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Is episodic memory change in aging associated with level of control processes and rate of control change? A 4-year longitudinal study

Le changement de la mémoire épisodique au cours du vieillissement est-il associé au niveau des processus de contrôle et au taux de changement des processus de contrôle ? : étude longitudinale sur une période de 4 ans

Lina Guerrero, Badiâa Bouazzaoui, Emilie Alibran, Michel Isingrini & Lucie Angel.

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

Titre courant: Memory and control change in aging: a longitudinal study

E-mails: lina.guerrero@univ-tours.fr

bouazzaoui@univ-tours.fr

emilie.alibran@univ-tours.fr

michel.isingrini@univ-tours.fr

lucie.angel@univ-tours.fr

Address Correspondence to:

Lina Guerrero, UMR-CNRS 7295 CeRCA,

Université de Tours, Psychology Department

3 rue des Tanneurs, 37041 Tours, France

Email: lina.guerrero@univ-tours.fr

Phone: +33 02 47 36 64 08

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Abstract

Using a longitudinal approach, we explored whether memory change over a 4-year period is associated with level of control at baseline and with change in control processes. Participants were evaluated twice with an interval of 4 years. Memory performance was assessed by a cued-recall test, and control processes by the Excluded Letter Fluency Test. We calculated an individual cognitive change index for each measure. Results indicated that both episodic memory and control processes declined significantly over time. Correlational analysis showed that memory change was significantly correlated with change in control processes but not with the level of control at baseline. Regression analysis indicated that 18% of the memory change variance could be explained by the change in control processes, consistent with the hypothesis that the level of memory change over time varies as a function of the rate of control change.

Keywords

Aging, episodic memory, control processes, longitudinal approach.

Résumé

En utilisant une approche longitudinale, nous avons exploré si le changement de la mémoire au cours de 4 ans est associé au niveau de contrôle de base et/ou au changement du niveau de contrôle sur la même période. Les participants ont été évalués deux fois à 4 ans d'intervalle avec une tâche de rappel indicé (mémoire épisodique) et une tâche de fluence verbale (contrôle). Un indice individuel de changement cognitif a été calculé pour chaque mesure. Les résultats ont montré que la mémoire et le contrôle ont diminué de façon significative au cours du temps et que l'indice de changement de la mémoire était corrélé significativement à l'indice de changement du contrôle mais pas au niveau de contrôle de base. Des analyses de régression indiquaient que 18% de la variance de l'indice de changement de la mémoire était expliqué par l'indice de changement du contrôle. Ces résultats suggèrent que le niveau de changement de la mémoire au cours du temps varie en fonction du taux de changement du contrôle.

Mots-clés

Vieillesse, mémoire épisodique, processus de contrôle, approche longitudinale.

Introduction

The rate of episodic memory decline in aging varies significantly (Habib et al., 2007). This heterogeneity can be explained by neural and cognitive mechanisms (Stern, 2002, 2009), including control processes, which have been shown to account for age-related episodic memory decline (Angel et al., 2010; Baudouin et al., 2009; Bouazzaoui et al., 2014; Bugajska et al., 2007; Burger et al., 2017; Crawford et al., 2000; Maggio et al., 2019; McFarland & Glisky, 2009). The main objective of this study was to explore, using a longitudinal approach, whether change in control processes over a 4-year period and level of control at baseline were linked to episodic memory decline over the same period.

Control processes involve a set of fluid operations involved in intentional and flexible behaviors. They underlie complex cognitive operations that enable a goal to be attained in an adaptive and flexible manner (Elliott, 2003). According to Craik and Bialystok (2008), control processes are equated to executive functions and support episodic memory functioning through strategy implementation (Bouazzaoui et al., 2010; Bryan et al., 1999; Burger et al., 2017; Guimond et al., 2017; Taconnat et al., 2006, 2007, 2009). Control processes decline gradually with aging (Craik & Bialystok, 2008; Cacciaglia et al., 2017), which could be explained by prefrontal cortex impairment. The prefrontal cortex, supporting top-down control processes (Miller & Cohen, 2001), is one of the main brain areas affected by aging (Raz, 2000). In line with the executive hypothesis (West, 1996), memory change in aging would be the consequence of an age-related decline in control processes.

Several cross-sectional studies support the executive hypothesis by showing that age-related episodic memory decline is significantly mediated by control level (Angel et al., 2010; Baudouin et al., 2009; Bouazzaoui et al., 2014; Bugajska et al., 2007; Burget et al., 2017; Crawford et al., 2000; Maggio et al., 2019; McCabe et al., 2010; Troyer et al., 1994). Age-

related decline in episodic memory could be explained by control deficits arising with aging. However, there is relatively little evidence about this issue from longitudinal studies. This approach could confirm the results of cross-sectional studies using a more efficient methodological approach (Schaie & Hofer, 2001). Moreover, age-related memory variance explained by control in cross-sectional studies could reveal the impact of two dimensions that cannot be differentiated using this approach: the level of control at baseline and the rate of control decline. For instance, a high control level for an older adult in a cross-sectional study could reflect low rate of decline with aging, or a high rate of decline for somebody whose control level at baseline was very high. Thus, it would be interesting to distinguish between the impact of control level at baseline and that of the rate of control change, identifying which of these two factors is linked to episodic memory decline over time. This would help determine whether it is better to focus on level of control processes in adulthood and/or on the rate of their decline in order to prevent episodic memory decline.

As far as we know, only two longitudinal studies have explored directly the link between control processes and episodic memory change in aging (Clark et al., 2012; Goh et al., 2012). Clark et al. (2012) showed that the level of control processes at baseline is a reliable predictor of episodic memory change over a one-year period. However, that study did not provide evidence about the link between the rate of change of episodic memory and of control processes with aging. Goh et al. (2012) explored this issue directly, by examining whether changes in control processes over a 14-year period were associated with memory change. They explored different dimensions of control (chunking, discrimination, abstraction, inhibition, phonological retrieval, semantic retrieval and switching). Results indicated that episodic memory change over time was only related to change in two dimensions: chunking (semantic clustering) and semantic retrieval (categorical verbal fluency). One of the main limitations of that study is that the practice effect was not controlled for; consequently, it is

possible that the multiple evaluations over the 14-year follow-up period could have affected the pattern of cognitive change. In fact, Goh et al. (2012) observed that performance on some tasks either improved or did not change over time.

The practice effect refers to performance improvement across multiple evaluations due to the repeated experience of the test (Rönnlund et al., 2005), which could lead to underestimating age-related cognitive decline. Previous experience of a task could improve performance through different mechanisms, such as a decrease in anxiety in the test situation, familiarity with the material, or improved task-related skills. As shown by Wilson et al. (2002), practice distorts measures of cognitive change rate in longitudinal studies and should thus be controlled for. The practice effect could be reduced by using different methodological strategies, such as alternative task versions or longer intervals between tests, but even under these conditions, the practice effect can disguise cognitive decline (Kausler, 1991). Consequently, different methods have been proposed to adjust longitudinal scores and to reduce the practice effect error (Basner et al., 2020; Racine et al., 2018). One of these methods consists of estimating the practice error by comparing the mean score of the longitudinal sample at T2 with the mean scores of a cohort-matched sample (reference sample), who have been assessed only once (Kausler, 1991; Schaie, 1987, Racine et al., 2018). Mean scores of the reference sample would reflect a reliable estimation of the cognitive performance expected for a given group without the progressive error linked to the practice effect. Consequently, differences between the longitudinal and the reference sample could be used as a correction factor to adjust the longitudinal scores. Racine et al. (2018) found this method to be a reliable and straightforward way of adjusting longitudinal scores. One of its main advantages is that the same constant error estimation derived from the reference sample is applied to every participant in the longitudinal sample. Thus, the scores

rank is not modified by the adjustment and the estimation would not be correlated to other variables.

Given the importance of controlling for the practice effect, the main aim of this study was to determine the role of control processes in age-related episodic memory decline, without this potential bias, taking a longitudinal approach. We examined whether memory change over a 4-year period is associated with the level of control at baseline and/or to control change over the same period. Episodic memory was evaluated with a Word-Stem Cued-Recall Test (WSCRT). Given that control processes are defined as a multidimensional concept, we used the Excluded Letter Fluency Test (ELFT, Bryan et al., 1997), considered as a global measure of control functioning involving different dimensions (strategic retrieval search, performance monitoring, inhibition and working memory) (Bryan et al., 1997; Stolwyk et al., 2015). Scores in the follow-up session were corrected for practice effects using the method proposed by Kausler (1991). In line with previous longitudinal studies, which revealed changes in episodic memory and control processes over periods of 4 to 6 years (Fleischman et al., 2004; Hertzog et al., 2003; Rönnlund et al., 2005; Tomaszewski et al., 2009; Wilson et al., 2002), we explored cognitive change over a 4-year period. Changes in episodic memory and control processes over this period were estimated using cognitive change indexes. As previous longitudinal studies suggest that episodic memory decline could be observed as early as the 40s (Singh-Manoux et al., 2012), participants in the present study were aged between 42 and 73 years at baseline.

First, we examined whether episodic memory and control processes declined over time. Given the wide age range of the participants, and in line with previous longitudinal studies suggesting that cognitive decline accelerates over time (Fleishman et al., 2004; Singh-Manoux et al., 2012; Wilson et al., 2002; but see Cullum et al., 2000; Goh et al., 2012 for different results), we examined whether the rate of cognitive decline varied according to age

group (middle aged vs. older group). Secondly, we conducted correlational analyses to explore whether the episodic memory change index was associated with the level of control at baseline and/or to the control change index. When necessary, supplementary regression analyses were carried out to determine the percentage of variance related to the episodic memory change index explained by the control level at baseline and/or by the control change index. Although we were mainly interested in the role of control processes on episodic memory decline over time, we also explored whether memory level at baseline was associated with the control change index. This constituted a complementary analysis enabling us to explore the validity of the theoretical framework of the present study. In fact, as the executive hypothesis (West, 1996) states that control decline triggers episodic memory decline and not the reverse, we expected that episodic memory at baseline would not be associated with the control change index. In line with the executive hypothesis (West, 1996) and with previous cross-sectional studies (Angel et al., 2010; Baudouin et al., 2009; Bouazzaoui et al., 2014; Bugajska et al., 2007; Burger et al., 2017; Crawford et al., 2000; Maggio et al., 2019; McCabe et al., 2010; Troyer et al., 1994), we expected that our longitudinal approach would confirm that control processes change and/or control level at baseline would be linked to episodic memory change.

Method

Participants

Fifty-two participants aged between 41 and 73 years ($M = 59.34$, $SD = 11.54$) were included at baseline. Twenty-nine participants completed the two waves of data collection (T1 and T2), with an interval of 4 years. This sample included 5 participants aged 40 to 49 years, 7 participants aged 50 to 59 years, 8 participants aged 60 to 69 years, and 9 participants aged 70 to 79 years at baseline. Attrition of the 23 non-returners was due to lack of time or interest

in the study (56.52%), lost contact (30.43%), or moving out of the area (13.04%). Data presented in Table 1 indicate no selective attrition bias. There were no significant differences between the participants who remained in the study and those who declined to be evaluated at T2 in terms of age, educational level, vocabulary (Mill Hill score, Raven, 1983), anxiety-depression level (Hospital Anxiety and Depression Scale, HADS, Zigmond & Snaith, 1983) or the main variables evaluated in this study. Moreover, the proportion of females to males was roughly similar in these two groups [$\chi^2(1) = 2,25, p=.13$]. Participants were French-speaking volunteers recruited from the general community. They all signed a consent form. In both waves of evaluation, all the older participants (age>60) scored above the cut-off of 27 on the Mini-Mental State Examination (MMSE, Folstein et al., 1975) and below the cut-off of 11 on both subscales of the HADS. Participants had no history of brain injury, cardiovascular or psychiatric disease, alcoholism, and were not taking medication affecting the central nervous system at T1 or T2. This study was approved (CERNI-TP 2015-02-02) by the ethics committee of the University of Tours (France).

Table 1. Means and standard deviations of participants' characteristics and cognitive performance at T1

Table1. Moyennes et écarts types des caractéristiques des participants et de la performance cognitive en T1

	Remaining Participants at T2 (n = 29) M (SD)	Drop-out Participants at T2 (n = 23) M (SD)	<i>t</i> (50)	<i>p</i>
% Females	58	78		
Age	60.72 (10.15)	57.61 (13.11)	.96	.33
Educational level	13.27 (3.22)	12.69 (3.14)	.65	.51
Mill Hill	27.62 (2.44)	26.87 (3.41)	.92	.35
HADS	10,72 (6.40)	9.30 (5.87)	.82	.41
Episodic Memory T1	25.15 (10.39)	21.03 (16.77)	1.08	.28
Control processes T1	20.89 (6.78)	20.87 (6.56)	.01	.99

Note: the table shows episodic memory and control processes performances at T1 of participants remaining at T2 and those who dropped out.

Materials and procedure

Assessments were conducted in a quiet room in a single session, in the same order in both waves of data collection. At the beginning of each session, participants were interviewed and then screened with the MMSE. After that, they completed the WSCRT and the ELFT. Finally, they completed the Mill Hill and the HADS.

Episodic Memory

Episodic memory was assessed by an experimental task developed by our research team, and which has been used in previous studies (e.g. Angel et al., 2010; Alibran et al., 2018; Guerrero et al., 2019). It consists of a Word-Stem Cued-Recall Test (WSCRT) with four successive study-test blocks. Target stimuli were 240 six- to ten-letter words obtained from the Brulex database (Content et al., 1990). Four lists of 60 words for each block were created from the original list, and each list was subdivided into three sub-lists matched for mean number of letters, frequency and number of possible choices to complete each stem. In the study phase, participants were asked to learn 40 words (from two sub-lists), presented one at a time for 500 ms each, and to complete a concreteness judgment. Four additional items were presented, two at the beginning and two at the end of the list, as primacy and recency buffers. During the test phase, 60 word-stems (first three letters of the words) were presented randomly for 500 ms each, 40 from the studied sub-lists and the remaining 20 from the unstudied sub-list; sub-lists were counterbalanced between participants. Stems were different from one another and the most frequent word was never used as the target word. Participants were asked to complete each stem as quickly as possible with a studied word, and if that was not possible, with another suitable word. For each completed word, they had to indicate if it was a studied or an unstudied word; they had 4.5 seconds to respond. Episodic memory score was the percentage of correctly recalled words (proportion of stems from studied words correctly completed and recognized as such) minus the percentage of false alarms (proportion of completed stems from unstudied words wrongly recognized as a studied word).

Control processes

The ELFT (Bryan et al., 1997) was used to assess control processes. Performance in this verbal fluency task has been strongly associated with control processes. Specifically, it is considered as a measure of multidimensional control processes involving different functions, including strategic retrieval search, performance monitoring, inhibition and working memory

(Bryan et al., 1997; Stolwyk et al., 2015). There are two trials, and in each one, participants are instructed to produce in one minute as many words as possible not containing a specified vowel; “A” in the first trial, and “E” in the second trial. The score is the sum of the number of correct responses in the two trials. Internal consistency of the ELFT is reliable ($\alpha = .84$) and it has moderate test-retest stability (.67) (Shores et al., 2006).

Correction for practice effect

In order to reduce the influence of the practice effect, scores at T2 were adjusted according to the method suggested by Kausler (1991), which postulates that the difference between the mean performance of a reference sample and that of the longitudinal group at T2 constitutes an estimation of the practice error. Thus, data from an independent cohort-matched sample was used ($n = 63$) as a reference sample. Participants in this reference sample (RS) had participated in a previous unpublished study using the same episodic memory and control tasks (WSCRT and the ELFT) as in the present study. RS was matched in age ($M = 58.68$, $SD = 11.43$; [$t(90) = .82$, $p = .41$]) and educational level ($M = 19.95$, $SD = 3.05$; [$t(90) = .82$, $p = .64$]) to the longitudinal sample at T2. Given that the practice effect could vary with age, the RS and the longitudinal sample were divided into four age groups (40 to 49, 50 to 59, 60 to 69 and 70 to 79 years) and the practice error was estimated independently for each age group. For each age group of both samples, mean scores for the WSCRT and the ELFT were calculated. The practice error for each cognitive test was estimated as the difference between the mean performance of a given age group in the reference sample and the mean performance at T2 of the corresponding age group in the longitudinal sample (Practice error estimation¹ = LS mean score at T2 - RS mean score; Baltes, 1968; Kausler, 1991). Finally, once the practice error had been estimated, an individual corrected score was calculated by subtracting the practice error estimation corresponding to the respective age group of reference from the individual score at

¹ Calculated independently for each age group.

T2. By way of example, we can take the case of a 43-year-old participant with a score of 25 on the ELFT at T2. First, we estimated the practice error, corresponding to the mean score of the 40-49 age group in the longitudinal sample at T2 (24.5) minus the mean score of the 40-49 age group in the RS (20.81). Thus, the practice error was estimated to be 3.69. Next, this practice error estimation was subtracted from the participant's score to obtain the individual corrected score. Thus, the corrected score for this participant would be 21.31.

Cognitive change indexes

We calculated a change index for each cognitive measure to estimate cognitive change over time. They were calculated by subtracting the score at T1 from the individual corrected score at T2 and dividing that by the score at T1. A positive index corresponded to performance improvement, while a negative one indicated performance decline over time.

Results

Statistical analyses were carried out using STATISTICA software (version 13). The data were analyzed in two steps. First, preliminary analyses explored cognitive change in episodic memory and executive control processes over time. Secondly, correlational analyses were conducted to explore whether the episodic memory change index was linked to the control level at baseline and/or to the control change index, and if necessary regression analyses were implemented to determine the extent to which these two factors (control at baseline and control change) could explain memory change over time.

Cognitive change over time

To determine whether episodic memory and control performance changed over time, a repeated measures analysis of variance (ANOVA), with Time (T1 vs. T2) as a within-subject factor, was performed for both episodic memory and control processes scores. Episodic memory and control processes scores by time are displayed in Table 2. For episodic memory,

analyses indicated that the main effect of Time was significant [$F(1, 28) = 4.67, p=.03, \eta^2=.14$], indicating that episodic memory scores decreased from T1 to T2. Regarding control processes, analyses showed a main significant effect of Time [$F(1, 28) = 4.57, p=.04, \eta^2=.14$], revealing that control scores declined from T1 to T2². We calculated the change index for each cognitive measure (See Table 2).

Table 2. Means and standard deviations of episodic memory and control processes measures at T1 and T2

Table 2. Moyennes et écart types des performances de mémoire épisodique et des processus de contrôle en T1 et T2

	T1 (n = 29)	T2 (n = 29)	Cohen's d_z	Cognitive change Index M (SD)
Episodic Memory	25.15 (10.39)	22.15 (12.41)	.40	-.14 (.35)
Control processes	20.89 (6.79)	18.55 (6.90)	.39	-0.09 (.27)

Note: the table includes data corresponding to the performances at the episodic memory (WSCRT) and control processes (ELFT) tasks at T1 and T2 and episodic memory and control change indexes

²: Given the wide age range of the participants in the present study, supplementary analyses were conducted in order to determine whether results were affected by this factor. As suggested by Bryan & Luszcz (1996), analyses were carried out using the age group variable rather than age as a continuous variable. In fact, individual age would be bimodally distributed as we compared two different age groups, which would lead to overestimating the results, particularly for correlation analyses. Thus, participants were divided into two equivalent subgroups (vocabulary: [$t(27) = 1.12, p=.27$] and anxiety and depression level [$t(27) = .97, p=.34$]) according to their age at baseline (Mdn = 63): a “middle-aged group” for participants aged below the median and an “older group” of participants aged above the median. Next, a repeated measures analysis of variance (ANOVA) with 2 Age group (middle-aged vs. older) \times 2 Time (T1 vs.T2) was performed on the episodic memory and control processes scores. As in the main analyses, the main effect of Time was significant for both episodic memory [$F(1, 27) = 5.03, p=.03, \eta^2=.16$] and control processes [$F(1, 27) = 4.66, p=.03, \eta^2=.15$]. Interestingly, the interaction between Age group and Time was not significant for either episodic memory [$F(1, 27) = 1.90, p=.18$] or control processes [$F(1, 27) = .78, p=.38$], suggesting that cognitive decline over time did not differ significantly between the two age groups. Consistent with these results, t-test comparison of both Episodic Memory [$t(27) = -.33, p=.74$] and Control Change Indexes [$t(27) = -.28, p=.78$] indicated that episodic memory and control change over time did not differ significantly between age groups.

Relationship between episodic memory change index and control level at baseline and control change index

Pearson correlations were conducted to examine the association between the episodic memory change index (EMCI) and the control processes change index (CCI), and also between the control level at baseline and the EMCI on the one hand, and between the episodic memory level at baseline and the CCI on the other. Results revealed that the EMCI was significantly and positively correlated with the CCI ($r = .42, p = .02$). By contrast, control level at baseline was not correlated with the EMCI ($r = .06, p = .74$), and episodic memory level at baseline was not correlated with the CCI ($r = .29, p = .13$). In line with these results and with the theoretical framework of this study (Executive hypothesis, West, 1996), we carried out a regression analysis to determine the percentage of variance related to the episodic memory change index explained by the control change index. It indicated that 18% ($\beta = .42, t(27) = 2.42, p = .02$) of the memory change index variance could be explained by the control processes change index, suggesting that the rate of memory change varied as a function of the level of control change over the 4-year period.

Discussion

In line with the literature (e.g. Balota et al., 2000; Rönnlund et al., 2005), the results of the present study, using a longitudinal approach and taking into account the practice effect, confirm that episodic memory and control processes decline with aging. Previous longitudinal studies have shown that episodic memory starts to decline in the 40s (Dixon et al., 2004; Singh-Manoux et al., 2012; Taylor et al., 1992) and that cognitive change can occur even over a period of 4 to 6 years (Fleischman et al., 2004; Hertzog et al., 2003; Rönnlund et al., 2005; Tomaszewski et al., 2009; Wilson et al., 2002). In line with previous studies (Cullum et al., 2000; Goh et al., 2012), the results indicate that the rate of cognitive decline did not accelerate

with age. By contrast, some studies found that the rate of cognitive decline increased with aging (e.g. Fleischman et al., 2004; Singh-Manoux et al., 2012; Wilson et al., 2002). These contradictory results could be explained by methodological differences between the studies. For instance, Fleischman et al. (2004) and Wilson et al. (2002) assessed cognitive change in a sample in which the mean age at baseline was higher than in the present study (78.6 and 75.9 years respectively). In fact, in Wilson et al.'s (2002) study, cognitive decline differed significantly between the 65-70 and 80-85 age groups. It is thus possible that the rate of cognitive decline accelerates with advancing age but only at later stages of aging, when compensatory cognitive and brain mechanisms are less efficient. This phenomenon could not be observed in the present study, as our older sample was relatively young. Singh-Manoux et al. (2012) found that age at baseline influenced cognitive decline even in a younger old population. However, they estimated cognitive change over a longer period (10 years) than in the present study. It is not known whether cognitive change over time and the factors affecting it differ according to the time between observations. It would be interesting to explore this issue in further studies. Additionally, it is possible that the nature of the task and the operations involved would affect the impact of age at baseline on cognitive decline. In fact, Goh et al. (2012) found that the impact of age at baseline on cognitive change varied between cognitive processes and even between different dimensions of the same cognitive process. They found that age at baseline did not affect cognitive change in episodic memory and some control processes, such as inhibition, chunking, abstraction and working memory, while changes in other dimensions, such as semantic and phonological fluency and switching, increased with aging. In the present study, we used a multidimensional measure of control processes, involving not only phonological fluency but also inhibition. Currently, there is insufficient evidence from longitudinal studies to explain this differential impact, and further studies are needed to better understand the factors underlying the effect of age on the rate of

decline of different cognitive processes. For instance, it would be interesting to explore whether the impact of age varies according to the nature of the episodic memory task by contrasting performance on free-recall, cued-recall and recognition tasks. Finally, given that the main focus of the present study was not on the impact of age on the rate of cognitive decline, we conducted supplementary analyses to explore this issue using a relatively small sample for each subgroup. These exploratory results should therefore be interpreted with caution and need to be confirmed by future studies.

While longitudinal assessment is the best approach to explore cognitive change, the results can be affected by the practice effect and by attrition bias (Rönnlund et al., 2005). For this reason, in the present study, we applied a correction in order to assess individual rates of cognitive decline independently of the practice effect (Kausler, 1991). Concerning attrition, participants who return at T2 could be those with better cognitive functioning at baseline, which could lead to overestimating cognitive performance (Hultsch et al., 1998; Schaie, 1996; Siegler & Botwinick, 1979; Wilson et al., 2006). However, the results of the present study indicated no attrition effect, as the sub-groups of remaining participants and drop-outs had the same characteristics (age, educational level and cultural level) and their cognitive performance at baseline was not statistically different.

Moreover, the results indicate that age-related decline of control processes was significantly associated with episodic memory change over time. In line with the executive hypothesis of cognitive aging (West, 1996), this finding suggests that the level of change of control processes over time could be involved in the changes in episodic memory in aging. Several cross-sectional studies (Angel et al., 2010; Baudouin et al., 2009; Bouazzaoui et al., 2014; Bugajska et al., 2007; Burger et al., 2017; Crawford et al., 2000; Maggio et al., 2018; McCabe et al., 2010; Troyer et al., 1994) have already provided empirical support for this hypothesis. However, to our knowledge, only one previous study has explored it using a

longitudinal approach. Goh et al. (2012) showed that age-related changes in control processes involving a semantic dimension (chunking or semantic retrieval) were associated with episodic memory decline over a 14-year period. The present study extends these results in three ways. First, by revealing that the link between episodic memory and change in control processes is observed even over a 4-year period. More studies are needed to understand whether the time between observations in longitudinal studies could have a differential effect on cognitive change and its underlying factors. Secondly, the present study found that even when the practice effect is taken into account in the analyses, the rate of episodic memory decline was associated with the longitudinal change in a more multidimensional measure of control functioning, involving to a lesser extent semantic processing. Thirdly, this study revealed that control level at baseline was not associated with episodic memory change over time. Control level at a given point in time is not a reliable predictor of memory change with advancing age. As suggested by Wilson et al. (2002), cognitive level at baseline provides limited information about rates of cognitive decline. A high control level in adulthood would not be sufficient to prevent or reduce memory decline. According to these results, an important issue in cognitive aging would be to diminish or avoid control decline in aging, independently of the control level at baseline. However, we could consider an alternative explanation concerning this lack of correlation. Clark et al. (2012) showed that some control measures at baseline (e.g. inhibition and semantic switch) but not others (e.g. spatial planning, task switch or spatial fluency) were reliable predictors of episodic memory decline. It is possible that the measures used in the present study did not involve critical control dimensions that at baseline predict episodic memory decline. Control is a construct composed of multiple, loosely related functions (McCabe et al., 2010). In the present study, we used a measure of control processes, allowing us to capture this multidimensionality and to explore the global impact of control change on episodic memory decline. In fact, the ELFT measure is

expected to involve different control dimensions, such as strategic retrieval search, performance monitoring, inhibition, and working memory (Bryan et al., 1997; Stolwyk et al., 2015). Unfortunately, this measure did not allow us to distinguish between the respective influence of each dimension. Thus, it would be interesting in further studies to explore the specific role of each control dimension and to examine the role played by other dimensions that were not evaluated in this study (flexibility, updating or planning). Additionally, it is important to note that in this study episodic memory at baseline was not linked to the control change index, which is consistent with the executive hypothesis (West, 1996), suggesting that control decline elicits episodic memory decline but not the reverse.

Control processes support the generation, implementation and adaptation of effective operations improving memory functioning, such as deep information processing, self-initiation of retrieval processes, goal maintenance and the generation of complex behaviors in order to reach these goals, and operations facilitating access to stored information (Bouazzaoui et al., 2010; Bryan et al., 1999; Burger et al., 2017; Tacconnat et al., 2006; 2007; 2009). Several studies have shown that reduced episodic memory capacity could be due to deficits in control processes, preventing older adults from self-initiating these strategic operations (Bryan et al., 1999; Tacconnat et al., 2006; 2007; 2009). Highly demanding memory strategic tasks that provide few external cues and depend more on self-initiated controlled processing, such as free-recall or cued-recall tasks, are more challenging for older adults and would be more affected by control deficits, than those providing more external support, such as recognition tasks (Craik, 1986; Craik et al., 1983; Hedden et al., 2005; Sauzeon et al., 2000). In line with this idea, Guerrero et al. (2019) have shown that control processes moderate age-related episodic memory decline in a cued-recall task, but not in a recognition task. Thus, the role played by control processes in episodic memory decline would be observed mainly in memory tasks relying to a greater extent on control related operations (e.g.

self-initiated strategies). As we used a single measure of episodic memory in the present study, it is not possible to explore whether the impact of control change varies according to the memory task (e.g. free-recall, cued-recall or recognition) and the processes involved in it. Further longitudinal studies are needed to explore whether the link between control change and episodic memory change differs according to the type of memory task. Given the correlational nature of the present study, the results should be interpreted with caution. In fact, the results indicate that control change and episodic memory change are linked, but the analyses do not make it possible to determine which of these factors predicts the other. However, in line with the neurocognitive aging literature and more precisely with the executive control hypothesis (West, 1996), the most plausible hypothesis is that control decline over time predicts episodic memory change. To extend the present results by testing this hypothesis directly, a future study with a larger sample should differentiate individuals according to their level of control change (decliners vs. maintainers) in order to explore whether control processes moderate episodic memory decline over time.

By using a longitudinal design and by controlling the potential bias of the practice effect, the present study provides reliable evidence supporting the executive hypothesis of cognitive aging (West, 1996). However, while the longitudinal design has the advantage of directly assessing within-person changes over time, enabling the determinants of these intra-individual changes to be better identified, this approach has some limitations. In longitudinal studies, it is difficult to control for all potential factors affecting cognition during the follow-up period. Over a relatively long period of 4 years, individuals might experience situations that could influence cognition; for example, cognitive training, retirement, leisure activities, etc. It would be interesting to explore how this inter-individual variability could affect the link between episodic memory and control processes. It is also important to note that, due partly to the attrition effect, the longitudinal sample followed-up was relatively small. Nevertheless,

we have shown that episodic memory change over time is linked to control change. However, these exploratory results should be confirmed by using a larger sample, and, as suggested above, by using composite measures of episodic memory and control processes, in order to improve the robustness and generalization of these results.

The control processes measure used in this study involved retrieval, inhibition and working memory. These dimensions could contribute to memory performance by facilitating strategic retrieval search, less vulnerability to interference and more efficient goal maintenance (Braver & West, 2008). Given that control processes decline with aging, fewer resources become available, preventing the implementation of efficient controlled memory operations. In line with recent studies (e.g. Bouazzaoui et al., 2013, 2014; Gombart et al., 2018; 2021; Guerrero et al., 2019), it could be hypothesized that older adults who maintain their control level to a greater extent would have more resources to optimize memory operations and compensate for memory failures. A number of studies have shown that episodic memory performance relies on control processes more for older than younger adults, and that this greater reliance enables them to compensate for the dysfunctioning of basic processes (Bouazzaoui et al., 2013, 2014; Glisky & Kong, 2008; Guerrero et al., 2019; Maggio et al., 2019). Thus, an important issue for future cognitive aging research would be to identify factors that could help improve and maintain control processes during aging.

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