Aging effects in sequential modulations of poorer-strategy effects during execution of memory strategies

By: Thomas Hinault, Patrick Lemaire & Dayna Touron

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Abstract:

In this study, we asked young adults and older adults to encode pairs of words. For each item, they were told which strategy to use, interactive imagery or rote repetition. Data revealed poorer-strategy effects in both young adults and older adults: Participants obtained better performance when executing better strategies (i.e., interactive-imagery strategy to encode pairs of concrete words; rote-repetition strategy on pairs of abstract words) than with poorer strategies (i.e., interactive-imagery strategy on pairs of abstract words; rote-repetition strategy on pairs of concrete words). Crucially, we showed that sequential modulations of poorer-strategy effects (i.e., poorer-strategy effects being larger when previous items were encoded with better relative to poorer strategies), previously demonstrated in arithmetic, generalise to memory strategies. We also found reduced sequential modulations of poorer-strategy effects in older adults relative to young adults. Finally, sequential modulations of poorer-strategy effects correlated with measures of cognitive control processes, suggesting that these processes underlie efficient trial-to-trial modulations during strategy execution. Differences in correlations with cognitive control processes were also found between older adults and young adults. These findings have important implications regarding mechanisms underlying memory strategy execution and age differences in memory performance.

Keywords: Aging | strategy | cognitive control | memory | sequential modulations

Article:

INTRODUCTION

In memory, like in other cognitive domains, performance depends on what strategies are selected and executed (e. g., Siegler, 2007). A strategy can be defined as "a procedure or a set of procedures for achieving a higher level goal or task" (Lemaire & Reder, 1999, p. 365). Previous research on memory strategies (e.g., Bailey, Dun- losky, & Hertzog, 2009; Dunlosky & Hertzog, 1998, 2001; Frank, Touron, & Hertzog, 2013; Hertzog, Price, & Dunlosky, 2012; Hertzog & Touron, 2011; Kuhlmann & Touron, 2012; Naveh-Benjamin, Brav, & Levy, 2007; Taconnat et al., 2006; Tournier & Postal, 2011; Touron & Hertzog, 2014) revealed that (a) participants rely on several strategies to encode and retrieve information, (b) these strategies differ in efficiency, (c) some encoding strategies yield better performance on some items than on others, and (d) older adults use memory strategies less efficiently and less adaptively than young adults. Of crucial interest is what factors influence strategy execution and age differences therein. The present study contributes to this issue by investigating how the efficiency of executing a memory strategy to encode current items is modulated by the strategies used on the immediately preceding items, and the effects of age on these sequential modulations.

To encode pairs of words (e.g., *cat–mouse*), participants can use several memory strategies. They can create a mental image with the words (i.e., mentally visualising a cat hunting a mouse), generate a sentence linking the two words (e.g., "the cat plays with the mouse"), or continuously repeat the words. The deeper encoding provided by sentence-generation and interactive-imagery strategies yields better recall performance relative to rote-repetition strategies (e.g., Craik & Lockhart, 1972; Dunlosky & Hertzog, 2000; Hertzog & Dunlosky, 2006; Hertzog et al., 2012; Paivio & Csapo, 1969). Moreover, the interactive- imagery strategy is more effective to encode concrete words, (e.g., Bower & Winzenz, 2013; Dirkx & Craik, 1992; McGilly & Siegler, 1989; Paivio & Csapo, 1969; Richardson, 2003; Robbins, Bray, Irvin, & Wise, 1974; Tournier & Postal, 2011; Treat & Reese, 1976), while the rote-repetition strategy has been found to be similarly accurate (e.g., Karchmer, 1974) or even more accurate (e.g., Rowe & Schnore, 1971) to encode abstract words. Furthermore, while proportions of use of interactive imagery were found to predict high recall on concrete words, this relationship was absent for abstract words (Richardson, 1978). Therefore, as the rote- repetition strategy is less demanding (i.e., no generation of mediator; for a review see Hertzog & Dunlosky, 2004) and at least as accurate as the interactive-imagery strategy, the rote-repetition strategy is considered as more effective than the interactive-imagery strategy to encode abstract words.

With aging, older adults show less adaptive strategy selection both in the memory domain and in many other cognitive domains (e.g., Hertzog et al., 2012; Lemaire, Arnaud, & Lecacheur, 2004; Tournier & Postal, 2011; Touron & Hertzog, 2014). In memory, compared to young adults, older adults use the interactive-imagery strategy less often to encode pairs of concrete words and the sentence-generation strategy less often to encode pairs of abstract words. Moreover, older adults execute the interactive-imagery strategy less efficiently compared to young adults (e.g., Craik & Dirkx, 1992; Dror & Kosslyn, 1994; Hertzog, Fulton, Mandviwala, & Dunlosky, 2013; Newson & Kemps, 2005; Palladino & De Beni, 2003), and tend to favour rote-repetition or sentence-generation strategies (e.g., Hulicka & Grossman, 1967; Rowe & Schnore, 1971).

Strategy selection and execution on a given item also depend on the strategies used on the immediately preceding item. In different cognitive domains, sequential modulations of strategy selection and execution were demonstrated by several effects such as strategy switch costs (i.e., better performance when participants are asked to repeat the same strategy over two consecutive trials than when they are asked to use two different strategies; Ardiale & Lemaire, 2012; Lemaire & Lecacheur, 2010; Lemaire & Leclère, 2014; Luwel, Schillemans, Onghena, & Verschaffel, 2009; Schillemans, Luwel, Bulté, Onghena, & Verschaffel, 2010; Schillemans, Luwel, Ceulemans, Onghena, & Verschaffel, 2012; Schillemans, Luwel, Onghena, & Verschaffel, 2011), and strategy sequential difficulty effects (i.e., better performance with a strategy after executing an easy strategy compared to following a difficult strategy; Lemaire & Brun, 2014; Uittenhove, Burger, Taconnat, & Lemaire, 2015; Uittenhove & Lemaire, 2012, 2013; Uittenhove, Poletti, Dufau, & Lemaire, 2013).

One goal of the present study was to further examine sequential effects in memory strategies. Specifically, we investigated sequential effects that have been found in other cognitive domains but were never studied in memory sequential modulations of poorer-strategy effects (Hinault, Dufau, & Lemaire, 2014; Lemaire & Brun, 2014; Lemaire & Hinault, 2014; Poletti, Sleimen-Malkoun, Lemaire, & Temprado, 2016). In arithmetic, Lemaire and Hinault found that poorer-strategy effects (i.e., poorer per- formance when the strategy used on a given item is not the better strategy for that item) on a given problem were modulated by whether a poorer or a better strategy was used on the immediately preceding problem. Poorer- strategy effects on current problems were smaller after executing a poorer strategy on the immediately preceding problem than following the execution of the better strategy. Moreover, reversed sequential modulations of poorer-strategy effect were found in older adults, as poorer-strategy effects were larger after the execution of the poorer strategy than after better strategy problems.

The present study aimed at determining whether sequential modulations of poorer-strategy effects were specific to the arithmetic domain or if these modulations reflect general processes involved during strategy execution. Following our previous approach in arithmetic, here we focused on sequential modulations of memory detriments, rather than on memory gains. As sequential modulations of poorer-strategy effects have been explained by cognitive control processes, finding these effects in the memory domain was expected to help further understand the role of these control processes, and their trial-to-trial modulations, when participants encode and retrieve information in episodic memory.

Sequential modulations of poorer-strategy effects were assumed to result from modulations of cognitive control processes. Cognitive control refers to top-down processes necessary to quickly overcome environmental changes and to solve problems (see Diamond, 2013, for a review). Following Miyake et al. (2000), cognitive control can be viewed as involving inhibition (i.e., not giving an automatic answer when necessary, and/or suppressing attention to irrelevant information), working-memory updating (i.e., maintaining representations or replacing them with more relevant ones) and cognitive flexibility (i.e., switching between multiple tasks, strategies, or representations). Lemaire and Hinault (2014) proposed that poorer-strategy effects result from the inhibition of the more automatically activated better strategy to execute the cued poorer strategy. As a consequence, these control mechanisms are maintained and/or in a higher state of activation on the next problems, enabling participants to prepare them- selves to execute the required, poorer strategy with no interference from the more readily available better strategy. One additional major goal of the present study was to determine if cognitive control processes are the under- lying mechanisms of sequential modulations of poorer- strategy effects. To achieve this end, we tested correlations between measures of executive control and sequential modulations of poorer-strategy effects.

An additional goal of the present study was to test changes with age in sequential modulations of poorer- strategy effects while participants encode pairs of words. Such age differences (with inefficient modulations in older adults) were found by Lemaire and Hinault (2014) during arithmetic problem solving. Changes in cognitive control processes could explain age differences in sequential modulations of poorer-strategy effects. Lemaire and Hinault proposed that reversed sequential modulations of poorer-strategy effects in older adults were assumed to reflect depleted resources for cognitive control after poorer strategy problems, preventing them from efficiently inhibiting the better strategy on the next problems. Consistent with this proposal, Hodzik and Lemaire (2011) found that, in arithmetic, age-related variance in percent use of the better strategy on a given problem was attenuated when measures of inhibition (44%) and of cognitive flexibility (39%) were controlled. Moreover, in memory, Bouazzaoui et al. (2010) found that decrease with age in use of an internal memory strategy was mediated by the efficiency of cognitive control processes. These findings suggest that decline in cognitive control processes is heavily responsible for less effective strategic processing in older adults. Moreover, older adults with higher cognitive control functioning were found to use memory strategies more often and more efficiently than low- functioning older adults (Bouazzaoui et al., 2010). Lemaire and Hinault (2014) also found that high-control older adults, who displayed efficient inhibitory control in a Simon task (i.e., a conflict task requiring to inhibit a spatial dimension and to focus on a target dimension, for example, the shape; Simon & Small, 1969), were as able as young adults to sequentially modulate execution of arithmetic strategies. This led us to ask here whether older adults would be less able to sequentially modulate poorer-strategy effects when they execute memory strategies.

The present study pursued three main goals. First, we tested sequential modulations of poorer-strategy effects in the memory domain. Second, we investigated whether sequential modulations of memory strategies change with age when participants encode pairs of words for future recall. Third, we investigated the role of cognitive control processes in sequential modulations of poorer- strategy effects, and how age differences in these processes could account for aging effects. All in all, these out- comes were expected to provide deeper understanding of the mechanisms underlying sequential modulations of poorer-strategy effects, and age differences in these mechanisms. Findings were also expected to further our under- standing of strategic processing in episodic memory.

To achieve these goals, we used a paired-associate word task with the same experimental approach as in Lemaire and Hinault (2014). On each item, participants were cued to use the poorer or the better strategy. Of interest was if differences in performance between poorer- and better- strategy items are modulated by whether the immediately preceding word pairs were encoded with the better versus the poorer strategy. The cued strategy (i.e., interactive- imagery strategy, rote-repetition strategy) could be the better or the poorer as a function of word concreteness. Indeed, the two strategies were selected because interac- tive-imagery strategy is more effective on concrete words (e.g., cat) than on abstract words (e.g., justice; Dirkx & Craik, 1992; Tournier & Postal, 2011; Treat & Reese, 1976), and rote-repetition is equally accurate and less demanding on abstract words than interactive imagery (e.g., Karchmer, 1974). We expected to find poorer-strategy effects, with poorer recalls when the poorer strategy was cued com- pared to when the better strategy was cued. Moreover, we expected sequential modulations of poorer-strategy effects, with reduced poorer-strategy effects on current items after poorer-strategy items compared to following better-strategy items. Given previous findings in arithmetic (Lemaire & Hinault, 2014) as well as less adaptive memory strategy use with age (Hertzog et al., 2012; see Touron, 2015, for a review), we also expected reduced sequential modulations with aging.

To examine the role of cognitive control processes on sequential modulations of poorer-strategy effects and on age differences in these sequential modulations, we collected measures of cognitive control in young and older adults. We adopted the distinction proposed by Miyake et al. (2000) and measured inhibition, working-memory updating and cognitive flexibility. We measured inhibition with the Simon task (Simon & Small, 1969), updating with the N-back task (Kirchner, 1958), and cognitive flexibility with the Trail Making Test (TMT, Partington & Leiter, 1949; Reitan, 1958). We expected correlations between cognitive control processes and sequential modulations of poorer-strategy effects. Due to overall decline of cognitive control with aging (see Craik & Salthouse, 2007; Salthouse, 2010, for reviews), these correlations were expected to be larger in older than in young adults.

METHOD

Participants

Thirty-one young adults and 36 older adults participated. Those who recalled zero or only one word pair in at least one condition (rote repetition yielded the most frequent null recall) were excluded from analyses (*N*s = 6 young adults, 11 older adults; see participants' characteristics in Table 1).

Stimuli

All participants studied a list of 40 pairs of words distribu- ted in two levels of concreteness. Following previous works (e.g., Hertzog & Touron, 2011; Tournier & Postal, 2011; Touron & Hertzog, 2004), we used pairs of words to provide cues that facilitate recall, especially in older adults. The words were derived from a list of French words taken from Bonin et al. (2003). There were 20 pairs of concrete words (e.g., *saddle–bear*) and 20 pairs of abstract words (e.g., *saint–weight*). The values of imagery differed for concrete words (mean = 4.70; range = .09) and abstract words (mean = 3.38, range = .58), $F(1, 78) = 202.81$, $MSe = .45$, $h2 = .72$. Moreover, concrete and abstract words did not differ in mean subjective frequency and emotional valence (Fs < 1). Associations between pairs of words were controlled based on Ferrand and Alario (1998) and Ferrand (2001).

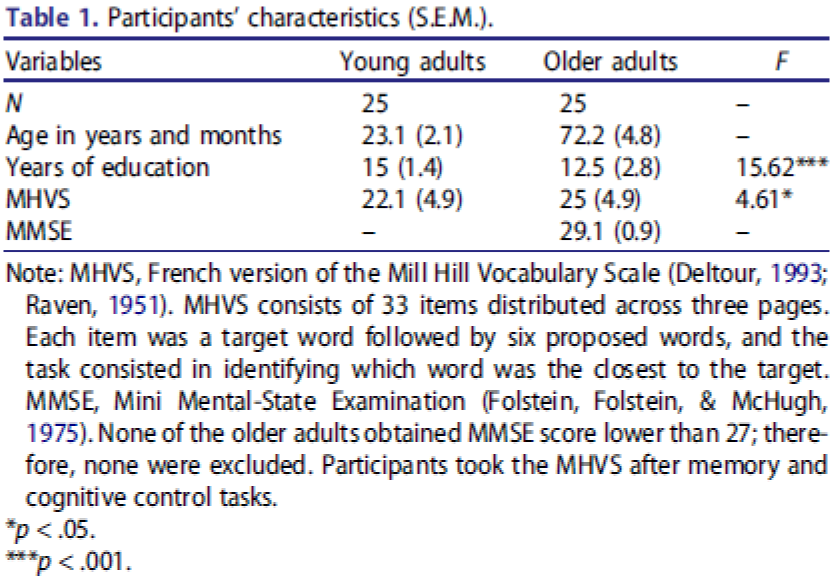

Table 1. Participants' characteristics (S.E.M.).

Variables	Young adults	Older adults	*F*
N	25	25	–
Age in years and months	23.1 (2.1)	72.2 (4.8)	–
Years of education	15 (1.4)	12.5 (2.8)	15.62***
MHVS	22.1 (4.9)	25 (4.9)	4.61*
MMSE	–	29.1 (0.9)	–

Note: MHVS, French version of the Mill Hill Vocabulary Scale (Deltour, 1993; Raven, 1951). MHVS consists of 33 items distributed across three pages. Each item was a target word followed by six proposed words, and the task consisted in identifying which word was the closest to the target. MMSE, Mini Mental-State Examination (Folstein, Folstein, & McHugh, 1975). None of the older adults obtained MMSE score lower than 27; therefore, none were excluded. Participants took the MHVS after memory and cognitive control tasks.

*$p < .05$.

***$p < .001$.

Procedure and design

We followed the same procedure as Tournier and Postal (2011). Participants were first told that they were going to memorise 40 pairs of words (e.g., *cat–mouse*) with one of two strategies. Then, they were explained that a cue would indicate which strategy to use for encoding. Participants were instructed, in a jargon-free manner, how to complete the two cued strategies, and were told to use no other memory strategies. The interactive-imagery strategy was described as creating a mental image linking the words, preferably in making items interact. The rote-repetition strategy was described as continuously repeating the words as many times as possible during display of pairs of words. Practice included eight pairs of words, four pairs to be encoded with the interactive-imagery strategy, and four with the repetition strategy. After the oral recall of practice items, the experimenter ensured that participants understood each strategy and how to implement them. Then, the experimental memory task started in earnest. The experimental stimuli were presented in 48- point bold courier font (black colour) in the centre of a 15.4-inch computer screen controlled by a DELL Latitude 120. The experiment was controlled with the E-Prime software (Psychology Software Tools, Pittsburgh, PA).

There were two types of items, better-strategy and poorer-strategy items. The better strategy was cued on the better-strategy items such that half the pairs of concrete words were cued with interactive-imagery strategy and half the pairs of abstract words were cued with the rote-repetition strategy. The poorer strategy was cued on the poorer-strategy items such that half the pairs of concrete words were cued with the rote-repetition strategy and half the pairs of abstract words were cued with the interactive-imagery strategy. Poorer-strategy and better-strategy items were matched on imagery, mean subjective frequency, and emotional valence (Fs < 1).

Four types of trials were tested: better–better trials (i.e., both current and previous items were cued with the better strategy), better–poorer trials (i.e., current items were cued with the poorer strategy and previous items with the better strategy), poorer–better trials (i.e., current items were cued with the better strategy and previous items with the poorer strategy), and poorer–poorer trials (i.e., both current and previous items were cued with the poorer strategy).

Three tests of cognitive control were used to assess efficiency of participants' executive functions. The Simon task (Simon & Small, 1969) was used to measure inhibition. Participants were asked to respond, as quickly and accurately as possible, by pressing the appropriate key with the right or the left index finger, according to the figure delivered 7 cm either to the left or to the right of a central fixation point. Participants had to press the left key if a rectangle (2 cm × 3 cm) was displayed and the right key if a circle (diameter: 6 cm) was displayed. There were two types of trials: 60 congruent trials and 60 incongruent trials. In the congruent trials, the spatial location of the stimulus matched the task-relevant aspect of the stimulus (i.e., the circle was displayed on the right and the rectangle on the left of the fixation point). In the incongruent trials, the spatial location of the stimulus did not match the task-relevant aspect of the stimulus (i.e., the circle was dis- played on the left and the rectangle on the right of the fixation point). Each trial began with the presentation of a cross, corresponding to a fixation point. After 800 ms, one of the two stimuli was presented, and participants had to respond. Participants practiced the Simon task on 20 items. In addition to congruency effect (e.g., incongruent trials minus congruent trials), sequential modulations of congruency effects (e.g., congruency effects after congruent trials minus congruency effects following incongruent trials; Gratton, Coles, & Donchin, 1992) were also measured to evaluate sequential modulations of inhibitory processes

The *N*-back test (Kirchner, 1958) was used as a measure of working-memory updating. In this test, participants had to indicate whether or not a presented letter was the same as some (*N*) position(s) before. Here, N was equal to two, and we measured the number of correct responses out of 28 trials. To assess cognitive flexibility, we used the TMT (Partington & Leiter, 1949; Reitan, 1958). In this test, participants had to connect targets as fast and accurately as possible. In part A, targets are numbers, and participants have to connect them in a sequential order. In part B, targets are numbers and letters, and participants have to flexibly alternate between the two target types (e.g., 1, A, 2, B, etc.). An index of cognitive flexibility was created by subtracting the number of correctly connected targets in part A from the number of correctly connected targets in part B, larger differences indicating increased switching costs or lower cognitive flexibility.

Participants were tested individually. Every pair of words was preceded by a cued strategy displayed for two seconds. The latency was originally one second but was increased to two seconds following pilot studies that revealed that it was too hard for participants to use the cued strategies under such short duration. Rote-repetition and interactive-imagery strategies were cued with the words “repetition” and “image”, respectively. The cue then remained on the top right corner of the screen, together with pairs of words. Following previous works (e.g., Hertzog et al., 2012), pairs of words were displayed in the centre of the screen at a rate of eight seconds in older adults and six seconds in young adults to ensure older adults would not have floor recall performance given cognitive slowing with aging (Salthouse, 1996). The experimenter monitored correct execution of the rote-repetition strategy by the verbal output (i.e., words repetition) of the participants during encoding. Following previous studies (e.g., Uittenhove et al., 2015), the experimenter asked participants at the end of the experiment to provide two of the mental images they constructed during the experiment. Three seconds between pairs were included to limit interference in the learning of different pairs. At the end of the list, recency effects in subsequent recall were eliminated by asking participants to execute a letter-judgment task (i.e., indicating whether a series of letters included both vowels and consonants or included only one type of letters; e.g., *aevc*), for 30 seconds. Immediately after this letter-judgment task, a cued recall task was presented: The first word of a pair (e.g., *cat*–???) was presented on the computer screen for a maximum of 15 seconds, and participants had to verbally recall the second word (within 15 seconds). Each pair appeared in a new order, different from the order in which it was encoded. Following the memory task, participants performed cognitive control tasks in a counter-balanced order.

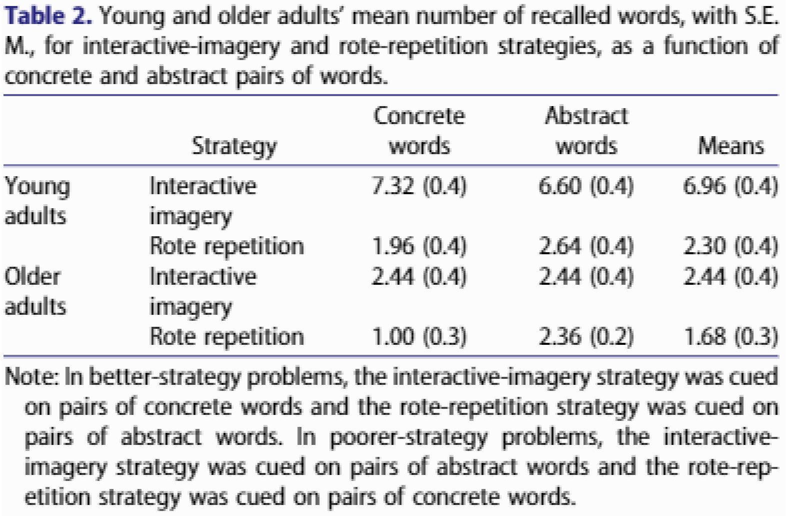

Table 2. Young and older adults' mean number of recalled words, with S.E. M., for interactive-imagery and rote-repetition strategies, as a function of concrete and abstract pairs of words.

	Strategy	Concrete words	Abstract words	Means
Young adults	Interactive imagery	7.32 (0.4)	6.60 (0.4)	6.96 (0.4)
	Rote repetition	1.96 (0.4)	2.64 (0.4)	2.30 (0.4)
Older adults	Interactive imagery	2.44 (0.4)	2.44 (0.4)	2.44 (0.4)
	Rote repetition	1.00 (0.3)	2.36 (0.2)	1.68 (0.3)

Note: In better-strategy problems, the interactive-imagery strategy was cued on pairs of concrete words and the rote-repetition strategy was cued on pairs of abstract words. In poorer-strategy problems, the interactive-imagery strategy was cued on pairs of abstract words and the rote-repetition strategy was cued on pairs of concrete words.

RESULTS

Four sets of analyses were conducted. First, to determine aging and strategy effects on memory performance, we analysed the mean number of correctly recalled words by young and older adults for the interactive-imagery and rote-repetition strategies. Second, we tested poorer-strategy effects in memory strategies, whether poorer-strategy effects were modulated from one trial to the next, and aging effects on these. Third, young and older adults' performance in cognitive control tasks was examined. Last, to test the role of cognitive control processes in sequential modulations of strategy execution, we calculated correlations between measures of cognitive control and sequential modulations of poorer-strategy effects. All data were log-transformed to minimise the effects of skewness and to ensure that age differences cannot be attributed to different baselines (e.g., Faust, Balota, Spieler, & Ferraro, 1999), but untransformed values were reported for the sake of clarity.

Memory task

Age differences in memory strategies

Log-transformed mean number of correctly recalled words (see Table 2) were analysed using a 2 (Age: young adults, older adults) × 2 (Strategy: interactive-imagery, rote-repetition) × 2 (Item: better-strategy, poorer-strategy) mixed-design ANOVA, with age as the only between-participants factor. Older adults recalled significantly fewer words than young adults (2.06 vs. 4.63 words, respectively), $F(1, 48) = 34.08$, $MSe = .09$, $\eta_p^2 = .42$. Overall, the interactive-imagery strategy yielded significantly better recall than the rote-repetition strategy (4.70 vs. 1.99 words, respectively), *F*(1, 48) = 80.39, *MS*e = .10, η_p^2 = .63. Also, mean numbers of correctly recalled words were significantly larger for better-strategy items, when interactive-imagery strategy was cued on pairs of concrete words and rote-repetition strategy was cued on pairs of abstract words compared to poorer-strategy items (3.69 vs. 3.00 word; *F*(1, 48) = 22.81, *MS*e = .01, η_p^2 = .32); the Age × Item interaction was not significant (*F* < 2). Moreover, the Age × Strategy interaction was significant, *F*(1, 48) = 29.41, *MS*e = .04, η_p^2 = .38. Contrasts revealed that the difference between the interactive-imagery strategy and the rote-repetition strategy was larger in young adults (6.96 vs. 2.30 words; *F*(1, 24) = 83.61, *MS*e = .06, η_p^2 = .64), than in older adults (2.44 vs. 1.68 words; *F*(1, 24) = 10.41, *MS*e = .06, η_p^2 = .18). Moreover, age differences in the mean number of correctly recalled words was found while participants executed the interactive-imagery strategy (2.44 vs. 6.96 words; *F*(1, 24) = 68.39, *MS*e = .06, η_p^2 = .59) but not when they used the rote-repetition strategy (1.68 vs. 2.30 words; *F* < 2). Furthermore, the Strategy × Item (*F*(1, 48) = 8.56, *MS*e = .01, η_p^2 = .15), and the Age × Strategy × Item (*F*(1, 48) = 5.87, *MS*e = .01, η_p^2 = .11) interactions were significant. Contrasts revealed that, while young adults showed differences between strategy and poorer-strategy items with both the rote-repetition strategy (2.64 vs. 1.96 words; *F*(1, 24) = 5.71, *MS*e = .29, η_p^2 = .11), and the interactive-imagery strategy (7.32 vs. 6.60 words; *F*(1, 24) = 6.55, *MS*e = .28, η_p^2 = .12), older adults showed item effects only with the rote-repetition strategy (2.36 vs. 1.00 words; *F*(1 ,24) = 22.84, *MS*e = .29, η_p^2 = .32), and not for the interactive-imagery strategy (2.44 vs. 2.44 words; *F* < 1).

Age differences in sequential modulations of poorer-strategy effects

Log-transformed mean number of correctly recalled words (see Figure 1), omission errors (i.e., participants did not recall any words), intrusion errors (i.e., participants recalled a word that was not previously encoded) and recuperation errors (i.e., participants recalled a word that was paired with another word than the cued word) were analysed using 2 (Age: young adults, older adults) × 2 (Strategy on the previous item: poorer, better) × 2 (Strategy on the current item: poorer, better) mixed-design ANOVAs, with age as the only between-participants factor. Preliminary analyses included the additional Strategy (interactive-imagery, rote-repetition) factor. However, neither Age × Strategy × Strategy on the previous item × Strategy on the current item, nor Strategy × Strategy on the previous item × Strategy on the current were significant (*F*s < 3.0). Older adults recalled significantly fewer words than young adults (1.94 vs. 4.63 words), *F*(1, 48) = 63.50, *MS*e = .14, η_p^2 = .57. Most importantly, the Strategy on the previous item × Strategy on the current item interaction was significant, *F*(1, 48) = 13.21, *MS*e = .01, η_p^2 = .22. Overall, poorer-strategy effects were significant when current items followed poorer-strategy items (*F*(1, 48) = 12.90, *MS*e = .03, η_p^2 = .21), and non-significant following better-strategy items (*F* < 2). Although the Age × Strategy on the current item × Strategy on the previous item interaction was not significant (*F* < 1), planned sub-group analyses in young and in older adults revealed several interesting findings.

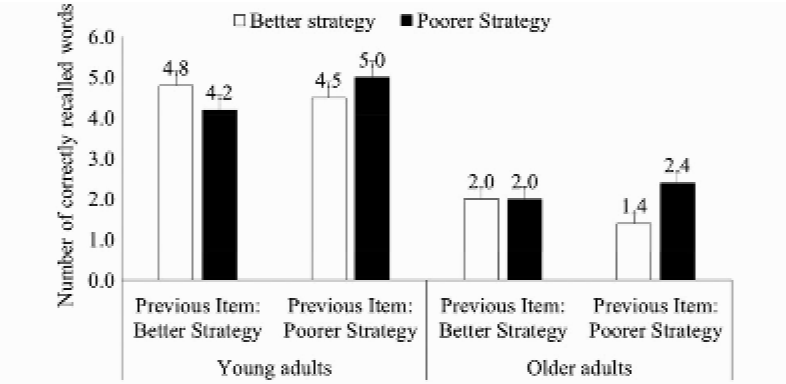

Figure 1. Young and older adults' mean number of recalled words for current better-strategy and poorer-strategy items following better-strategy or poorer-strategy items. Error bars represent S.E.M. The maximum number of words that could be recalled in each condition was of 10 items.

In young adults, the Strategy on the previous item × Strategy on the current item interaction was significant, *F*(1, 24) = 5.15, *MS*e = .01, $\eta_p^2 = .18$, revealing sequential modulations of poorer-strategy effects. Poorer-strategy effects were significant after better-strategy items (*F*(1, 24) = 4.29, *MS*e = .03, $\eta_p^2 = .15$), but not following poorer-strategy items (*F* < 1), indicating sequential modulations of poorer-strategy effects. In older adults, the Strategy on the previous item × Strategy on the current item interaction was also significant, *F*(1, 24) = 6.37, *MS*e = .01, $\eta_p^2 = .21$, and revealed reversed sequential modulations of poorer-strategy effects. Poorer-strategy effects were significant after poorer-strategy items (*F*(1, 24) = 18.52, *MS*e = .45, $\eta_p^2 = .44$), but not significant after better-strategy items (*F* < 1).

Regarding errors, analyses revealed that participants showed reversed poorer-strategy effects, with significantly more omission errors on better-strategy items relative to poorer-strategy items (6.38 vs. 5.86; *F*(1, 48) = 4.96, *MS*e = .01, $\eta_p^2 = .09$). These reverse poorer-strategy effects did not interact with age (*F* < 1). Moreover, the Strategy on the previous item × Strategy on the current item was significant, *F*(1, 48) = 5.89, *MS*e = .01, $\eta_p^2 = .11$. Contrasts revealed reversed sequential modulations of poorer-strategy effects, with significant poorer-strategy effects after poorer-strategy items (*F*(1, 48) = 12.54, *MS*e = .03, $\eta_p^2 = .20$), but not after better-strategy items (*F* < 1). The Age × Strategy on the previous item × Strategy on the current item was not significant (*F* < 1). Moreover, analyses on intrusion and recuperation errors yield no significant sequential modulations of poorer-strategy effects (*F* < 1), most likely because of floor effects (intrusion and recuperation word rates were 3.8% and 1.8%, respectively).

Relationships among sequential modulations of poorer-strategy effects in memory task and performance in cognitive control tasks

Age differences in conflict tasks

In the Simon task, mean solution times and percentages of errors (see Table 3) were analysed using 2 (Age: young adults, older adults) × 2 (Congruency of the previous item: congruent, incongruent) × 2 (Congruency of the current item: congruent, incongruent) mixed-design ANOVAs, with age as the only between-participants factor. Older adults were slower than young adults (551 vs. 422 ms; $F(1, 48) = 69.82$; $MSe = 17294.09$, $\eta_p^2 = 59$). Overall, participants were slower when current items were incongruent than when they were congruent (505 vs. 468 ms; $F(1, 48) = 121.69$, $MSe = 1443.83$, $\eta_p^2 = .72$). Congruency effects were larger in older adults (60 ms) than in young adults (14 ms), as revealed by the Age × Congruency of the current item interaction, $F(1, 48) = 47.38$, $MSe = 562.12$, $\eta_p^2 = .50$. Most importantly, the Congruency of the previous item × Congruency of the current item interaction was significant, $F(1, 48) = 180.88$, $MSe = 2278.58$, $\eta_p^2 = .79$. Contrasts revealed that congruency effects were significant following congruent items ($F(1, 48) = 223.80$, $MSe = 5.62$, $\eta_p^2 = .82$), and non-significant after incongruent items ($F < 2.5$). The Age × Congruency of the previous item × Congruent of the current item was not significant ($F < 3$), and sub-group analyses did not reveal different patterns between young and older adults.

Table 3. Younger and older adults' mean solution times (in ms) and percentages of errors, with S.E.M, in the Simon task for congruent and incongruent items when the previous item was congruent or incongruent.

	Younger adults			Older adults		
Congruency of current item	Congruent previous item	Incongruent previous item	Means	Congruent previous item	Incongruent previous item	Means
	Mean solution times (in ms)					
Congruent	394 (6.9)	437 (10.2)	416	490 (13.5)	552 (13.5)	521
Incongruent	449 (8.7)	410 (7.5)	430	604 (12.2)	559 (17.5)	582
CE	55	−27	14	114	7	61
	Mean percentages of errors					
Congruent	0.4 (0.2)	4.9 (0.7)	2.7	0.3 (0.2)	1.3 (0.4)	0.8
Incongruent	6.3 (1.1)	1.5 (0.4)	3.9	9.3 (1.9)	3.5 (1.0)	6.4
CE	5.9	3.4	1.2	9.0	2.2	5.6

Note: CE, congruency effects (incongruent–congruent).

Analyses of percentages of errors revealed a main effect of congruency of the previous item, as participants made significantly more errors after congruent items relative to after incongruent items (4.06% vs. 2.80%; $F(1, 48) = 8.87$, $MSe = 1.67$, $\eta_p^2 = .16$). The Age × Congruency of the previous item interaction ($F(1, 48) = 7.11$, $MSe = 1.34$, $\eta_p^2 = .13$) revealed that this difference was significant in older adults but not in young adults (2.40% vs. 0.13%, respectively). Moreover, significant congruency effects were found, with larger percentages of errors for incongruent items than for congruent items (5.13% vs. 1.73%; $F(1, 48) = 23.51$, $MSe = 12.04$, $\eta_p^2 = .33$). The Age × Congruency of the current item interaction ($F(1, 48) = 9.84$, $MSe = 5.04$, $\eta_p^2 = .17$) revealed that congruency effects were larger in older adults (5.60%) than in young adults (1.20%). Most importantly, the Congruency on the previous item × Congruency on the current item interaction was significant ($F(1, 48) = 55.85$, $MSe = 12.23$, $\eta_p^2 = .54$). Contrasts revealed that congruency effects were significant when previous items were congruent (7.47%; $F(1, 48) = 45.34$, $MSe = 1.11$, $\eta_p^2 = .48$) and non-significant after incongruent items (−0.66%; $F < 1$). Sub-group analyses did not reveal different patterns between young and older adults.

Analyses of age differences in the TMT revealed that older adults had reduced cognitive flexibility relative to young adults, $F(1, 48) = 16.60$, $MSe = 163.94$, $\eta_p^2 = .26$. Indeed, differences between part B and A was 19 seconds in young adults, and 44 seconds in older adults. Age differences were not found in the *N*-back task (*F*s < 1).

Group differences in correlations between sequential modulations of poorer-strategy effects and cognitive control tasks

The goal of these analyses was to examine correlations between sequential modulations of poorer-strategy effects in the memory task and performance in cognitive control tasks in young and older adults. Correlations in each group were calculated between the following measures: from the memory task, (a) poorer-strategy effects (i.e., latencies on poorer strategy problems–latencies on better strategy problems) following better strategy problems, (b) poorer-strategy effects following poorer strategy problems, (c) sequential modulations of poorer-strategy effects (i.e., latencies on poorer-strategy effects following better strategy problems–latencies on poorer-strategy effects following poorer strategy problems); from the Simon task, (d) congruency effects (i.e., latencies on incongruent items–latencies on congruent items) following congruent items, (e) congruency effects following incongruent items, (f) congruency sequence effects (i.e., congruency effects following congruent items minus congruency effects following incongruent items); (g) *N*-back updating scores, (h) index of cognitive flexibility from the TMT (i.e., TMT B–TMT A) and (i) verbal fluency.

In young adults (see Table 4), poorer-strategy effects following poorer-strategy items in the memory task correlated positively with congruency effects following incongruent items ($r = .46$, $p = .02$) and congruency sequence effects ($r = .57$, $p = .01$) in the Simon task. Participants showing the largest sequential modulations of cognitive control mechanisms also had the largest poorer-strategy effects following poorer-strategy items in the memory task, with better recall performance on poorer–poorer trials.

In older adults, poorer-strategy effects after poorer-strategy items in the memory task were negatively correlated with TMT B–TMT A ($r = -.43$, $p = .02$). Furthermore, verbal fluency correlated negatively TMT B–TMT A ($r = -.41$, $p = .04$), and positively with performance in the *N*-back task ($r = .41$, $p = .04$). Participants with higher cognitive flexibility also had the largest poorer-strategy effects following poorer-strategy items in the memory task. Moreover, participants with the highest scores in verbal fluency showed the best performance in cognitive flexibility and working-memory updating.

DISCUSSION

This study revealed sequential modulations of poorer-strategy effects in memory. The results further our understanding of the underlying mechanisms of these modulations. They also document how these modulations change with age during adulthood. Although the numbers of correctly recalled words were relatively low, recall performance in the present study did not differ from the previous works on memory strategies (e.g., Hayes, Kelly, & Smith, 2013; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005; Uittenhove et al., 2015). Sequential modulations were found when young and older adults were asked to encode pairs of words with a cued strategy, and to subsequently recall the second word of each pair upon presentation of the first word. First, we replicated the previously found better memory performance with an interactive-imagery strategy than with a rote-repetition strategy in young and older adults (see Hertzog & Dunlosky, 2004, for a review). Second, we replicated modulations of strategy execution by characteristics of items (i.e., showing poorer-strategy effects; e.g., Hinault et al., 2014, 2015 Lemaire & Hinault, 2014). Participants' performance was poorest when asked to execute the poorer strategy (i.e., interactive-imagery strategy on abstract words and rote-repetition strategy on concrete words) relative to when required to execute the better strategy (i.e., interactive-imagery strategy on concrete words and rote-repetition strategy on abstract words). Most originally, our findings uniquely revealed that these poorer-strategy effects were modulated by whether previous pairs of words were encoded with the better or the poorer strategy. Also, we found age differences in sequential modulations of poorer-strategy effects. Finally, performance in cognitive control tasks was found to correlate with sequential modulations of poorer-strategy effects. These findings have important implications to further our understanding of the mechanisms underlying memory strategy execution and age differences in memory performance.

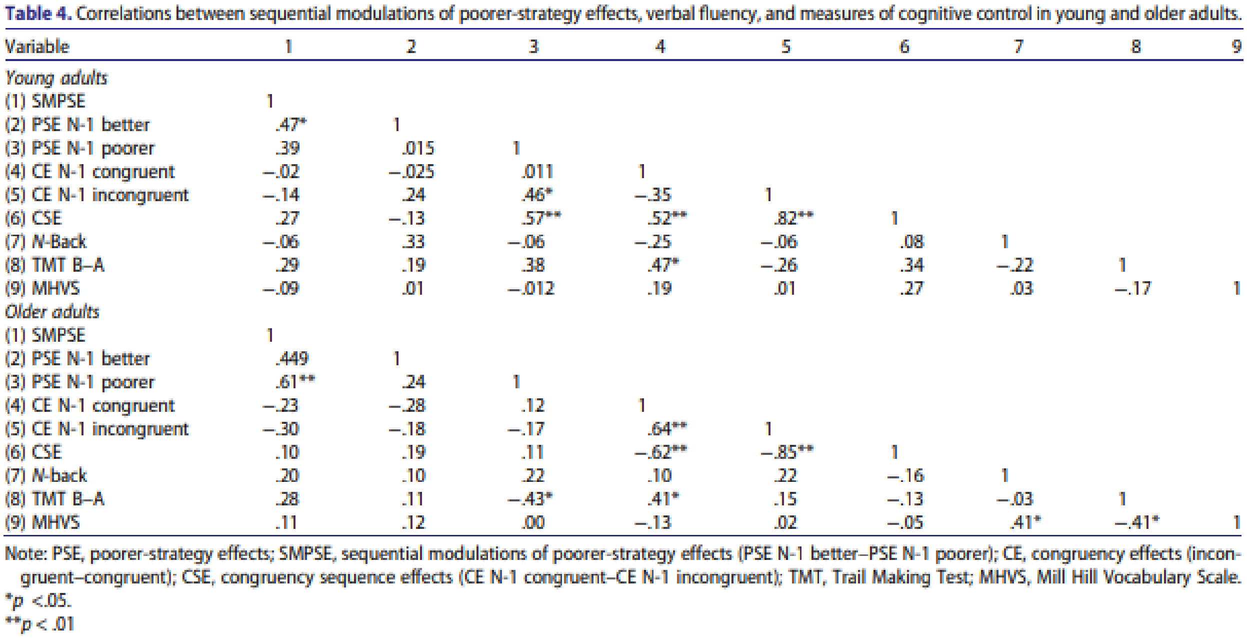

Table 4. Correlations between sequential modulations of poorer-strategy effects, verbal fluency, and measures of cognitive control in young and older adults.

Variable	1	2	3	4	5	6	7	8	9
Young adults									
(1) SMPSE	1								
(2) PSE N-1 better	.47*	1							
(3) PSE N-1 poorer	.39	.015	1						
(4) CE N-1 congruent	−.02	−.025	.011	1					
(5) CE N-1 incongruent	−.14	.24	.46*	−.35	1				
(6) CSE	.27	−.13	.57**	.52**	.82**	1			
(7) *N*-Back	−.06	.33	−.06	−.25	−.06	.08	1		
(8) TMT B–A	.29	.19	.38	.47*	−.26	.34	−.22	1	
(9) MHVS	−.09	.01	−.012	.19	.01	.27	.03	−.17	1
Older adults									
(1) SMPSE	1								
(2) PSE N-1 better	.449	1							
(3) PSE N-1 poorer	.61**	.24	1						
(4) CE N-1 congruent	−.23	−.28	.12	1					
(5) CE N-1 incongruent	−.30	−.18	−.17	.64**	1				
(6) CSE	.10	.19	.11	−.62**	−.85**	1			
(7) *N*-back	.20	.10	.22	.10	.22	−.16	1		
(8) TMT B–A	.28	.11	−.43*	.41*	.15	−.13	−.03	1	
(9) MHVS	.11	.12	.00	−.13	.02	−.05	.41*	−.41*	1

Note: PSE, poorer-strategy effects; SMPSE, sequential modulations of poorer-strategy effects (PSE N-1 better–PSE N-1 poorer); CE, congruency effects (incongruent–congruent); CSE, congruency sequence effects (CE N-1 congruent–CE N-1 incongruent); TMT, Trail Making Test; MHVS, Mill Hill Vocabulary Scale.
*$p < .05$.
**$p < .01$

One of the most important and original findings here concerns sequential modulations of poorer-strategy effects in the memory domain. These sequential modulations were previously found in arithmetic problem-solving tasks (Hinault et al., 2014; Lemaire & Hinault, 2014). The present findings revealed that the mechanisms of sequential modulations of poorer-strategy effects are not specific to the arithmetic domain, but are also at stake in memory. In fact, they may generalise to all cognitive domains where participants' performance depends on which strategies they use. Interestingly, we also found that these sequential modulations of poorer-strategy effects changed during adulthood. In young adults, poorer-strategy effects were observed after better-strategy items, and not after execution of a poorer strategy on previous items. Note that the present findings are not only consistent with previous results on strategies (Hinault et al., 2014; Lemaire & Hinault, 2014), but also with research on sequential modulations of cognitive control processes in general (see Duthoo, Abrahamse, Braem, Boehler, & Notebaert, 2014, for a review). How participants sequentially modulate control processes during execution of poorer strategies while they encode pairs of words may share similarities with how they do it while solving arithmetic problems. Following previous empirical and theoretical works on cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gratton et al., 1992; see Duthoo et al., 2014, for a review), Lemaire and Hinault (2014) proposed that having to execute a poorer strategy on current items increases the level of control on immediately following items. When they encode pairs of words, participants first activate the most efficient and readily available strategy (i.e., interactive-imagery strategy on pairs of concrete words, and rote-repetition strategy on pairs of abstract words). Then, they inhibit this strategy to execute the cued strategy if this required strategy differs from the most automatically activated strategy, like when encoding poorer-strategy items. On the next item, participants are better prepared to focus on the cue for the execution of the required strategy and to inhibit the most automatically activated better strategy. This results in more efficient execution of the cued poorer strategy, leading to reduced poorer-strategy effects on subsequent items.

In older adults, poorer-strategy effects were significant only when previous items were encoded with the poorer strategy. These reverse sequential modulations of poorer-strategy effects could suggest less efficient control processes in older adults. However, recall performance was better on poorer–poorer trials relative to poorer–better trials. In contrast to previous studies (e.g., Lemaire & Hinault, 2014) that mainly focused on reaction times, we focused here on accuracy. Then, this suggests that older adults were able to modulate control processes to improve the recall performance. It is important to note that older adults did not differ from young adults in the *N*-back task, and showed similar congruency sequence effects in the Simon task. Hence, it is possible that older adults tested in this study had preserved cognitive control processes, similar to high-control older adults studied in Lemaire and Hinault (2014). To determine if a minority of highly efficient participants could account for these results, we performed analyses after removing the five best older participants but the results remained unchanged. Thus, older adults seemed able to compensate, at least in part, for aging effects on cognitive control processes and improved their recall performance on poorer-strategy items when immediately preceding items were encoded with the poorer strategy.

Before any definitive conclusions, it is important to consider limitations of the current study. First, a number of participants were excluded due to extremely poor recall, leading to a relatively small sample size. This may have resulted from the list of words being harder to encode and recall than lists presented in previous studies (e.g., Tournier & Postal, 2011), as other task parameters were similar to previous studies on memory strategies (e.g., Hertzog et al., 2012; Tournier & Postal, 2011). Moreover, we did not collect trial-by-trial strategy ratings from participants, to ensure that interactive-imagery strategy is implemented as successfully in young and older adults (e.g., Hertzog & Dunlosky, 2006). Trial-by-trial assessments were not used to avoid interference with sequential modulations of strategy execution. However, results of the present study are consistent with previous works on aging and memory strategies, showing that the benefit of interactive-imagery strategy is reduced in older adults relative to young adults (e.g., Craik & Dirkx, 1992; Dror & Kosslyn, 1994; Newson & Kemps, 2005; Palladino & De Beni, 2003). This provides converging evidence that the interactive-imagery strategy was correctly used during the task.

Also, some of our task parameters may have driven some of our effects. Indeed, cues were presented for two seconds between pairs of words. This may have reduced sequential effects, as well as aging effects on sequential modulations of poorer-strategy effects. Indeed, presenting cues for two seconds before pairs of words could lead to smaller conflict compared to when cues and pairs of words are presented simultaneously, or with shorter delay, because participants have more time to prepare themselves to use the required strategy. Moreover, older adults could have been less affected with this two-second period compared to a condition where cues and pairs of words are presented at the same time. Future studies may test this possibility by varying cue-target durations and by collecting eye movements. Patterns of eye movements across cues and pairs of words would tell whether young and older adults encode pairs of words before cues or the reverse. It is easy to imagine that a participant gazing first at cues then at words would have different performance than a participant looking first words then at cues. Also, our hypothesis of sequential modulations of control processes predicts that participants will look at cues longer on better–poorer trials than on poorer–poorer trials, because participants will not be prepared to process poorer-strategy items.

Interestingly, the present study makes an original contribution to account for the hypothesis proposed by Lemaire and Hinault (2014), regarding the role of cognitive control processes in modulations of strategy execution. Results suggest that the efficiency of strategy execution was related to the efficiency of executive control processes. In young adults, poorer-strategy effects after executing a poorer strategy on previous items were positively correlated with congruency sequence effects in the Simon task. These findings revealed that efficient sequential modulations of inhibitory processes allow more effective encoding and better subsequent recall of an item, when a poorer strategy has been executed on the immediately preceding item. Moreover, it was interesting to observe here that, in contrast to other sequential effects modulating memory strategy execution (Uittenhove et al., 2015), working-memory updating was not associated with sequential modulations of poorer-strategy effects. All in all, these results suggest that (a) sequential modulations of strategy execution involve cognitive control processes, and (b) different sequential effects rely on different control processes.

In older adults, we found that cognitive flexibility, and not inhibitory control, was correlated with poorer=strategy effects following execution of a poorer strategy on previous items. This could suggest that better and poorer strategies are not activated in the same manner for young and older adults. Decline in cognitive flexibility, rather than inhibition, seems to be related to less efficient sequential modulations of poorer-strategy effects with age. Indeed, because strategies are executed in short succession, cognitive flexibility is needed to efficiently execute the required strategies. Older adults with efficient cognitive flexibility could be able to disengage from the better strategy to activate the cued strategy when a poorer strategy was cued. Also, these findings have practical implications, as training programmes targeting cognitive flexibility could lead to optimising memory strategy use in older adults (e.g., Cavallini et al., 2015). Future studies will investigate whether older adults with higher cognitive flexibility have better performance in everyday memory tasks, and whether training in cognitive flexibility leads to improvement of memory performance. These findings will further our understanding of how cognitive flexibility processes influence memory efficiency, and how cognitive flexibility training can improve daily cognitive functioning in older adults.

At a very general level, the present findings confirm that memory performance is crucially influenced by which strategies are used on each item (e.g., whether the better or poorer strategy is used), and that this performance is modulated by strategy execution on previous items. Also, age differences in memory performance are influenced by how young and older adults execute memory strategies, even when differences in strategy use across groups are controlled. Findings originally showed that the execution of memory strategies involves executive control processes, that these control processes are modulated from one trial to the next, and that young and older adults differ in such sequential modulations.

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