and Inclusion Conditions*

Variable	Standard						Inclusion					
	Hp	HI	St	DF	GIS	Age	Hp	HI	St	DF	GIS	Age
CRs	.65**	.33*	.22	.13	.50**	-.14	.58**	.09	.26*	.26*	.45**	.17
CLs	-.24 <sup>†</sup>	-.19	-.29*	-.17	-.33*	.30*	.12	.07	-.15	.04	.03	.01
SIs	-.09	-.06	-.24	-.16	-.20	.16	.20	.08	-.12	.23 <sup>†</sup>	.14	-.23 <sup>†</sup>
Age	-.30*	-.30*	-.22	-.04	-.32*		-.16	-.26*	-.06	-.28*	-.28*	

Note. Hp = Hayling penalties; HI = Hayling latency; St = Stroop interference; DF = Directed Forgetting; GIS = Global Inhibition Score.

<sup>†</sup>  $p < .10$ . \*  $p < .05$ . \*\*  $p < .01$ .

positive correlation indicates that higher inhibition scores were associated with a higher probability of accurate recalls,  $r = .50$ ,  $p < .001$ . More important for the current purposes are the results for false recalls. In agreement with previous studies (Chan & McDermott, 2007), the significant negative correlation between CLs and GIS,  $r = -.33$ ,  $p = .014$  indicates that higher inhibition scores were associated with lower probabilities of false recalls. Overall, a high level of inhibition was associated with better recall of CRs and reduced production of CLs. Furthermore, no significant correlation was observed between GIS and the production of semantic intrusions,  $r = -.21$ ,  $p = .136$ . These results show that the relationship between inhibition and production of CLs is different from that between inhibition and SIs. Finally, we observed a significant negative correlation between GIS and Age,  $r = -.32$ ,  $p = .018$ , indicating a poorer level of inhibition for older participants. Moreover, Age was significantly positively correlated to the production of CLs,  $r = .30$ ,  $p = .028$  confirming the increased production of CLs with age while no significant correlations were observed between Age and the production of CRs,  $r = -.14$ ,  $p = .30$  and SIs,  $r = .16$ ,  $p = .24$ .

When the results were differentiated by type of inhibition indicator, two of the three indicators of the restraint function (Hayling penalties and Hayling latency) were positively correlated with the production of CRs ( $r = .65$ ,  $p < .001$  and  $r = .328$ ,  $p = .015$ , respectively). Moreover, the function of deletion measured by the directed forgetting task was not correlated with CRs,  $r = .13$ ,  $p = .329$  while CL production was negatively correlated with the Stroop test,  $r = -.29$ ,  $p = .034$ . In addition, Age was negatively correlated with two indicators (Hayling penalties and Hayling latency) of the restraint function ( $r = -.30$ ,  $p = .03$  and  $r = -.30$ ,  $p = .027$ , respectively).

Significant group differences were found for Age and MMSE; therefore, we conducted partial correlations controlling for these variables (see Table 4). All the previous significant correlations remained significant when Age and MMSE were partialled out, except the negative correlation between the Stroop test and CL production (partial correlation =  $-.26$ ,  $p = .057$ ).

Finally, a set of ascendant hierarchical regressions was conducted to determine the indicators of inhibition that best predict the production of CRs and CLs in the standard condition. The results showed that CRs were only predicted by Hayling penalties and that this accounted for 42.3% of the variance ( $\beta = .651$ ,  $p < .001$ ). CLs were only predicted by GIS and this accounted for 11% of the variance in CLs ( $\beta = -.332$ ,  $p = .014$ ).

**Inclusion condition.** Overall, and as expected, the GIS was correlated with the CRs,  $r = .45$ ,  $p < .001$ . In fact, the same pattern of results was observed in both instruction conditions.

However, GIS was not correlated with the production of CLs,  $r = .03$ ,  $p = .847$ , which was expected since the monitoring processes were no longer required in this condition. The level of inhibition was no longer associated with the production of CLs,  $r = .03$ ,  $p = .85$ .

In the same manner, the correlation between Age and the production of CLs was no longer significant,  $r = .01$ ,  $p = .93$ . However, a negative correlation was still observed between Age and GIS,  $r = -.28$ ,  $p = .032$ .

When the results were differentiated by type of inhibition indicator, 3 of the 4 indicators showed positive correlations with the CRs: the Stroop,  $r = .26$ ,  $p = .047$  and Hayling penalties,  $r = .58$ ,  $p < .001$  for the function of restraint and directed forgetting,  $r = .26$ ,  $p = .049$  for the function of deletion: higher inhibitory functions of restraint and deletion were associated with a higher probability of accurate recall. The regression analyses showed that CRs were only predicted by Hayling penalties, which accounted for 32.2% of the variance,  $\beta = .578$ ,  $p < .001$ .

Furthermore, none of the four indicators was significantly correlated with the production of CLs. The monitoring processes being no longer required, there was no longer a relationship between the level of inhibition and the production of false recalls. No significant correlation was demonstrated either for SIs. Finally, a negative correlation was observed between Age and two inhibition indicators: Hayling latency,  $r = -.26$ ,  $p = .047$  and directed forgetting,  $r = -.28$ ,  $p = .032$ .

Table 4

*Partial Correlations Between Inhibition Indicators and Percentages of Correct Recalls (CRs), Critical Lures (CLs), and Semantic Intrusions (SIs) in the Standard Condition with Age and MMSE Partialled Out*

Variable	Hp	HI	St	DF	GIS
CRs	.60**	.29*	.15	.13	.44**
CLs	-.23 <sup>†</sup>	-.12	-.26 <sup>†</sup>	-.17	-.30*
SIs	.01	-.00	-.19	-.15	-.14

Note. Hp = Hayling penalties; HI = Hayling latency; St = Stroop interference; DF = Directed Forgetting; GIS = Global Inhibition Score.

<sup>†</sup>  $p < .10$ . \*  $p < .05$ . \*\*  $p < .01$ .

## Mediation Analysis

A second set of multiple regressions was computed to determine if the relationship between age and the production of CLs was mediated by inhibition. Baron and Kenny (1986) proposed a two-step regression procedure according to which, to demonstrate a significant mediating effect, one must ensure that the predictor, the mediator and the dependent variable are significantly related and that the association between the predictor and the dependent variable is lowered after controlling for the mediator. Analysis showed that Age was a significant predictor of the production of CLs. In addition, Age was a significant predictor of the GIS that was also a significant predictor of the production of CLs. As shown in Figure 2, including inhibition (GIS) in the model reduced the effect of age on the production of CLs from  $\beta = .300, p = .028$  to  $\beta = .215, p = .12$ . Thus, Inhibition is a mediator of the relationship between Age and the production of CLs in the standard DRM task.

## Discussion

Following the activation-monitoring account of an age-related increase in DRM false memories, the present study was aimed at a better understanding of the age-related deficits in source monitoring (Johnson & Raye, 2000). More specifically, we proposed to examine the role of inhibition in the production of false memories.

This study reveals at least two important findings. These concern, (a) the link between inhibition (and its various components) and the production of CLs in a DRM paradigm (standard condition) including the mediating role of inhibition between Age and the production of CLs and (b) the link between inhibition and monitoring processes at retrieval (comparison of both instruction conditions).

Although ANOVAs showed that participants with a low level of inhibition produce fewer CRs but not, as expected, more CLs and SIs than those with a high level of inhibition, correlations highlighted that a high level of inhibition is associated with better recall of CRs and reduced production of CLs. The nonsignificant difference may be due to the very large *SDs* in the production of CLs (see Figure 1) that shows a large interindividual variability in the production of CLs in older people. This may also be because of an insufficient contrast between our two groups of participants. For example, about 40 participants had inhibition levels at more or less a half *SD* from the median. Despite this, the correlation results attest a link between the production of CLs and the level of inhibition. As expected, a high GIS is associated with better CRs and reduced production of CLs. Furthermore, although the Hayling

penalties enabled the production of CRs to be predicted by explaining 43% of the variance in their production, none of the four indicators is significantly correlated with the production of CLs (only the GIS allowed the production of CLs to be predicted).

This result questions the nature of the inhibitory mechanisms that are involved in the production of false memories. In their inhibitory deficit theory, Hasher and colleagues (Hasher & Zacks, 1988; Hasher et al., 1999; Lustig et al., 2007) distinguished three aspects of inhibitory control: access, deletion, and restraint. Inhibition controls access to working memory by preventing any activated but goal-irrelevant information. Deletion decreases the activation in working memory of information that has become irrelevant, while restraint prevents the strong responses available from being produced before others have been considered. On the basis of this model, Feyereisen and Charlot (2008) showed that declines in inhibition were not uniform but varied depending on task-specific characteristics: the decrease was greater for the functions of deletion (directed forgetting and listening span word tasks) and restraint (Hayling and Stroop-like tasks) than for the access function (problem-solving task and reading with distraction). However, in the present study, specific functions related to the production of false memories are still poorly identified. Only the restraint function, as measured by the Hayling task (penalties), seems to be particularly associated with the production of CRs. According to Hasher et al. (1999), the restraint function prevents the available strong responses from being produced before others have been considered. Thus, as suggested by Waldie and Kwong See (2003), false memories may result from uncontrolled intrusions of dominant responses at output. Older adults may thus be less efficient at inhibiting responses to the automatically activated nonpresented lure (deletion function). Further research seems necessary to retest the role of each function of inhibition. Furthermore, the deletion function, measured by the directed forgetting task, is correlated neither with the production of CRs or with that of CLs. This function, which decreases the activation of information in working memory that has become irrelevant, does not seem to be involved in the production of CRs or CLs. In the same way, no partial correlation is significant for the SIs. This result suggests that the relationship between inhibition and SIs is different from that between inhibition and production of CLs.

All these elements indicate that the link between inhibition and production of false memories seems relatively fragile and we cannot rule out the possibility that the measure of inhibition is an index of more general cognitive functioning, allowing participants to implement effective encoding strategies that will later be helpful for monitoring CLs. This suggestion is consistent with previous research on the relationship between inhibition and false recall in older adults (Lövdén, 2003; Sommers & Huff, 2003). Lövdén suggested that inhibition affects the frequency of false memories indirectly via episodic memory performance. Sommers and Huff (2003, Exp. 2) reported that older participants may have a reduced ability to inhibit activation levels on CLs. Because inhibitory abilities accounted for a relatively small percentage of the total variance in false memories, the authors suggested that other factors must therefore contribute to individual differences in susceptibility to false remembering. Following these suggestions, episodic memory, executive functions, attentional resources, and processing speed seem especially interesting paths to follow to understand the link between inhibition and production of CLs. Research seem

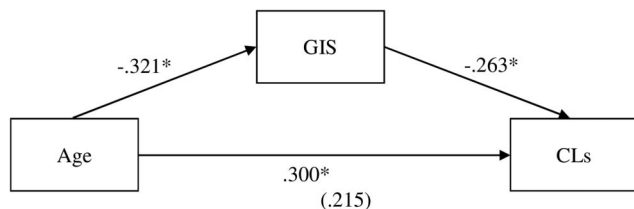


Figure 2. Standardized regression coefficients for the relationship between Age and the production of CLs as mediated by Inhibition. The regression coefficient between Age and the production of CLs, controlling for Inhibition is in parentheses. \*  $p < .05$ .



particularly necessary because our results show that the relationship between Age and the production of CLs is mediated by Inhibition. Thus, Inhibition seems to be one of the factors responsible for the increased production of false memories in the elderly.

Nevertheless, the originality of the present research was to use an inclusion condition to identify the loci of influence of inhibition. The comparison of the production of lures following a standard instruction, requiring the normal use of monitoring processes, with an inclusion instruction, explicitly telling the participants not to use monitoring processes, highlighted the inability of the elderly group with a low level of inhibition to implement effective controlled monitoring strategies. In fact, only this group showed no difference in the production of lures between the standard and the inclusion instruction, proving the inefficiency of their monitoring processes during the standard instruction condition (see Figure 1). Thus, the source monitoring processes, enabling the CLs (i.e., irrelevant but activated information) to be restrained and then deleted, could be more difficult to implement when inhibitory capacities have declined. This pattern of results was not found in the group with a high level of inhibition, thus, strengthening the link between difficulties in monitoring and level of inhibition.

These results support the activation-monitoring model (Roediger et al., 2001), which underlines the possible failure of the source monitoring process with advancing age during the retrieval of items of DRM lists. They may also be accounted for in the framework of the fuzzy-trace theory (Brainerd, Reyna, & Kneer, 1995). In general terms, these two theories envisage the involvement of two key processes in the production of false memories in the context of the DRM paradigm: (a) an automatic spreading of semantic activation (activation-monitoring theory) or of "gist" or semantic processing (fuzzy-trace theory) at the origin of the formation of false memories and (2) a source monitoring process (activation-monitoring theory) or "verbatim" or form processing (fuzzy-trace theory) that, if it is deficient, can no longer prevent the production of false memories.

The results of the present study can provide a link between the difficulties in implementing strategic processes (a monitoring process or verbatim processing) proposed by the theories mentioned above and the potentially reduced level of inhibition in older adults. We have shown that the level of inhibition could be one of the factors that acts at the time of retrieval of items of the DRM lists, weakening the source monitoring processes, and leaving the door open for the production of false memories. However, we cannot rule out the possibility that inhibition deficits may occur at a different stage of information processing because Dehon and colleagues showed that both young and older adults thought of CLs at the same rate at encoding (e.g., Dehon, 2006; Dehon & Brédart, 2004). Consistent with this idea, the analyses of the SIs indicated that low inhibitors produced slightly more intrusions than high inhibitors, but the comparisons were not significant.

It is also interesting that the pattern of results for the CRs is identical in the two instruction conditions. Therefore, the monitoring processes at retrieval do not participate in the production of CRs in the elderly, which seems mainly because of the activation process at encoding. A high level of inhibition could enable older people to encode better items that must be memorized. These results are supported by the positive correlation found between two specific indicators of inhibition (Hayling penalties and latency in addition to GIS) in the standard condition and three specific indicators (Stroop interfer-

ence, Hayling penalties and directed forgetting in addition to GIS) in the condition of inclusion.

Overall, our results support the idea that the source-monitoring deficit in older adults, the main factor responsible for the occurrence of false memories in the DRM paradigm, can be partly explained by a deficit in inhibition. Inhibition abilities contribute, at least partly, to the age-related increase in the production of false memories. More specifically, analyses showed for the first time that the age-false memories association was mediated by a measure of global inhibition capacities. The comparison of both instruction conditions enables the loci of influence of the level of inhibition to be identified; older low inhibitors have difficulty in strategic monitoring processes at retrieval. This link between inhibition and monitoring processes at retrieval is probably not direct. The role played by inhibition might be primarily mediated by the influence of a more general cognitive functioning (speed processing, attentional resources, episodic memory, and executive functioning). Future research is needed to examine this issue further. Finally, the different facets of inhibition also need to be investigated to understand better which function is specifically responsible for part of the deficit in the monitoring processes during the retrieval of information in the DRM paradigm.

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