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Lina Guerrero Sastoque, Michel Isingrini, Lucie Angel, S. Fay, Laurence  
Taconnat, Badiâa Bouazzaoui

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Effect of self-reported internal memory strategy use on age-related episodic and working  
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Lina Guerrero, Michel Isingrini, Lucie Angel, Séverine Fay, Laurence Taconnat & Badiâa

Bouazzaoui

Université de Tours, Université de Poitiers, UMR CNRS 7295, « Centre de Recherches sur la  
Cognition et l'Apprentissage (CeRCA) », France

Address Correspondence to:

Lina Guerrero

UMR CNRS 7295 CeRCA,

Université de Tours

3 rue des Tanneurs, BP 4103 37041 Tours Cedex 1, France

Adresse mail: [lina.guerrero@univ-tours.fr](mailto:lina.guerrero@univ-tours.fr)

## **Effect of self-reported internal memory strategy use on age-related episodic and working memory decline: Contribution of control processes**

### **Abstract:**

We explored whether control processes could account for age-related differences in internal strategy use, which in turn would contribute to episodic and working memory decline in aging. Young and older adults completed the internal strategy subscale of the Metamemory in Adulthood (MIA) questionnaire, a free-recall task (FRT), a reading span task (RST), and three executive control tasks (the Wisconsin Card Sorting Test, the Initial Letter Fluency Test and the Digit Symbol Substitution Test) allowing us to calculate a composite index of control processes. Results indicated that both self-reported internal strategy use and control processes index accounted for a significant proportion of the age-related variance in the FRT and the RST. However, once control processes index was controlled for, variance in both FRT and RST explained by internal strategy use were significantly reduced. Additionally, age-related variance in internal strategy use was mediated by the control processes index. These results suggest a cascade model in which individual control level would mediate age-related differences in internal strategy use, which in turn would mediate age-related differences in episodic and working memory performance.

### **Keywords**

Aging, internal strategies, control processes, episodic memory, working memory.

## **Public Significance Statements**

Control processes play a crucial role in episodic and working memory functioning. These processes could be considered as a cognitive resource sustaining internal strategy implementation. Deficits in control processes in older adults would be responsible for the age-related decline in internal strategy use, thereby contributing to episodic and working memory decline in aging.

### *1.1 Episodic and working memory in aging: the role of control processes*

Research in aging cognition has consistently shown that normal aging is characterized by episodic and working memory decline (for reviews see Balota et al., 2000; Craik & Jennings, 1992; Zacks et al., 2000), due to structural and functional neural modifications (Craik & Rose, 2012; Grady, 2012; Nyberg et al., 2012). According to the Craik and Bialystok framework (2006, 2008) cognitive performance would rely on control processes, consequently, deficits on these processes across lifespan would determine age-related cognitive changes. Control processes correspond to a set of fluid operations (Catell, 1963), involved in flexible behavior, problem solving and executive and adaptive operations (Elliot, 2003). Concerning episodic and working memory, control processes are postulated as mainly involved in strategy implementation (Bouazzaoui et al., 2010; Guimond et al., 2017; Shimamura, 1995; Tacconnat et al., 2006, 2007, 2009; Ward & Tan, 2019).

Control processes increase from childhood up to adulthood, and then gradually decline with aging (Craik & Bialystok, 2006). In line with the Craik and Bialystok framework (2006, 2008), the executive deficit hypothesis (West, 1996) assumes that episodic and working memory decline in aging could be the result of an impaired functioning of the prefrontal cortex, which is particularly affected by the age-related neural changes (Reuter-Lorenz et al., 2016). Prefrontal cortex supports top-down executive control processes, and it is implicated in adaptive and flexible behaviors facilitating goal attainment (Kesner & Churchwell, 2011; Miller & Cohen, 2001; Yuan & Raz, 2014). Recent functional imaging studies exploring memory processes in aging have revealed that older adults exhibit a greater activity than the younger adults at the prefrontal cortex (Angel et al., 2016; Qin & Basak, 2020; Reuter-Lorenz & Cappell, 2008), reflecting possibly a greater recourse to control processes (Craik & Rose, 2012). This greater reliance in the frontal cortex and in the control processes has been interpreted as a possible compensation mechanism allowing to improve memory

functioning and to cope with age-related memory deficits (Bouazzaoui et al., 2013, 2014; Craik & Rose, 2012; Davis et al., 2008; Gombart et al., 2017).

### *1.2 Control processes and internal strategy use*

Memory strategies are defined as cognitive operations implemented at encoding or retrieval, helping improve information storage and retrieval. They are classically classified into two broad categories, external and internal (Bouazzaoui et al., 2010; Dixon & Hultsh, 1983a). External strategies are memory aids based on the use of external supports (e.g., shopping lists, appointment book, notes), whereas internal strategies involve mental processes initiated by the individual in order to increase memory processes efficacy. This study focused on this last type of memory strategies because in contrast to external strategy use, internal strategy use is considered as a more effortful dependent process, relying on control processes (Bouazzaoui et al., 2010; Braver & West, 2008; Dixon, 1988; Lovelace & Twohig, 1990).

Additionally, it has been well established that implementation of appropriate internal memory strategies during encoding and retrieval is crucial for an optimal episodic and working memory performance (e.g. Bailey et al., 2014; Burger et al., 2017; Dunlosky & Kane, 2007; Gross & Rebok, 2011; Kaakinen & Hyona, 2007; McNamara & Scott, 2001; Saczynski et al., 2007; Touron et al., 2010; and for a review see Kirchhoff, 2009; Shing et al., 2010). Precisely, control processes contributes to internal strategy implementation by supporting different high order mental memory operations as generation and maintain of abstract representations, memory goals attainment through complex operation sequences and implementation of efficient encoding and retrieval processes. In line with this idea, it has been shown that prefrontal cortex sustaining control processes is also implicated in strategy implementation (Gouveia et al., 2007; Kirchhoff et al., 2014).

There are numerous evidence that older adults have difficulties to implement internal strategies when assessing strategy use with concurrent or retrospective self-reports during a given memory task (Dunlosky & Hertzog, 2001; Froger et al., 2012; Hertzog et al., 1998; Hertzog et al., 2010; but see Bailey et al., 2009 for different results) or self-report questionnaires about strategies used in everyday life (Bouazzaoui et al., 2010, Frankenmolen et al., 2018; Guerrero et al., 2019). Several studies using either a direct (strategy assessment during a memory task) (Abellán-Martínez et al., 2019; Bryan et al., 1999; Parkin & Walter, 1992; Souchay & Isingrini, 2004; Tacconnat et al., 2006, 2007, 2009) or indirect (self-report of strategy use in daily life) (Bouazzaoui et al., 2010) self-report measures of strategy use have shown that the age-related decline in internal strategy use is explained by the age-related deterioration of control processes.

### *1.3 Internal strategy use and episodic memory and working memory functioning in aging*

According to the aging memory strategy-deficit hypothesis (see Bailey et al., 2009; Dunlosky & Hertzog, 2001; Naveh-Benjamin et al., 2007), age-related deficits in strategy use would contribute to explain episodic and working memory loss in aging. Evidence from different studies (e.g., Dunlosky & Hertzog, 1998; Forsberg et al., 2019; Froger et al., 2012; Naveh-Benjamin et al., 2007; Shing et al., 2010; Greene et al., 2020; Guerrero et al., 2019; Tacconnat et al., 2007) have suggested that age-related decline in episodic and working memory could be the result of a deficient strategy use. However, other studies have not revealed a mediation role of internal strategy use in age-related differences in episodic and working memory (Bailey et al., 2009; Hertzog et al., 1998; Hertzog et al., 2010).

For instance, Hertzog et al. (1998; 2010) assessed strategy use with retrospective self-reports (use mentioned spontaneously and/or in response to a direct question) after a recall task. Both studies showed that a larger proportion of younger than older adults reported using effective internal relational strategies and that older and younger adults who used more

effective strategies performed better than those using less effective strategies or no strategy. However, effective strategy use did not account for age differences in recall performance. Regarding working memory, Bailey et al. (2009) also used retrospective self-reports of strategy use after two working memory tasks (reading span and operation span). The results indicated that young and older adults reported using the same proportion of effective strategies (e.g., interactive imagery or sentence generation) in both span tasks, and that the two age groups benefited similarly from using effective strategies. Consequently, variance in working memory performance was not accounted for by age differences in effective strategy use. These studies used self-reports of strategy use for a current memory task, and this approach could have some limitations. Indirect questions about strategy use (e.g. “*Which factors helped you remember words?*” ) used in some of these studies can lead to pass over participants that have used strategies but did not report to use them because they are not asked directly to do it (Hertzog et al., 1998). In contrast, the use of direct questions about strategy use concerning a particular memory task could persuade participants that strategy use is desirable and increase strategy use reports even when they have not been actually implemented (Desirability bias, Perinelli & Gremigni, 2016).

In the present study, we used a more general and independent self-report measure of internal strategy use, with a questionnaire about internal strategy use in daily life (Metamemory In Adulthood questionnaire, MIA, Dixon et al., 1988). The objective was to obtain a multidimensional, global and naturalistic measure of internal strategy use, providing an estimation of the general capacity to implement internal strategies in daily life. Note that some authors have observed that this kind of questionnaires are suitable tools to tap real-world or everyday memory strategies, leading to a more naturalistic estimation of strategy use (Dixon et al., 2003). It would also contribute to overcome difficulties associated to indirect and direct questions used by previous studies examining self-reports of strategy use



during the memory task. In fact, given that these questionnaires are not presented at the same time as the memory task and that they are not related to it, desirability bias would be less likely. Thus, in that case, direct questions asking specifically about strategy use can be used, preventing limits from indirect questions. Additionally, concurrent self-reports of strategy use during the memory task could induce reactive effect. It refers to participants who decide to implement a strategy because it has been questioned about it in previous trials. MIA internal strategy use would allow also to reduce this reactive effect.

#### *1.4 Aims and hypothesis*

In sum, previous studies revealed (1) that the age-related decline in both internal memory strategy use and control processes could account for episodic memory and working memory deficits, and (2) that age-related decline on control processes may contribute to internal strategy deficits in aging. However, to our knowledge, no studies have yet explored at the same time the contribution of everyday internal strategy use and control processes to the age-related differences in episodic and working memory. Considering that the internal strategy use is a resource-demanding control process, we extended the memory strategy-deficit model (see Bailey et al., 2009; Dunlosky & Hertzog, 2001; Naveh-Benjamin et al., 2007) by including the control processes. Thus, the aim of this study was to examine whether control processes are a mediator of the age-related decline in everyday internal strategy use, which would then mediate the age-related episodic memory and working memory decline.

To test this model, we examined responses to the internal and the external strategy use subscales of the MIA (Dixon et al., 1988). Control processes are considered as a multidimensional construct involving different cognitive processes. Consequently, we calculated a composite index combining the scores of three tasks expected to measure control processes (the Wisconsin Card Sorting Test, Nelson, 1976; the Initial Letter Fluency

Test, Stuss & Benson, 1986; and the Digit Symbol Substitution Test, Wechsler, 1997). This index including different dimensions of the executive control functioning allowed us to reflect in some extent the multidimensional nature of the control processes. Two memory tasks, a free-recall task to assess episodic memory, and a reading-span task to measure working memory were used. Performance at these tasks is influenced by strategy use (Becker & Lim, 2003; Dunlosky & Kane, 2007; Friedman & Miyake, 2004; Grenfell-Essam & Geoff, 2012; Hertzog et al., 1998; McNamara & Scott, 2001; Turley-Ames & Whitfield, 2003) and they have been used by previous studies exploring the strategy-deficit hypothesis (Bailey et al., 2009; Hertzog et al., 1998).

Bouazzaoui et al. (2010) demonstrated that the age-related decline in self-reported internal strategy use is explained by age-related executive control deficits. The present study allows us to extend Bouazzaoui et al. (2010) results, by exploring not only the relationship between control processes and memory strategy use, but also their impact on the age-related decline in episodic and working memory abilities. To this end, firstly, we examined whether internal strategy use and the control processes constitute significant mediators of the age-related differences in episodic and working memory. We expected to observe an age-related deficit in internal strategy use in daily life (Bouazzaoui et al., 2010; Frankenmolen et al., 2018; Guerrero et al., 2019) that would contribute to explain at least partly the age-related episodic and working memory decline (e.g., Dunlosky & Hertzog, 1998; Forsberg et al., 2019; Froger et al., 2012; Naveh-Benjamin et al., 2007; Shing et al., 2010; Greene et al., 2020; Guerrero et al., 2019; Tacconnat et al., 2007). Furthermore, in line with Craik and Bialystok's model (2006, 2008) and with the executive hypothesis (West, 1996), we expected that control processes would determine age-related changes in episodic and working memory ability, and that age-related decline in control processes would contribute to episodic and working memory loss in aging. Secondly, we explored whether internal

strategy use continued to account for age-related memory decline after controlling for control processes. Control processes are thought to be crucial resources for internal strategy implementation. Consequently, we expected that control processes decline with aging would contribute to the age-related deficits in the internal strategy use, which would then affect episodic and working memory performance. If it is the case, the age-related episodic and working memory variance explained by the internal strategy should be reduced to a non-significant level when control process are controlled for. To better explore this hypotheses, we also verified whether control processes constitute a significant predictor of the age-related decline of everyday internal strategy use.

Note that the external strategy subscale, measuring the use of external supports facilitating information retrieval (e.g., shopping lists, appointment book, notes), was included in this study as a control condition. This comparative approach permitted to ensure that it is specifically the use of internal strategy (*self-initiated mentally processes*), which would rely on control processes, and would contribute to explain age-related episodic and working memory decline. Then, it was expected that external subscale would not be associated to episodic and working memory and/or control processes.

## **2. Method**

### *2.1. Participants.*

A total of 107 French-speaking volunteers, living in a medium-sized town, participated in the study after providing their informed consent. Participants were divided into two age groups (G1: young,  $n = 44$ , range 25 - 45 years; G2: older,  $n = 63$ ; range 60 - 80 years). All reported themselves to be in good physical and mental health and free from medication known to affect the central nervous system. The Mini-Mental State Examination (MMSE, Folstein et al., 1975) was used to screen for cognitive dysfunction and/or preclinical dementia in older adults. All older participants achieved scores over the cut-off of 27 points

on this test. The participants' characteristics by age group and the results of group comparisons are summarized in Table 1. The proportion of males to females (Young: 24 M/20 F; Older: 31 M/32 F) was roughly equivalent in the two groups [ $\chi^2 = .30$ , ns]. A significant effect of age was found on education level (number of years of formal education), reflecting classic age-related cohort differences. However, older adults performed better than younger ones on the information test of the WAIS III (Wechsler, 1997), which measures general knowledge, suggesting that despite a lesser educational level older adult had a higher cultural level than younger adults (e.g. Albinet et al., 2012; Gombart et al., 2016; Touron & Hertzog, 2004). The Geriatric Depression Scale (GDS; Yesavage et al., 1983) was used to measure depressive symptoms; no age-related difference was observed for this measure. This study received the approval of the ethics committee of the University of Tours (France).

Table 1. Participants' Characteristics by Age Group

	Young (n = 44)	Older (n = 63)	<i>F</i> (1-105)
	M (SD)	M (SD)	
Age	36.82 (6,15)	69.24 (5.54)	
Educational level	14.98 (3.66)	11.67 (4.25)	17.57***
Cultural level (IT)	21.25 (1.89)	25.17 (1.77)	119.94***
Depression score (GDS)	6.61 (3.56)	7.49 (4.89)	1.03 ns

Note: ns = not significant, \*\*\* $p < .001$ ; IT = Information Test; GDS = Geriatric Depression Scale

## 2.2. Materials and design

Participants were evaluated in a single session in a quiet room convenient for them. At the beginning of each session, participants were interviewed and then screened with the MMSE. After that, they performed the Free-recall and the Reading Span tasks. Then, the three executive control tasks were achieved. Afterward, they performed the information test

and then they completed the internal strategy and the external strategy subscales of the MIA and the GDS.

### Memory tasks

We administered two memory tasks, one for episodic memory (Free Recall) and one for working memory (Reading Span).

*Free-Recall Task (FRT)* – In this test, stimuli were 36 common nouns presented on a computer screen for 5 s each. Participants were instructed to learn the words for a subsequent free-recall test. The presentation was immediately followed by a 1-min back-counting interference task. Participants then had to orally recall the previously learned items in their own time. The score was the proportion of correctly recalled words.

*Reading Span Task (RST)* – This complex span task is one of the most widely tests used to assess working memory (Daneman & Hannon, 2007). We used the short version of the French adaptation of the Reading Span Test (Daneman & Carpenter, 1980; Desmette et al., 1995), which consists of 3 sets of 20 sentences organized in 5 successive blocks of 2, 3, 4, 5 and 6 sentences presented on a computer screen. Participants were instructed to read the sentences aloud, without pausing between the sentences of each block. They were instructed to memorize the last word of each sentence, and to recall them at the end of each block. For each set, the presentation started with the block of 2 sentences and continued up to the 6-sentence block. Following the presentation of each block, the participant had to recall the last word of each component sentence of the block. Whether the responses were correct or not for a given block, the next block was presented until the end of the set, followed by the next set. The participants were familiarized with the procedure with a block of 2 sentences and then a block of 3 sentences that did not count towards the final score, which was the percentage of correctly recalled words in relation to the total number of sentences. A total of 55 words could be recalled.

### Strategy questionnaire (Metamemory in Adulthood questionnaire, MIA)

In its usual form, this questionnaire (MIA, Dixon et al., 1988) has eight subscales (*Task, Capacity, Change, Anxiety, Achievement, Locus of control, External Strategy, and Internal Strategy*) measuring memory functioning and knowledge about general memory processes. In this study, we used the internal and the external strategy subscales of the French version of the abridged MIA (Boucheron, 1995; Fort, 2005), which reproduces the factorial structure of the original questionnaire. Internal consistency assessed with Cronbach's alpha is reliable for internal and external strategy subscales (.80 and .77 respectively). The participants rated statements on a 5-point Likert scale (1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5=always). The External Strategy subscale measures self-reported frequency of use of external memory aids in daily life (ESU; e.g., making a shopping list, writing down appointments on a calendar) using 6 items (e.g., “How often do you write down in a notebook things that you want to remember?”), giving a maximum score of 30. The internal strategy subscale measures self-reported frequency of internal mnemonics use (ISU, e.g., mental retracing, forming visual images) using 8 items (e.g., “How often do you create a visual image of something you want to remember, like a name and a face?”), with a maximum score of 40. A total score was calculated for each participant; high scores indicate frequent use of a given strategy.

### Control Processes

Control processes were assessed with three widely used executive control tasks (Cepeda et al., 2013; Davis & Pierson, 2012; Lezak, 1995)

*Wisconsin Card Sorting Test (WCST-Modified; Nelson, 1976)*. This test measures set formation and attention shifts, and it has been widely used in literature to explore control abilities (e.g. Bouazzaoui et al., 2014; Salthouse et al., 2003; Stuss & Alexander, 2000). In this standardized test, participants have to sort cards containing multidimensional drawings

in one of three dimensions (color, shape & number of geometric patterns). Sorting criterion must be inferred through the feedback provided by the experimenter (“right” or “wrong”). This task is assumed to measure cognitive flexibility, set shifting and problem solving. Several scores reflecting executive processes can be obtained from this test; in this study, we used the total number of perseverative errors, which is widely used to assess switching abilities and is the most affected by age (Salthouse et al., 2003; Tacconnat et al., 2006; Tacconnat et al., 2007).

*Initial Letter Fluency Test (ILFT; Stuss & Benson, 1986).* Fluency tests are extensively used in the literature to assess control processes. We were particularly interested in this task because it requires the executive processes of strategic retrieval search and monitoring operations (Bryan & Luszcz, 2000; Parker & Crawford, 1992). In this task, participants are given one minute to produce as many words as possible beginning with a specific letter, avoiding names of people or places and repetitions. The initial letters were F, A and S. The score was the total number of correctly produced words for the three letters.

*Digit Symbol Substitution Test (DSST) (WAIS III, Wechsler, 1997).* It is one of the neuropsychological tests the most extensively used and validated in the literature (Jaeger, 2018) which measures both executive processes and perceptual and graphomotor speed (Baudouin et al., 2009). In this test, participants are given a sheet of paper with a key containing nine two-dimensional geometric symbols each paired with a number between 1 and 9. They are then presented with a row of symbols and asked to add the corresponding digit for each symbol, referring to the code table. The score was the total number of correct symbols completed in 90 seconds.

A composite index was calculated to reduce control processes data. First, we carried out an Oblimin rotation (Varimax) principal component analysis on the control scores in order to examine whether the three measures loaded on the same factor. The factor analyses

indicated that the three measures loaded on a single factor (eigenvalue greater than one), reflecting control processes. The factor loadings were .89; -.89, and .91 for the WCST, ILFT and DSST, respectively. These results enabled us to compute a composite control score for each participant. Before calculating this index, the sign of the WCST scores were inverted to make sure that the three control processes measures would vary in the same way. The composite control index corresponded to the average of the z-scores of the three control measures. A higher control index indicates a good level of control processing.

### **3. Results**

Statistical analyses were carried out using STATISTICA software (version 13). Given that older adults had a lower educational level than younger ones, the number of years of education was introduced as a covariate in all the analyses. Preliminary analyses were conducted to examine the classic effect of age group on the two memory measures (FRT and RST), on the MIA internal and external strategy use measures (MIA-ISU), and on the control processes index (CPI). We then analyzed correlations between internal and external strategy use (MIA-ISU), control processes index and performance on both episodic and working memory tasks after partialling out age variable, in order to explore whether these measures were associated regardless of age. Additionally, to identify the best cognitive model accounting for age-related differences in episodic and working memory performance, a series of regression analyses were conducted. First, we examined whether the internal strategy use and the control processes variables significantly mediated the age-related differences in Free Recall and Reading Span performance. Secondly, we explored whether internal strategy use continued to account for age-related memory decline after controlling for control processes. The final regression analysis explored whether control process level contributed to the age-related decline of everyday internal strategy use. We specifically examined the hypothesis that control processes mediate the effect of age on everyday



internal strategy use, which in turn would mediate age-related variance on episodic memory and working memory performance.

*3.1. Age-related differences in memory performance (FRT and RST), internal strategy use (MIA-ISU) external strategy use (MIA-ESU) and control processes (DSST, WCST, ILFT and CPI)*

To explore age-related differences, a 2 age-group one-way analysis of variance (ANCOVA) was performed on episodic and working memory performance, MIA internal and external strategy use, and the control process measures. Educational level was entered as a covariate. Bonferroni correction was applied to correct for multiple comparisons, with the adjusted p-value value being set at 0.006 (0.05 divided by 8 comparisons). Table 2 presents mean scores on the Free Recall and Reading Span tests, the MIA internal strategy use and the control processes measures by age group, and results for group comparisons. Analysis revealed that age group had a significant effect on the two memory measures, older adults performing less accurately on both the FRT and the RST. The analyses also indicated a significant decrease in self-reported internal strategy use (MIA-ISU) in older adults. The opposed pattern was observed for external strategy use, with a significant increase of self-reported external strategy use (MIA-ESU) in older adults in contrast to younger adults. The results also showed a significant effect of the age group for the ILFT, the DSST, and the control processes index (CPI), indicating an age-related decline of control processes. The age-related deficit on the WCST ( $p = .02$ ) was no longer significant at the adjusted p-value for multiple comparisons.

Table 2. Means and Standard Deviations of memory performance (FRT and RST), Internal Strategy Use (MIA-ISU), External Strategy Use (MIA-ESU) and Control process measures (WCST, ILFT, DSST, and CPI) by age group

	Young (n = 44)	Older (n = 63)	F (1, 104)
	M (SD)	M (SD)	
FRT	.66 (.07)	.52 (.11)	46.79***
RST	.65 (.04)	.50 (.09)	84.54***
MIA-ISU	28.59 (1.62)	26.79 (2.48)	13.33***
MIA-ESU	18.29 (1.91)	20.79 (1.32)	53.42***
WCST	4.32 (3.28)	7.90 (7.21)	5.06 <sup>+</sup>
ILFT	35.25 (3.65)	27.90 (7.44)	23.04***
DSST	79.36 (6.35)	53.84 (15.24)	79.33***
CPI	.60 (.32)	-.42 (.93)	31.56***

Note: + p = .02; \*\*\* p < .001; FRT = Free Recall Task; RST = Reading Span Task; MIA-ISU = Internal Strategy Use; MIA-ESU = External Strategy Use; CPI = Control Processes Index.

p < 0.006 level of significance after Bonferroni correction.

### *3.2. Relationship between age, memory performance (FRT and RST), internal strategy use (MIA-ISU) external strategy use (MIA-ESU) and control processes (WCST, ILFT, DSST, and CPI)*

Partial Pearson correlations were calculated between the memory performance, the MIA-ISU, the MIA-ESU and the control processes measures (WCST, ILFT, DSST, and CPI) after age and educational level have been controlled for. The results are presented in Table 3. The Bonferroni correction for multiple comparisons was applied with the adjusted p-value being set at 0.001 (0.05 divided by 28 tests). Results indicated that internal strategy use and the control measures were positively and significantly correlated with memory performance; individuals who reported more frequent use of internal strategies or who had a

higher level of control processes also had better episodic and working memory performance. Concerning the relationship between the control processes measures and self-reported internal strategy use, the results revealed that MIA-ISU was correlated positively with the control processes measures; individuals who reported more internal strategy use in their daily life also had a higher control processes level. In contrast to MIA-ISU, as expected, results revealed that MIA-ESU was not correlated to episodic and working memory nor to control processes. Consequently, this variable was not included in regression analyses. Only the CPI was used in the following analyses as an indicator of control processes.

Table 3. Partial correlations between memory performance (FRT and RST), internal strategy use (MIA-ISU), external strategy use (MIA-ESU) and control processes measures (WCST, ILFT, DSST, and CPI) with age and educational level partialled out

	CPI	FRT	RST	MIA-ISU	MIA-ESU	WCST	ILFT
FRT	.62***	-					
RST	.62***	.51***	-				
MIA-ISU	.57***	.44***	.51***	-			
MIA-ESU	-.05	.01	.01	.01	-		
WCST	-.90***	-.53***	-.50***	-.48***	.03	-	
ILFT	.86***	-.53***	.52***	.51***	-.01	-.60***	-
DDST	.89***	.58***	.66***	.53***	-.11	-.75***	.66***

Note: \*\*\*  $p < .001$ ; FRT = Free Recall Task; RST = Reading Span Task; MIA-ISU = Internal Strategy Use; MIA-ESU = External Strategy Use; CPI = Control Processes Index  $p < 0.001$  level of significance after Bonferroni correction.

### *3.3. Mediating role of internal strategy use (MIA-ISU) and control processes (CPI) on age-related differences in FRT and RST*

As internal strategy use and control processes were correlated with the memory measures, we examined whether these variables could account for the age-group related differences in episodic memory and in working memory. When the number of years of education was entered in the regression analyses, the pattern of results for each tested model did not change, thus only results before the control of this variable are presented here. First, we conducted regression analyses to explore the potential mediation role played by internal strategy use (MIA-ISU) and control processes (CPI) on the relationship between the age-group and episodic and working memory performance. Five regression models for each memory task (FRT and RST) were tested (Table 4). A second series of regression analyses was computed to examine specifically whether control processes mediated age-related variance in internal strategy use (MIA-ISU) (Table 5). Correlations involving the age continuous variable could be overestimated because of the range of scores from the two extreme groups (young vs. old). Consequently, as suggested by Bryan and Luszcz (1996), the age variable was coded as a categorical variable rather than a continuous variable. All regressions analyses would be referred to the path model presented in the Figure 1, which accounts for the different hypothesis tested.

In Model 1, we examined the direct effect of the age-group on the episodic and working memory performance (path A in the Figure 1). When entered alone, the age-group predicted 36% ( $\beta = -.60$ ,  $t(105) = -7.66$ ,  $p < .001$ ) and 49% ( $\beta = -.70$ ,  $t(105) = -10.03$ ,  $p < .001$ ) of the variance of the episodic memory and the working memory performance respectively.

Model 2 tested the indirect effect of the age-group in memory performance through the internal strategy use (path A, B, C in the Figure 1). When entered alone, internal strategy

use was a reliable predictor of memory performance, accounting for 29% ( $\beta = .54$ ,  $t(105) = 6.59$ ,  $p < .001$ ) and 34% ( $\beta = .59$ ,  $t(105) = 7.43$ ,  $p < .001$ ) of the variance related to the episodic memory and the working memory performance respectively. When internal strategy use and the age-group were entered in the equation, internal strategy use explained 12% ( $\beta = .38$ ,  $t(104) = 5.01$ ,  $p < .001$ ) and 13% ( $\beta = .39$ ,  $t(104) = 6.05$ ,  $p < .001$ ) of the variance related to the episodic memory and the working memory performance respectively. The change in  $R^2$  for the age-group variable remained significant, but was reduced to 19 % for the episodic memory ( $\beta = -.46$ ,  $t(105) = -6.21$ ,  $p < .001$ ) and to 28% for the working memory ( $\beta = -.56$ ,  $t(105) = -6.05$ ,  $p < .001$ ). Accordingly, the age-group related variance was significantly reduced by 47% for the episodic memory ( $t(106) = -3.34$ ,  $p < .001$ ) and 43% for the working memory ( $t(106) = -3.43$ ,  $p < .001$ ). As the age-group related variance was not reduced to a non-significant level after partialling out internal strategy use, these results support the hypothesis of a partial mediation of internal strategy use on age-related differences in episodic and working memory performance.

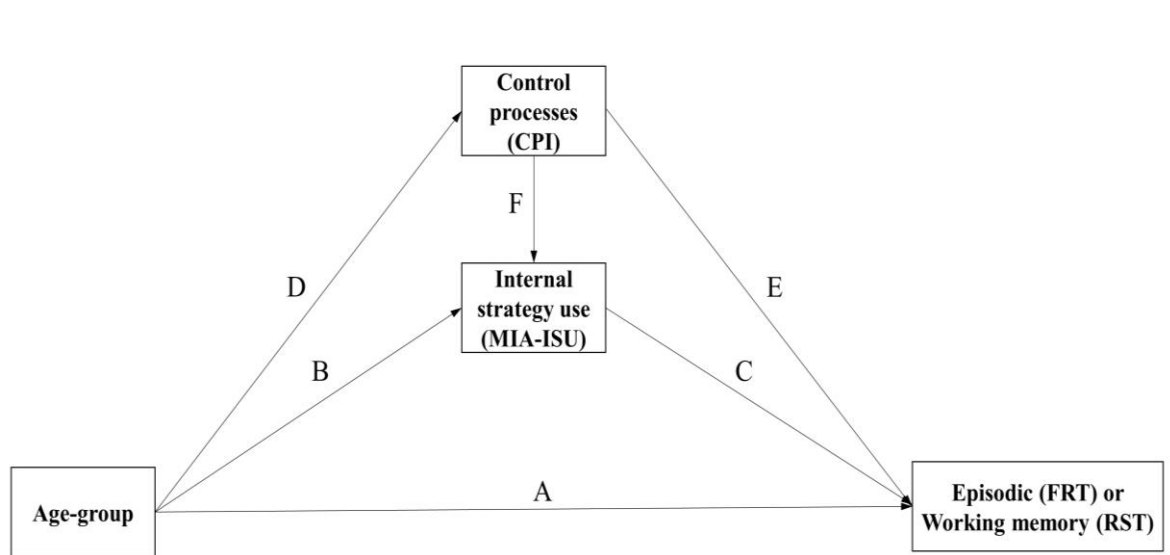
Model 3 tested the indirect effect of the age-group in memory performance through control processes (path A, D, E in the Figure 1). When entered alone, control processes explained 56% ( $\beta = .74$ ,  $t(105) = 11.47$ ,  $p < .001$ ) and 61% ( $\beta = .78$ ,  $t(105) = 12.79$ ,  $p < .001$ ) of the variance of the episodic memory and the working memory performance respectively. When control processes and the age-group were entered in the equation, control processes explained 24% ( $\beta = .60$ ,  $t(105) = 7.98$ ,  $p < .001$ ) and 22% ( $\beta = .56$ ,  $t(104) = -5.91$ ,  $p < .001$ ) of the variance related to the episodic memory and the working memory performance respectively. After partialling out control processes, the variance explained by the age-group was significantly reduced to 5% for the episodic memory ( $\beta = -.26$ ,  $t(104) = -3.49$ ,  $p < .001$ ) and to 10% for the working memory ( $\beta = -.38$ ,  $t(104) = -5.91$ ,  $p < .001$ ). Accordingly, the age-group related variance was reduced by 86% for the episodic memory and by 79% for the

working memory, suggesting that control process level partially mediated the age-group related variance in episodic and working memory performance.

Model 4 explored the concurrently amount of variance in memory performance accounted by control processes and internal strategy use (path E vs. path C relationship in the Figure 1). It showed that when control processes and internal strategy use were entered in the model, control processes was a reliable predictor for both episodic memory and working memory performance, accounting for 56% ( $\beta = .68$ ,  $t(104) = 8.02$ ,  $p < .001$ ) and 61% ( $\beta = .69$ ,  $t(104) = 8.73$ ,  $p < .001$ ) of the variance respectively. By contrast, internal strategy use did not continue to account reliably for this variance [Episodic memory: ( $\beta = .11$ ,  $t(104) = 1.26$ , ns); Working memory: ( $\beta = .15$ ,  $t(104) = 1.87$ ,  $p = .06$ )], suggesting that control processes mediated the variance related to internal strategy use in episodic and working memory performance.

Finally, Model 5 tested the indirect effect of the age-group in memory performance through the internal strategy use when control processes are included in the model (path A, B, C vs. path A, D, E in the Figure 1). It indicated that when the age-group, internal strategy use and control processes were entered in the equation, control emerged as the most significant predictor of the episodic memory and working memory performance, accounting for 13% ( $\beta = .52$ ,  $t(103) = 5.78$ ,  $p < .001$ ) and 10% ( $\beta = .46$ ,  $t(103) = 6.06$ ,  $p < .001$ ) respectively. The age-group continued to explain a significant amount of variance for these variables, but added only 5% ( $\beta = -.26$ ,  $t(103) = -3.53$ ,  $p < .001$ ) and 10% ( $\beta = -.38$ ,  $t(103) = 6.07$ ,  $p < .001$ ). After control processes was entered in the model, the amount of variance explained by internal strategy use was reduced to 1% for the working memory ( $\beta = .15$ ,  $t(103) = 2.28$ ,  $p < .05$ ) and to a non-significant level for the episodic memory ( $\beta = .11$ ,  $t(103) = 1.39$ , ns). These results suggest that age-group related variance in episodic and working memory performance is partially mediated by the internal strategy use and control

processes, but the latter seems to be the best predictor.



**Figure 1.** Path model accounting for the different relationships and mediation hypotheses.

The fact that internal strategy use did not add any variance once control processes index was entered in the equation for episodic memory and working memory suggests that control processes may also mediate the age-group related differences in the internal strategy use. To explore this hypothesis, a second series of analyses were carried out. First, we verified whether the age-group constituted a reliable predictor of control processes level, and secondly, we examined whether the age-group and control processes contributed to the internal strategy use variance (see Models 1-3 in Table 5).

Model 1 tested the direct effect of the age-group on the control processes (path D in the Figure 1). It showed that the age-group constituted a reliable predictor of control processes, explaining 36% ( $\beta = -.56$ ,  $t(105) = -7.01$ ,  $p < .001$ ) of the variance of this variable.

In Model 2, we tested the direct effect of the age-group on the internal strategy use (path B in the Figure 1). The age-group accounted for 12% ( $\beta = -.35$ ,  $t(105) = -3.84$ ,  $p < .001$ ) of the internal strategy use variance when entered as sole predictor.

Model 3 tested the indirect effect of the age-group in internal strategy use through control processes (path B, D, F in Figure 1). It showed that when the age-group and control processes were entered, only control processes proved to be a reliable predictor, accounting for 41% ( $\beta = .65$ ,  $t(104) = 7.13$ ,  $p < .001$ ) of the internal strategy use variance. The change in  $R^2$  for added age-group was reduced to a non-significant level ( $\beta = .02$ ,  $t(104) = .18$ , ns). Accordingly, the age-group related variance was reduced by 99%, suggesting that the age-related deficit in internal strategy use was strongly mediated by control processes. These results suggest, first, that the age-group contributes to the variance in control processes, and secondly, that the age-group related differences observed in internal strategy use are mediated by control processes.



Table 4. Regression analyses predicting episodic and working memory performances (FRT and RST) by Age-group, internal strategy use (MIA-ISU) and control processes Index (CPI)

Regression Models	Variables	Episodic memory				Working memory			
		$\beta$	R <sup>2</sup>	R <sup>2</sup> C	p	$\beta$	R <sup>2</sup>	R <sup>2</sup> C	p
1	Age-group	-.60	.36	.36	***	-.70	.49	.49	***
2	Age-group	-.46	.19	.19	***	-.56	.28	.28	***
	MIA-ISU	.38	.31	.12	***	.39	.41	.13	***
3	CPI	.60	.24	.24	***	.56	.22	.22	***
	Age-group	-.26	.29	.05	***	-.38	.33	.10	***
4	CPI	.68	.56	.56	***	.69	.61	.61	***
	MIA-ISU	.11	.56	.01	ns	.15	.62	.01	p=.06
5	CPI	.52	.13	.13	***	.46	.10	.10	***
	Age-group	.26	.18	.05	***	-.38	.20	.10	***
	MIA-ISU	.11	.19	.01	ns	.15	.21	.01	*

Note: \*p < .05; \*\*\* p < .001; R<sup>2</sup>C = R<sup>2</sup> change; MIA-ISU = Internal Strategy Use; CPI = Control Processes Index

Table 5. Regression analyses predicting Control processes (CPI) by Age, and internal strategy use (MIA-ISU) by Age-group and control processes index (CPI)

Regression Model	Variables	$\beta$	R <sup>2</sup>	R <sup>2</sup> change	p
Control processes Index (CPI)					
1	Age-group	-.56	.32	.32	***
Internal strategy Use (MIA-ISU)					
2	Age-group	-.35	.12	.12	***
3	CPI	.65	.41	.41	***
	Age	.02	.41	.00	ns

Note: ns: not significant; \*\*\*p <.001; CPI = Control Processes Index; MIA-ISU = Internal Strategy Use

#### 4. Discussion

The aim of this study was to test a cascade model in which control processes deficits in aging would account for the age-related variance in everyday internal memory strategy use, which would thus mediate age-related differences in memory and working performance. The main findings of the study can be summarized as follows. Episodic and working memory, internal strategy use and control processes decline with aging. Self-reported internal strategy use in daily life and control processes are involved in episodic memory and working memory functioning. Both of these processes constitute reliable mediators of the age-related decline in episodic and working memory. In line with the main objective of this study, results are consistent with the view that individual control processes are involved in the implementation of internal memory strategies in daily life. Age-related decline of control processes would explain reduced internal strategy use in aging, which would in turn mediate age-related differences in episodic memory and working memory performance.

#### *4.1 Age-related decline on episodic and working memory, internal strategy use and control processes*

First, the results confirm the classic age-related decline in episodic and working memory performance, in the frequency of internal strategy use and in control processes. The results of the present study, showing that the use of internal memory strategies in daily life decreases with aging, confirms those of previous studies using self-report methods (Bouazzaoui et al., 2010; Frankenmolen et al., 2018; Guerrero et al., 2019; Hertzog et al., 2010, but see Bailey et al., 2009 for a different result) and objective measures of strategy implementation (Dunlosky & Hertzog, 2001; Dunlosky et al., 2005; Froger et al., 2012; Naveh-Benjamin et al., 2007; Sauzéon et al., 2001; Taconnat et al., 2006, 2007, 2009). Effortful self-initiated processes, such as internal encoding and retrieval strategies, are considered as resource-demanding operations. Due to the age-related decline in processing resources, older adults would have more difficulty implementing this type of processes (Anderson & Craik, 2000; Craik, 1986, Craik & Byrd, 1982; Hasher & Zacks, 1979).

The results also confirm the classical effect of age on control processes (Braver & West, 2008; Craik & Bialystok, 2006, 2008; Dempster, 1992; Dennis & Cabeza, 2008; Manard et al., 2014; Moscovitch & Winocur, 1992; West, 1996). As proposed by Craik and Bialystok (2006, 2008), control processes would decline progressively during aging. This decline would be the consequence of deficits in the prefrontal cortex, which sustains complex and flexible goal-directed operations, and would be particularly sensitive to structural and functional neural changes in aging (Raz, 2000).

#### *4.2. Implication of control processes and internal strategy use on episodic and working memory performance*

We hypothesized that the free-recall and reading-span tasks, widely believed to be strategy-driven memory tasks, would be positively influenced by the level of internal

memory strategy use in daily life. This view was supported, as the results show that self-reported internal memory strategy use was correlated with performance in free recall and reading span tasks. These results suggest that people who use more internal strategies in their daily life would be more likely to implement efficient internal strategies in episodic and working memory laboratory tasks, improving their performance.

The present study confirmed the positive relationship previously observed between internal memory strategy use self-reports and measures of episodic memory (e.g. Dunlosky & Hertzog, 1998; Froger et al., 2012; Gross & Rebok, 2011; Hertzog et al., 1998; Hertzog et al., 2010; Saczynski et al., 2007 and for a review see Kirchhoff, 2009; Shing et al., 2010) or working memory (Bailey et al., 2009; Bailey et al., 2014; Dunlosky & Kane, 2007; Friedman & Miyake, 2004; Kaakinen & Hyona, 2007; McNamara & Scott, 2001; Touron et al., 2010; Turley-Ames & Whitfield, 2003). However, in contrast to these previous studies, strategy self-report was not here referred to a concurrent or a previous memory task. A subjective measure of internal memory strategy use in everyday life can be also associated to episodic and working memory performance in a laboratory task (Dixon & Hultsh, 1983b; Guerrero-Sastoque et al., 2017; Hultsh et al., 1985). The convergence of the results from objective and self-report measures of memory strategy use indicates that the capacity to self-initiate internal memory strategies is an important cognitive process that can help improve effortful memory operations. It is important to note that we observed that internal strategy but not external strategy use was correlated to episodic and working memory performances and to control processes, suggesting that only internal memory strategy use involves control processes (Bouazzaoui et al., 2010) and plays a specific role in memory processes.

Moreover, the control processes in our study were positively correlated with memory performance, as found in previous studies (Angel et al., 2010; Bouazzaoui et al., 2013, 2014; Engel & Kane, 2004; Glisky & Kong, 2008; Gombart et al., 2017; Isingrini et al., 2015;

McFarland & Glisky, 2009). This suggests that control processes could be considered as a cognitive resource sustaining memory performance, particularly in tasks requiring greater self-initiated processing, as in free-recall or working-memory tasks where environmental support is minimal and retrieval relies mainly on internal resources (Craik, 1986; Taconnat & Isingrini, 2004).

Concerning working memory, the reading span task used in this study could have some limitations that could potentially reduce the generalization of the results. Firstly, given that this task involves a verbal component, one could suggest that it could be more sensitive than other tasks (e.g. N-back) to age-related differences in vocabulary or fluency. In the present study, fluency was used to compute a multidimensional index of control, which included other tests that do not involve a verbal component. The use of this composite index could attenuate the potential impact of fluency in the reading span performance. Secondly, it could be considered that the version of the reading span task used in this study, in which the sentences set size increased gradually across trials can lead to a greater proactive interference. It could be more difficult for the participants to inhibit word of previous trials when the sentences are longer (May et al., 1999). As suggested by previous studies (Lustig et al., 2001), older adults would be particularly sensitive to this proactive interference, which would require to deploy supplementary control processes. Thus, it may be possible that the use of this format in this study lead to an overestimation of the implication of control processes in the working memory performance. Thirdly, reading span task used in this study requires remembering the last word of a sentence. In this case, working memory performance could be influenced by the reading comprehension ability. Versions of this task in which participants are asked to remember an information independent of the sentence, would allow to measure working memory performance independently reading comprehension. Finally, reading span task is considered as a verbal working task. It would

be interesting to explore whether strategy use and control processes involvement is the same for verbal and spatial working memory task, for instance by using other tasks such as the N-back test.

#### *4.3 Age-related decline in episodic memory and in working memory: role-played by control processes and internal strategy use*

Regarding the main aim of this study, the results showed that age-related differences in free-recall and reading-span tasks can be moderately but reliably accounted for by age-related limitations in internal memory strategy use in daily life and in control processes.

##### 4.3.1 Internal strategy use

The mediation effect of internal memory strategy use on the relationship between age and free recall, and between age and reading span tasks, although partial, suggests a specific pattern of relationships between aging, internal memory strategy use, and memory variables. Age-related decline in episodic memory and working memory performance would be explained by deficits in internal strategy use with advancing age. Use of internal memory strategies can thus be seen as a cognitive mechanism involved in effortful episodic memory and working memory functioning that can improve memory processes. These findings thus complement those of previous studies using objective measures of memory strategy use (Bryan et al., 1999; Dunlosky & Connor, 1997; Dunlosky & Hertzog, 1998; Souchay & Isingrini, 2004; Tacconnat et al., 2006, 2007, 2009), suggesting that age-related differences in memory performance are crucially dependent on the individual's capacity to implement effective internal memory strategies. They suggest that verbal-report questionnaires, which are supposed to assess the multidimensional nature of memory processes in everyday life, could constitute reliable tools to examine the aging memory strategy-deficit hypothesis.

We should point out that our results are different from those of Hertzog et al. (1998, 2010) and Bailey et al. (2009), who did not find a mediating role of internal strategies on the

effect of age on episodic memory and working memory. These discrepancies may be due to methodological differences, as the earlier studies (Bailey et al., 2009; Hertzog et al., 1998, 2010) used a retrospective self-report method to assess the type of strategy used in the memory task, whereas in our study, we used a general self-report questionnaire. Hertzog et al. (1998) used an indirect question about strategy use, asking participants whether they thought that strategy use had a positive impact on memory. However, some participants may have used strategies but failed to report them because they were not specifically asked to do so. In a later study, Hertzog et al. (2010) asked participants specifically about their strategy use in semi-structured interviews. However, the authors themselves suggested that the extensive face-to-face interview could have biased the results, as participants may have said that they used strategies even when they had not actually done so. This could also have been the case in the study by Bailey et al. (2009), in which direct questions could have persuaded participants that strategy use was desirable. Moreover, even if participants use internal strategies effectively in an experimental task, they will not necessarily self-initiate the same strategies in everyday life.

In the present study, the use of a general self-report questionnaire (MIA) to assess self-reported use of memory strategy, completed independently of the memory tasks, could have reduced this desirability effect, while also enabling us to assess the capacity to implement efficient strategies in daily life. Another possibility that could be suggested would be that the effect of laboratory instructions would be more likely to have an effect in individuals that usually use internal memory strategies in their daily life. It is possible that these individuals could be familiar in adapting their memory strategies to different contexts and probably they would be more likely to use it successfully in a laboratory task. One could also consider that internal strategies used by older adults in their daily-life have been improved through experience and practice in a naturalistic complex context. These strategies would be more

efficient and adapted for memory performance than item-specific strategies in a laboratory task. However, further studies exploring at the same time general self-report questionnaires (e.g MIA) and task-specific strategy reports are needed. This approach would allow to determine reliably whether one of these approaches constitutes a better indicator of strategy use and which of them could be considered as a better predictor of episodic and working memory performance. Moreover, it would be interesting to explore whether these approaches involve differential cognitive, motivational or emotional mechanisms.

It is important to note that self-reported memory strategy questionnaires are valid instruments for evaluating real-world memory strategy use (Dixon et al., 2003). Additionally, it has been shown that the scores at the internal strategy use subscale of the MIA are correlated significantly with measures of strategy implementation during a laboratory memory task (Guerrero et al., 2019). Nevertheless, as a self-report measure, it could be biased by conscientiousness in reporting or by the fact that individuals could interpret questions differentially. The advantage of the strategy subscale used in this study is that it proposes direct and simple questions about strategy use, corresponding to common situations that both age-groups encounter often in their daily live. This aspect of the strategy subscale would contribute to reduce misinterpretation and differential self-interpretation across age-groups.

#### 4.3.2 Control processes

It is widely accepted that control processes are cognitive resources underlying age-related memory decline. The results of the present study are consistent with this hypothesis and with previous studies showing that age-related variance of episodic and working memory performance is mainly explained by individual differences in control processes (Bryan et al., 1999; Moscovitch & Winocur, 1992; Shimamura, 1995; Taconnat et al., 2006, 2007, 2009; Van Gerven et al., 2007). It is also in line with Craik and Bialystok's framework



(2006, 2008), suggesting that the age-related decline in control processes could determine and contribute to cognitive changes during aging. Control is implicated in the selection, maintenance and adaptation of behavior in order to achieve a goal and in flexible cognitive operations. Thus, control processes would be an essential cognitive factor for strategy implementation.

#### *4.4 Involvement of control processes in internal strategy use*

Consistent with previous studies (Bouazzaoui et al., 2010; Shimamura, 1995; Taconnat et al., 2006, 2007, 2009), we showed that internal memory strategy use was linked to control processes. It is important to note that when control processes were controlled for, the variance explained by internal strategy use in both episodic and working memory performance was significantly reduced. This suggests that the deficit of control with aging is a reliable predictor of age-related memory decline. As found by Bouazzaoui et al. (2010), the regression analyses conducted in the present study show that deficits in internal strategy use in aging could be explained by an age-related decline in control processes. Our study complements the findings of Bouazzaoui et al. (2010) by introducing memory performance measures and exploring episodic and working memory performance, internal strategy use and control processes at the same time.

The results of the present study are consistent with the hypothesis that age-related decline in control processes in older adults is responsible for the deficits in implementing internal memory strategies observed in aging, thereby contributing to episodic and working memory decline. However, it is also important to consider that the link between control processes and episodic and working memory may rely in a direct mechanism independent of the internal strategy use (path E in Figure 1). Consistent with this idea, when both mediators (control processes and internal strategy use) were entered in the model, variance explained by the control processes remain significant. Thus, control processes would predict directly

the memory performance independently of the internal strategy use. Free-recall tasks and complex span tasks involve intrinsically control processes such as inhibition, updating or flexibility, which would be necessary to perform well these tasks.

This study contributes to extend the strategy-deficit hypothesis (see Bailey et al., 2009; Dunlosky & Hertzog, 2001; Naveh-Benjamin et al., 2007) by exploring control processes as a mechanism accounting for strategy decline in aging. The results suggest that strategy deficits observed in aging are not only the result of a production deficiency (Naveh-Benjamin et al., 2005; 2007; Schneider & Presseley, 1997; Verhaeghen & Marcoen, 1994). According to the production deficiency hypothesis, older adults are able to implement strategies effectively but they do not do it spontaneously. However, in the present study we showed that mechanisms inherent to strategy implementation, in this case control processes, would be impaired with aging. Control deficits would prevent older adults to implement efficient internal strategies during memory tasks. In the present study, we calculated a composite index for the control processes, including different executive control dimensions. It allowed us to capture the multidimensional nature of the control process concept. Conversely, a single measure was used for both the episodic and the working memory tasks. It would have been interesting to include also composite measures for both the episodic and the working memory. Even if episodic and working memory are less multidimensional than control processes, it would have allowed us to obtain a more robust measure of memory processing, contributing to improve the reliability of the present results. Relatedly, further studies could explore whether the link between the control processes and the internal strategy use in the age-related memory decline, varies as a function of the nature of the episodic and/or the working memory task.

Control processes would be implicated in strategy-related operations as the capacity to focus and maintain attentional resources on abstract representations, producing sequences of

behaviors and cognitive operations to achieve complex memory goals, implement adapted and flexible encoding and retrieval processes, and facilitate access to stored information (Bouazzaoui et al., 2010; Bryan et al., 1999; Tacconnat et al., 2006, 2007, 2009). Our results suggest that the use of internal memory strategies is a cognitive activity that plays a protective role and helps reduce age-related difficulties in performing highly strategy-demanding episodic and working memory tasks. A higher control level would allow older adults to implement efficient internal strategies enabling them to overcome their memory problems. Even if it seems very likely that daily life strategy use self-reports are a reliable indicator of strategy use during a laboratory task (Guerrero et al., 2019), it only constitutes an indirect estimation. One could not be entirely sure that daily life strategy use self-reports reflect entirely strategy use during a laboratory task. Consequently, it would be important to explore the cascade model tested in this study by assessing directly strategy implementation during the memory task. For instance, during the Free-recall task, it could be determined whether the participants use clustering strategies (organize words into related groups according to semantic, phonological or even subjective criterion), reflecting a more elaborated processing contributing to improve memory performance. It would be interesting to explore the link between these concurrent direct measures of the strategy use and the self-reported strategy use in daily life and whether these two measures rely differentially on control processes.

In sum, the present study reports three major findings. First, it shows that self-reported use of internal memory strategies and control processes are correlated with performance in effortful memory tasks such as free recall and working memory. Secondly, it shows that age-related differences in episodic memory (free recall) and working memory (reading span) tasks are mediated by the level of internal memory strategy use in daily life and by the level of control processes. Finally, the results suggest that the role played by internal strategy use

in the age-related decline of episodic and working memory can be explained by the age-related decline of control processes. These findings support the view that control processes play an important role during aging, enabling the implementation of efficient strategies to improve memory performance and reduce memory failure.

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