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# Strategy difficulty effects in young and older adults' episodic memory are modulated by inter-stimulus intervals and executive control processes<sup>☆</sup>



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## ABSTRACT

Efficient execution of strategies is crucial to memory performance and to age-related differences in this performance. Relative strategy complexity influences memory performance and aging effects on memory. Here, we aimed to further our understanding of the effects of relative strategy complexity by looking at the role of cognitive control functions and the time-course of the effects of relative strategy complexity. Thus, we manipulated inter-stimulus intervals (ISI) and assessed executive functions. Results showed that (a) performance as a function of the relative strategy difficulty of the current and previous trial was modulated by ISI, (b) these effects were modulated by inhibition capacities, and (c) significant age differences were found in the way ISI modulates relative strategy difficulty. These findings have important implications for understanding the relationships between aging, executive control, and strategy execution in episodic memory.

## 1. Introduction

One of the most robust findings in aging research on memory is that older adults perform less well than young adults in most memory tasks (Dunlosky & Hertzog, 2001; Light, 1996; for review). To encode, store, and recall information, both young and older adults use different strategies. A strategy is defined as “a procedure or a set of procedures to achieve a higher level goal” (Lemaire & Reder, 1999, p. 365). Performance and age-related differences depend on the strategies used (type, number, frequency, and how they are executed). Of great importance is how age-related differences in strategy selection and execution lead to differences in memory performance. The present study contributes to this issue by investigating how strategy execution and age-related differences therein are modulated by task parameters such as inter-stimulus intervals and by individual characteristics like executive functions.

Memory performance in both young and older adults depends on which strategies participants use (e.g., Froger, Bouazzaoui, Isingrini, & Taconnat, 2012; Lemaire, 2016). Strategies differ in difficulty and efficiency. Relative strategy difficulty arises from the number and complexity of processing steps involved. Usually, harder strategies

involve more and/or more complex steps, require more effort to execute, and are more demanding in processing resources. In the memory domain, complex strategies based on deep encoding usually yield better performance (e.g. Craik & Lockhart, 1972; Paivio & Csapo, 1969). An example of an efficient memory strategy is mental imagery, which involves linking the word to be memorized to a corresponding visual representation (i.e., representational processing, Paivio, 1986), but it requires a relatively long time to be correctly implemented (Paivio & Csapo, 1971; Plaie & Thomas, 2008). By contrast, rote repetition involves perceptive-lexical encoding, which requires less time and fewer cognitive resources and thus leads to shallower encoding (Tulving & Thomson, 1973; Froger et al., 2012). Studies in aging have shown that the efficiency of mental image generation declines in old age (e.g., Bruyer & Scailquin, 2000; Dror & Kosslyn, 1994; Dunlosky & Hertzog, 2001; Plaie & Isingrini, 2003). Using multiple imagery tasks (i.e., perception, generation, rotation), Briggs, Raz, and Marks (1999) showed that imagery capacity is impaired in old age, and that age-related differences could be explained by individual differences in control processes (e.g., working memory). Subsequently, further studies on mental imagery and memory found that (1) older adults use mental imagery less often than young adults (Dunlosky & Hertzog, 2001;

<sup>☆</sup> The same analyses were run with (imagery-repetition)/repetition, with the same significant results.

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Froger et al., 2012; Froger, Toczé, & Taconnat, 2014; Tournier & Postal, 2011), and (2) when they are encouraged or instructed to use mental imagery, older adults execute it less efficiently than young adults. In sum, previous research in memory found that strategy use and efficiency of strategy execution change during aging (e.g., Froger et al., 2012; Tournier & Postal, 2011). The present study provides further evidence of the origins of the relative efficiency and difficulty of memory strategies, as well as age-related differences in the strategies used.

Relative strategy difficulty has been shown to influence performance not only on current trials but also on subsequent trials. This is evidenced by different effects such as strategy switch costs (e.g., Lemaire & Lecacheur, 2010; Ardiale & Lemaire, 2012, 2013), strategy sequence congruency effects (Lemaire & Hinault, 2014; Hinault, Dufau, & Lemaire, 2015; Hinault, Lemaire, & Phillips, 2016), and by strategy sequential difficulty effects (SSDE). The latter were originally found in arithmetic problem solving (e.g., Uittenhove & Lemaire, 2012, 2013a, 2013b; Uittenhove, Poletti, Dufau, & Lemaire, 2013) and more recently in episodic memory (Uittenhove, Burger, Taconnat, & Lemaire, 2015). In SSDE, performance on current trials is influenced by the relative difficulty of the strategies used on immediately preceding trials. In memory, Uittenhove et al. (2015) found that both young and older participants correctly recalled more words using a sentence-construction strategy when this followed an easier strategy (i.e., repetition) than after a harder strategy (i.e., mental imagery).

One of the reasons why SSDE are interesting is that they show that relative strategy performance cannot be investigated on a trial-by-trial basis, but has to be understood in the context of trial-to-trial strategy transitions. It is theoretically interesting because computational models of strategies (Lovett & Anderson's, 1996 ACT-R model; Lovett & Schunn's, 1999 RCCL model; Rieskamp & Otto's, 2006 SSL model; or Siegler & Araya's, 2005 SCADS model) assume that strategy selection and execution on each trial are independent of strategies used on preceding trials. This assumption of trial-to-trial independence in strategy execution is inconsistent with SSDE.

Another motivation for studying SSDE is that they are assumed to result from executive control processes and hence provide a fruitful context to examine the role of these processes in trial-to-trial modulation of relative strategy performance. More precisely, Schneider and Anderson (2010) suggested that SSDE could result from the temporary depletion of relevant cognitive resources by difficult cognitive tasks or problems. Similarly, Uittenhove and Lemaire (2012) proposed that difficult strategies temporarily reduce available executive resources, or could interfere with the following strategy. Thus, SSDE could be due to fewer available resources and/or the possibility of interference by execution of a previous strategy. For example, traces could remain in working memory after a difficult strategy has been implemented on Trial 1, and these traces could interfere with the implementation of the strategy on the next trial. Consistent with these suggestions, Uittenhove and Lemaire (2013a) found a correlation between working-memory capacities and SSDE in arithmetic tasks, as participants with larger working-memory capacities showed smaller SSDE. Additionally, Uittenhove et al. (2015) found that SSDE in memory correlated with measures of inhibition processes. Their findings suggest that demands on working-memory and inhibition resources contribute to SSDE. A harder strategy could be more difficult to inhibit or require more time to be inhibited than an easier one, leading to a greater impact on strategy execution on the following items.

Given the reduced efficiency of cognitive control processes in older adults (e.g., Daniels, Toth, & Jacoby, 2006; Park & Hedden, 2001; see Diamond, 2013, for a review), if these processes are involved in SSDE, the latter should increase with age, as older adults should be relatively more impaired after executing a complex strategy. However, previous findings showed that SSDE were surprisingly comparable in young and older adults both in arithmetic (Uittenhove & Lemaire, 2013b) and in memory (Uittenhove et al., 2015). These findings question the role of

executive control mechanisms in SSDE, or at least make it unclear what mechanisms underlie SSDE and why older adults are not more sensitive to them than young adults. The aim of the current study was therefore to further our understanding of SSDE and aging in episodic memory. To achieve this end, we asked participants to carry out cognitive tests known to assess control processes (West, 1996) or processing speed (Salthouse, 1990). To our knowledge, no studies have examined directly the relations among executive function, processing speed, and strategies in the memory domain. The executive functions we assessed included inhibition and up-dating of working-memory tasks (Miyake et al., 2000), which have both been found to be involved in SSDE (e.g., Uittenhove et al., 2015). Inhibition enables individuals to ignore irrelevant information that competes for attention with relevant information. This is important when words have to be learnt successively with different encoding strategies, because a previously used strategy has to be inhibited in order to implement the subsequent strategy effectively. Updating is linked to working-memory capacity, because information in working memory has to be updated by replacing older elements with new relevant elements. Executing tasks in rapid succession may require more updating capacities to replace the information and procedures for a difficult strategy than an easy strategy (Uittenhove et al., 2015). We also examined processing speed because this variable is often considered as a basic cognitive resource, which is not only crucial in most cognitive processes (Kail & Salthouse, 1994) but is also responsible for age-related decline (Salthouse, 1996).

To better understand the origins of relative strategy performance on both current and subsequent trials in episodic memory, we extended the approach adopted by Uittenhove et al. (2015) who manipulated the strategies required to learn words so that a strategy of medium difficulty (i.e., sentence construction) used for the target words was preceded by a word encoded with either an easier strategy (i.e., rote repetition) or a more difficult strategy (i.e., mental imagery). More precisely, we examined how relative strategy difficulty executed on current and subsequent trials varied with ISI. Participants were tested under either a short ISI condition (i.e., an interval of 1000 ms between word presentations) or a long ISI condition (i.e., an interval of 2000 ms). We used 1000 ms because it is the interval that is most widely used in the literature, as it is sufficient to process words at encoding, in particular when the stimulus presentation time is 3 s (e.g., Toczé et al., 2012). Furthermore, we assessed each individual's processing resources (i.e., inhibition, processing speed, and updating) in order to better understand the mechanisms underlying relative strategy difficulty effects (on current and subsequent trials) in young and older adults as modulated by ISI. The goal of the current study was twofold.

First, we tested the hypothesis that the more demanding mental imagery strategy involves more processing resources than the easier rote repetition strategy. This demand would be greater with short than long ISI, because short ISI means that the task has to be achieved rapidly, requiring more processing resources. The demand would also be greater in older adults due to their lower processing resources, in line with recent findings that memory performance depends more on executive abilities in older than in young adults (Bouazzaoui et al., 2014). We therefore compared the memory performance of young and older adults using imagery and repetition strategies under short and long ISI conditions, and performed correlational analyses to test the relations between these data and processing resources (i.e., inhibition, working-memory updating, and processing speed). We tested the following predictions. Differences in strategy performance were expected to increase with longer ISI, especially in older adults, as longer ISI would give participants more time to implement and execute the harder strategy efficiently. This would result in improved performance with imagery under the long ISI condition. This effect was expected to be larger in older adults, who, given their decreased processing speed, would benefit more from longer ISI to execute the imagery strategy efficiently. We also predicted correlations between processing re-

**Table 1**  
Participants' characteristics (Means and SD) in each group and each ISI condition.

	Young adults		Older adults		ANOVA		
	Short ISI (n = 33)	Long ISI (n = 36)	Short ISI (n = 38)	Long ISI (n = 36)	Age	ISI	Interaction
Age	22.81 (4.72)	25.78 (4.21)	69.47 (7.28)	68.64 (6.03)	***	ns	ns
MMSE	–	–	28.55 (1.18)	28.08 (1.13)	–	–	–
Educational level	13.57 (1.44)	13.19 (1.56)	12.47 (2.45)	12.97 (2.60)	+	ns	ns
Mill-Hill	22.69 (2.84)	23.44 (4.48)	26.74 (4.09)	25.83 (4.85)	***	ns	ns
VVIQ	53.33 (4.46)	51.97 (7.86)	54.95 (5.09)	55.75 (7.05)	**	ns	ns

Note. \*:  $p < 0.05$ , \*\*:  $p < 0.01$ , \*\*\*:  $p < 0.001$ , +:  $p = 0.07$ .

sources and strategy execution performance, especially for the relatively harder mental imagery strategy. However, we expected these correlations to be modified by ISI, with larger correlations for short ISI, because processing resources would have to be more efficient in this condition to successfully execute successive harder strategies. For older adults, increasing the time between items would attenuate the effect of low processing resources. In fact, because the older adults are slower than the younger ones, increasing the time to implement a strategy may decrease the difficulty of the task for them, because they may need more time to execute a task or a strategy.

Secondly, to understand how relative strategy complexity affects participants' performance on successive trials, we tested the role of ISI on SSDE in young and older adults. This was motivated in part by [Uittenhove and Lemaire's \(2013a\)](#) findings that SSDE in arithmetic problem solving decreased with increased response-stimulus intervals (RSI) in young adults, who showed significant SSDE with short RSIs (i.e., when subsequent problems were displayed 300 ms after participant's response to previous problems), but non-significant SSDE under a 600-ms RSI condition. The authors assumed that longer RSI would allow previous traces to be inhibited, or to simply dissipate from working memory. The present study tested whether, as in arithmetic, SSDE in memory are influenced by the interval between the presentation of stimuli (ISI), and also whether this influence is the same in young and older adults. This was motivated by the fact that [Uittenhove et al. \(2015\)](#) did not test how SSDE in memory change with ISI in older adults. More specifically, we tested the hypothesis that longer inter-stimulus intervals would modulate SSDE, particularly in young adults, as they would have more time to recover from executing a harder memory strategy in order to use a different strategy on a subsequent trial. As a consequence, young adults would show smaller SSDE with long than short ISI. By contrast, due to their slower processing speed and fewer available executive control resources, older adults would be less able to recover under the long ISI condition. The decrease in SSDE with longer ISI should thus be smaller in older than in young adults.

Finally, we assessed the relationship between processing resources, aging, and SSDE. To this end, we first calculated correlations between measures of processing resource and SSDE, and then performed regression analyses to examine which variables accounted for the largest amount of variance in SSDE. [Uittenhove et al. \(2015\)](#) found that SSDE were correlated with a measure of inhibition in both young and older adults. Interestingly, they also found that SSDE and working memory capacities correlated in young adults only. However, they did not measure other processing resources (e.g. processing speed) known to play a crucial role in cognitive performance and in age-related differences in performance. In the present study, we investigated more systematically and exhaustively the role of processing resources (i.e., processing speed, memory updating, and inhibition) on SSDE in young and older adults.

## 2. Method

### 2.1. Participants

One hundred and sixty individuals participated in this study, 80 young adults aged between 20 and 40 years, and 80 older adults aged between 60 and 80 years. Participants in each age group were randomly assigned to one of two ISI conditions, short ISI (1000 ms between items) or long ISI (2000 ms). Thus, 40 young adults (20 women and 20 men) and 40 older adults (21 women and 19 men) were tested under the short ISI condition, and 40 young adults (22 women and 18 men) and 40 older adults (30 women and 10 men) under the long ISI condition. All participants lived independently at home and were recruited mainly through local newspapers. In order to minimize possible cohort effects, and because none of the older adults had a high level of education, young participants were not recruited at university. Participants were all volunteers, and were individually interviewed to exclude those with a history of alcoholism, undergoing treatment for psychiatric illness, or taking psychoactive medication. They were screened for anxiety-depression with the Hospital Anxiety and Depression Scale (HADS, [Zigmond & Snaith, 1983](#)); participants with a score over 11 were excluded. Seven young adults and two older adults were thus removed from the short ISI group, and four young and two older adults from the long ISI group. Older adults were also screened for cognitive impairment with the Mini-Mental State Examination ([Folstein, Folstein, & McHugh, 1975](#)) and those who obtained a score below 27 were excluded from the analyses (two participants) to reduce the risk of including participants with potential dementia. Ethical approval for the research was obtained from the local ethics committee of the University of Tours, and all participants signed consent forms. The Mill-Hill vocabulary test ([Raven, Court, & Raven, 1986](#)) was used to assess verbal fluency, which could influence episodic memory, and the Visual Imagery Vividness Questionnaire (VVIQ, [Marks, 1973](#)) to assess mental imagery capacity.

As shown in [Table 1](#), young adults had a higher education level than older adults, but older adults had a higher vocabulary level. This pattern is consistent with what is typically found in the literature (e.g., [Craik & Bialystok, 2006](#)) and also with the idea that crystallized knowledge (general knowledge, semantic memory) is likely to increase throughout life. No age-related differences were found in the VVIQ, suggesting that participants in each age group and under each ISI condition were equally fluent in mental imagery.

Three processing resources were measured: inhibition (assessed with the Stroop test), updating (assessed with the *N*-back test), and processing speed (assessed with the letter-comparison test). Effects of Age Group were found on inhibition, on updating and on processing speed in both long and short ISI conditions. A 2 (Age Group)  $\times$  2 (ISI condition) between-participants ANOVA was conducted on these measures.

Young participants scored significantly higher on all measures; *N*-back (23.97 vs. 22.70 in young and older adults, respectively;  $F(1, 139) = 10.67, p < 0.01, \eta_p^2 = 0.07$ ), inhibition (0.37 vs. 0.49)  $F(1, 139)$

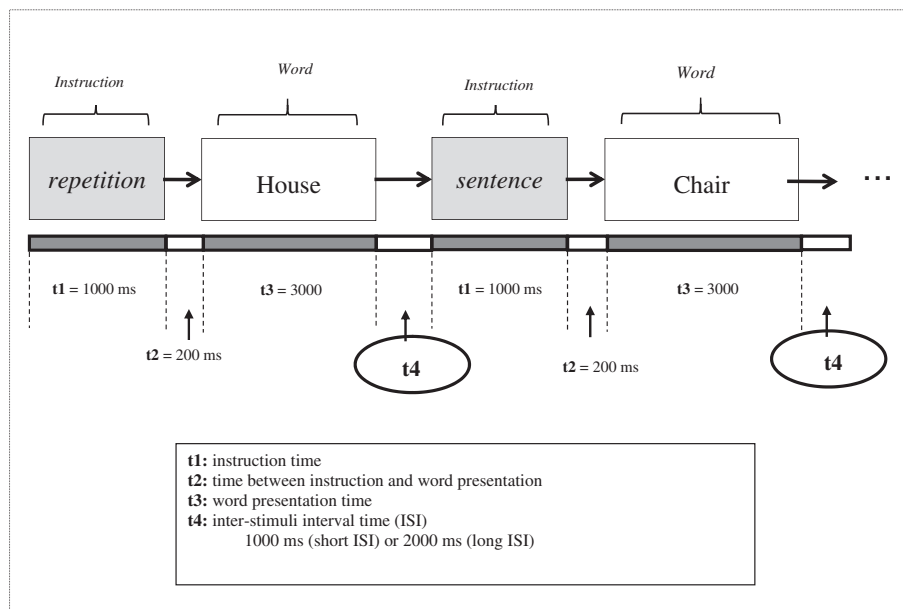


Fig. 1. Example of sequential presentation of instructions and words for the memory test.

= 35.93,  $p < 0.0001$ ,  $\eta_p^2 = 0.20$ ), and letter comparison (32.14 vs. 25.88)  $F(1, 139) = 55.15$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.28$ ). This is consistent with the literature (e.g., Houx, Jolles, & Vreeling, 1993 for inhibition index, Dobbs & Rule, 1989 for *N*-back, and Salthouse, 1996 for processing speed). Main effect of ISI and Age  $\times$  ISI interaction were non-significant on executive functions and processing speed, indicating that participants were comparable in each ISI group.

## 2.2. Material and procedure

### 2.2.1. Memory task

In this experiment, the procedure and materials were the same as in Uittenhove et al.'s (2015) study, except that we manipulated the inter-stimuli interval (ISI). As shown in Fig. 1, ISI was either short (1000 ms) or long (2000 ms).

We constructed two lists of 30 words taken from Bonin et al. (2003). The two lists were matched on imaging values,  $F(1, 58) = 1.90$ , ns, (means = 3.09 and 3.01, for Lists 1 and 2, respectively), on frequency in the French language (2.41 and 2.63), and on emotional valence (2.76 and 2.19, which corresponds to neutral values), all  $F$ s  $< 1.43$ . We created four versions of these two lists by mixing the words in each list (one version of each list is provided in Appendix 1).

Each word could be encoded with one of three available strategies varying in relative difficulty: (a) easy strategy (rote repetition): Participants had to encode the word by saying it aloud three times. The word was preceded by the “repetition” cue; (b) target strategy (sentence construction, the strategy used for the target words): The word was preceded by the “sentence” cue, and participants had to make a simple sentence with the word and say it aloud; and (c) difficult strategy (mental imagery): The word was preceded by the “image” cue, and participants had to make a mental image of the word. At the end of the experiment, participants were asked to describe three mental images in order to verify that they had implemented the strategy.

Words were individually displayed on a computer screen, and presentation was controlled by E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). First, the strategy cue for the following word was displayed for 1 s (see Fig. 1), followed after 200 ms by the word to be learnt, displayed in the centre of the screen for 3 s. After that, the strategy cue for the next word was displayed for 1000 ms (short ISI) or 2000 ms (long ISI). This procedure was repeated for the 30 words and was the same for the second list.

We selected words and strategy transitions to produce two kinds of trial: (1) easy trials involving words encoded with the target strategy and the preceding words encoded with the easy, repetition strategy, and (2) difficult trials involving words encoded with the target strategy and the preceding words encoded with the difficult, mental imagery strategy.

In both lists of words, 15 words were encoded with the target (sentence) strategy and the other words by either repetition or mental imagery. The repetition strategy was cued on eight words in the first list and on seven words in the second list; the mental imagery strategy was cued on seven words in the first list and on eight words in the second list. In both lists, every other word was encoded with the sentence strategy and was randomly preceded by a word encoded with either mental imagery or rote repetition. An example of strategy transition is image-sentence-repetition-sentence-repetition-sentence-image-sentence. The two lists were randomly presented in first or second position, and the strategies assigned to each word were counter-balanced from one participant to another so that each word was encoded with all strategies, and in an easy or difficult condition. After presentation of each list and an interference task, participants performed a free recall task in which they had to retrieve and say aloud every word they could remember without help and in their own time; the experimenter wrote the words down to avoid any writing difficulty, especially for the older adults.

For each participant, we calculated the proportions of correctly recalled words, with two different indexes. The first was a difficulty index and was calculated as follows: [(mean proportion of correctly recalled words learnt with imagery) – (mean proportion of correctly recalled words learnt with rote repetition)]. This index represents the proportion of words recalled with a difficult strategy (mental imagery) to those recalled with the easy strategy (rote repetition). A high difficulty index indicates more words recalled with mental imagery and represents the capacity to benefit more from that strategy than from repetition. By contrast, a low index suggests that imagery is difficult to implement and yields poor recall performance. The second index, named SSDE (an index of strategy sequential difficulty effects) was calculated for each participant as follows: [(mean proportion of correctly recalled words for easy trials) – (mean proportion of correctly recalled words for difficult trials) / (mean proportion of correctly recalled words for easy trials)]. Thus, this index took into account only the words learnt with a sentence strategy, either in the difficult trials

(when the words to be learnt followed a word learnt with a mental image strategy) or in the easy trials (when the words to be learnt followed a word learnt with a repetition strategy). This index represents the impact of using a difficult strategy (mental imagery) on the following (sentence) strategy. Higher SSDE indicates a more negative impact.

Before encoding each list of words, and before the free recall tasks, participants carried out a 30-s interference task (letter comparison test, Salthouse, 1990). This served the dual goal of removing any recency effects and of assessing individuals' processing speed with an independent test. After the memory tasks, participants had a short rest and then took the other tests (*N*-back, Stroop, MMSE, HADS, Mill-Hill Vocabulary test).

### 2.2.2. Executive and processing speed tasks

The Stroop test (Stroop, 1935) was used to assess inhibition and the *N*-back test (Baddeley, 1996) to assess updating of working memory. Both are "paper-and-pencil" tasks commonly used to assess inhibition (Derrfuss, Brass, & Von Cramon, 2004; Hasher & Zacks, 1988) and updating (Owen, McMillan, Laird, & Bullmore, 2005). In the Stroop test, participants had to name the colours of crosses (XXX) on the B card. They also had to name the colour in which a word was written (and to ignore the printed colour word, e.g. RED printed in BLUE) on the C card. They had 30 s per card. Scores for each participant were transformed into proportion scores (inhibition index) as follows: [(number of colours named in baseline condition) – (number of colours named in interference condition)] / (number of colours named in baseline condition) (Li & Bosman, 1996). With this formula, the higher the score, the smaller the inhibition capacity.

In the *N*-back test, participants had to indicate whether or not a letter was the same as one presented (*N*) positions before. In our test, *N* was equal to two, and we measured the number of correct responses in 27 trials.

Processing speed was assessed which the letter-comparison test (Salthouse, 1990). This task is simple and rapid; it is classically used to assess processing speed (Salthouse, 1996; Conway, Cowan, Bunting, Theriault, & Minkoff, 2002). Participants were presented with a page containing pairs of letters (X-O) and were instructed to decide whether the two members of each pair were identical or not, and to tick the 'identical' or 'different' column accordingly. The processing speed measure was the number of items answered correctly within 30 s.

At the end of the experiment, participants were informed about the general goal of the research.

## 3. Results

Results are reported in three main parts. First, we analysed memory performance on current trials in order to investigate how the effects of strategy varied with ISI in young and older adults. Secondly, we examined whether SSDE changed under long ISI (compared to short ISI) in young and older adults. Finally, we examined relationships between aging, processing resources, and strategy performance under short and long ISI conditions. All analyses were run on both the average number of correctly recalled words and the mean proportions of correctly recalled words. The results were the same. Therefore, only proportions of correctly recalled words are reported here (see means in Table 2).

### 3.1. Effects of strategies under short and long ISI conditions

Mean proportions of correctly recalled words were analysed with a mixed-design ANOVA, 2 (Age Group: young, older) × 2 (ISI: short, long) × 3 (Strategy: imagery, sentence, repetition), with Strategy as the only within-participants factor (see Fig. 2).

The effect of Strategy was significant  $F(2,139) = 38.90$ ,  $MSe = 0.38$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.22$ . Overall, participants recalled fewer words

encoded with the repetition strategy (0.16) than words encoded with the sentence strategy (0.26)  $F(1,139) = 80.53$ ,  $MSe = 0.01$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.25$ . This pattern was seen in 75% and 68% of young and older participants, respectively. Also, participants recalled more words with the imagery strategy (0.23) than with the repetition strategy  $F(1,139) = 32.21$ ,  $MSe = 0.01$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.18$ . The imagery strategy yielded higher rates of recall than the repetition strategy in 80% and 66% of young and older participants respectively. Participants recalled more words with the sentence strategy than with the imagery strategy  $F(1,139) = 6.09$ ,  $MSe = 0.01$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.03$ , this pattern was seen in 30% and 64% of the young and older participants respectively. Moreover, the main effect of age showed that young adults recalled more words than older adults (0.28 vs. 0.16)  $F(1,139) = 116.39$ ,  $MSe = 0.01$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.45$ . The significant Age × Strategy interaction,  $F(2,139) = 10.48$ ,  $MSe = 0.10$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.07$  indicated that age-related differences were larger when participants used the imagery strategy  $F(1,139) = 82.07$ ,  $MSe = 0.02$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.31$ ) than when using the sentence Strategy  $F(1,139) = 19.46$ ,  $MSe = 0.001$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.18$  or the repetition strategy ( $F(1,139) = 29.01$ ,  $MSe = 0.01$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.04$ ).

The Age Group × ISI × Strategy interaction was significant  $F(2,139) = 4.68$ ,  $MSe = 0.04$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.03$ . To further analyse this interaction, two 2 (ISI) × 2 (Strategy) breakdown analyses were conducted in each age group separately.

In young adults, the ISI × Strategy was significant,  $F(2,139) = 3.28$ ,  $MSe = 0.01$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.05$  indicating larger strategy effects under the long ISI condition  $F(2, 70) = 26.84$ ,  $MSe = 0.23$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.43$ ) than under the short ISI condition  $F(2, 64) = 6.38$ ,  $MSe = 0.06$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.17$ ). However, the effect of ISI was only marginally significant when participants used the repetition strategy, as recall slightly decreased with increasing ISI (0.22 vs. 0.19)  $F(1, 67) = 2.85$ ,  $p = 0.09$ , and with the imagery strategy. However, the effect of ISI was only marginally significant when participants used the repetition strategy, as recall slightly decreased with increasing ISI (0.22 vs. 0.19)  $F(1, 67) = 2.85$ ,  $p = 0.09$ , and with the imagery strategy  $F(1, 67) = 3.17$ ,  $MSe = 0.03$ ,  $p = 0.07$ , as recall slightly increased with increasing ISI (0.30 vs. 0.35). The effect of ISI was not significant when participants used the sentence strategy (0.29 vs. 0.30)  $F(1, 67) < 1$ .

In older adult, the Strategy × ISI interaction was not significant ( $F < 1$ ), indicating comparable strategy differences under short and long ISI.

### 3.2. Strategy sequential difficulty effects under short and long ISI conditions

Mean proportions of correctly recalled words encoded by the sentence strategy were analysed with a mixed-design ANOVA, 2 (Age Group: young, older) × 2 (Trial difficulty: easy, difficult) × 2 (ISI Condition: short, long). Note that in the easy trials words encoded with the sentence strategy followed words encoded with the repetition strategy, and in difficult trials they followed words encoded with the imagery strategy.

As shown in Table 2, young adults recalled more words than older adults (30% vs. 23%),  $F(1,139) = 29.05$ ,  $MSe = 0.02$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.35$ . The main effect of trial difficulty,  $F(1, 139) = 86.35$ ,  $MSe = 0.008$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.13$ , revealed significant SSDE, as participants recalled more words when the current sentence strategy followed the easier repetition strategy (31%) on the preceding trial than when it followed the harder imagery strategy (21%). Interestingly, SSDE were larger in older adults (36%;  $F(1, 139) = 74.64$ ,  $MSe = 0.008$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.38$ ) than in young adults (15%;  $F(1, 139) = 20.94$ ,  $MSe = 0.008$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.38$ ), as shown by the significant Age × Trial Difficulty interaction,  $F(1, 139) = 7.32$ ,  $MSe = 0.008$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.05$ .

The most original and interesting effect was the significant

**Table 2**

Mean proportions (and SDs) of recalled words learnt with repetition, sentence, and imagery strategies, and strategy sequential difficulty effect (SSDE) in each group and each ISI condition.

	Young adults		Older adults		ANOVA		
	Short ISI (n = 33)	Long ISI (n = 36)	Short ISI (n = 38)	Long ISI (n = 36)	Age	ISI	Interaction
<b>Strategy effects</b>							
Repetition	0.22 (0.10)	0.19 (0.09)	0.12 (0.09)	0.13 (0.10)	***	ns	ns
Imagery	0.30 (0.09)	0.35 (0.12)	0.17 (0.13)	0.15 (0.10)	***	ns	*
Sentence <sup>a</sup>	0.29 (0.12)	0.30 (0.08)	0.22 (0.15)	0.23 (0.11)	***	ns	ns
Difficulty index <sup>b</sup>	0.06 (0.14)	0.14 (0.18)	0.06 (0.16)	0.02 (0.13)	*	ns	*
<b>SSDE</b>							
Sentence-easy trial	0.35 (0.11)	0.32 (0.11)	0.26 (0.11)	0.31 (0.13)	**	ns	ns
Sentence-difficult trial	0.24 (0.12)	0.30 (0.09)	0.17 (0.11)	0.16 (0.08)	***	ns	+
SSDE index <sup>c</sup>	0.26 (0.30)	0.03 (0.37)	0.35 (0.42)	0.36 (0.54)	**	ns	ns

Note. \*:  $p < 0.05$ , \*\*:  $p < 0.01$ , \*\*\*:  $p < 0.001$ , +:  $p = 0.07$ .

<sup>a</sup> Mean proportions of words recalled with sentence strategy in easy and difficult trials.

<sup>b</sup> [(Mean proportions of correctly recalled words learnt with imagery strategy) – (mean proportions of correctly recalled words learnt with rote repetition)].

<sup>c</sup> [(Mean proportions of correctly recalled words for easy trials) – (mean proportions of correctly recalled words for difficult trials) / (mean proportions of correctly recalled words for easy trials)].

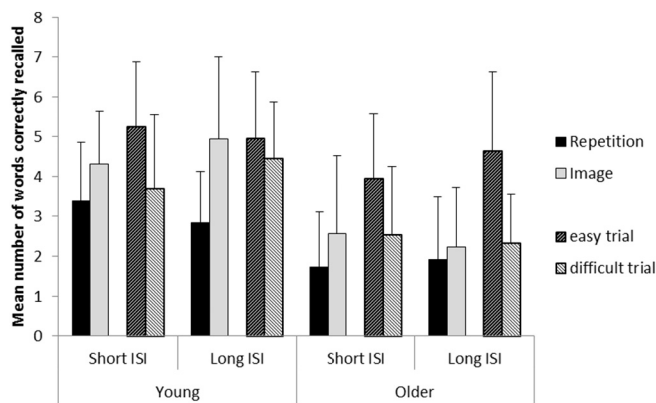


Fig. 2. Mean (and SD) numbers of words correctly recalled as a function of the strategy used in young and older adults under short and long ISI conditions.

Age  $\times$  Trial  $\times$  ISI interaction,  $F(1, 139) = 9.65$ ,  $MSe = 0.008$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.06$ , revealing that SSDE decreased with long ISI for young adults only. To examine this interaction further, two 2 (ISI)  $\times$  2 (Trial Difficulty) breakdown analyses were conducted in each age group.

In young adults, there was a main effect of trial difficulty,  $F(1, 67) = 21.62$ ,  $MSe = 0.007$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.25$ , that interacted with ISI,  $F(1, 67) = 5.65$ ,  $MSe = 0.007$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.08$ . This interaction resulted from significant SSDE in the short ISI condition (27%),  $F(1, 67) = 23.66$ ,  $MSe = 0.007$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.26$ , and non-significant SSDE in the long ISI condition (4%),  $F < 2.71$ . Under the short ISI condition, SSDE were found in 75% of the participants, compared to 25% under the long ISI condition. Under the long ISI condition, SSDE in young adults were not significantly different from 0 [ $t(1, 35) = 0.52$ , ns].

In older adults, there was a main effect of trial difficulty,  $F(1, 72) = 72.52$ ,  $MSe = 0.008$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.50$ , that interacted with ISI,  $F(1, 72) = 4.09$ ,  $MSe = 0.008$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.05$ . This interaction indicated increased SSDE under the long ISI condition (37%),  $F(1, 72) = 54.05$ ,  $MSe = 0.008$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.43$ , compared to the short ISI condition (35%),  $F(1, 72) = 21.68$ ,  $MSe = 0.008$ ,  $p < 0.0001$ ,  $\eta_p^2 = 0.23$ . Under the short ISI condition, SSDE were observed in 76% of the participants, compared to 79% under the long ISI condition.

### 3.3. Relationships among aging, strategies, and processing resources

Two series of correlational analyses were run, one to examine the relationships between processing resources and relative difficulty of strategies, and one to test the relationships between SSDE and processing resources. Both analyses were run in young and older adults under short and long ISI conditions separately. First, correlations between inhibition failure score (Stroop interference), updating (N-back), processing speed (letter comparison), imagery performance, repetition performance, and relative strategy difficulty (Imagery – Repetition)<sup>1</sup> are shown in Table 3.

In young adults, one correlation was significant in the short ISI condition and two in the long ISI condition: Mean number of correctly recalled words encoded with the repetition strategy correlated marginally (positively) with processing speed under the short ISI condition and negatively with updating under the long ISI condition. Difficulty index correlated positively with updating under the long ISI condition. In older adults, four correlations were significant in the short ISI condition and two in the long ISI condition. Under the short ISI condition, mean number of correctly recalled words encoded with imagery correlated negatively with inhibition failure score and positively with processing speed measures. Difficulty index correlated positively with processing speed and correlated negatively with inhibition failure score. Under the long ISI condition, older adults' mean number of correctly recalled words encoded with repetition correlated positively with processing speed, but the difficulty index correlated negatively with processing speed. These correlations indicate that (a) the young individuals who executed the repetition strategy most efficiently were those who had the highest processing speed among participants in the short ISI group, and those who had the least efficient updating capacities among participants in the long ISI group, (b) under the long ISI condition, young individuals with the highest updating capacities were those who benefited more from the imagery strategy relative to the repetition strategy, whereas those with low updating capacities recalled more words learnt with the repetition strategy, (c) older adults with the best inhibition and processing speed capacities executed the harder imagery strategy most efficiently under the short ISI condition, (d) older adults tested under the long ISI condition with higher processing speed benefited less from the imagery than the repetition strategy. This negative correlation may seem surprising, but it arises from the increase in correctly recalled words learnt with repetition, while the recall of words learnt with the imagery strategy did not improve with longer ISI. Consequently, the difficulty index decreased because there was less difference between the two types of words and reflects better perfor-

**Table 3**

Correlations between measures of processing resources (inhibition, updating, processing speed) and strategy performance in young and older adults tested under short and long ISI conditions.

	Short ISI							Long ISI						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
<b>Young adults</b>														
1. Imagery	–	0.01	0.72***	–0.24	–0.20	0.26	0.10	–	–0.21	0.59***	–0.22	0.13	0.26	0.30
2. Repetition		–	–0.77***	0.07	0.16	–0.06	0.33 +		–	–0.76***	0.12	–0.16	–0.35*	–0.07
3. Difficulty index			–	–0.21	–0.24	0.21	–0.17			–	–0.23	0.18	0.37*	0.26
4. SSDE				–	0.37*	–0.37*	0.24				–	0.15	–0.05	–0.13
5. Inhibition					–	–0.60***	0.04					–	–0.18	–0.46**
6. Updating						–	–0.15						–	0.10
7. Processing speed							–							–
<b>Older adults</b>														
1. Imagery	–	0.19	0.80***	–0.45*	–0.37*	0.33	0.57**	–	0.43*	0.72***	–0.49**	–0.29	0.10	–0.17
2. Repetition		–	–0.43*	–0.15	0.02	0.19	0.14		–	–0.33	–0.06	–0.12	0.40*	0.46**
3. Difficulty index			–	–0.32	–0.36*	0.19	0.43*			–	–0.47*	–0.21	–0.20	–0.53**
4. SSDE				–	0.37*	–0.10	–0.28				–	0.38*	0.35	0.11
5. Inhibition					–	–0.24	–0.19					–	–0.13	–0.03
6. Updating						–	0.15						–	0.15
7. Processing speed							–							–

Note. +:  $p = 0.06$ ; \*:  $p < 0.05$ ; \*\*:  $p < 0.01$ ; \*\*\*:  $p < 0.001$ ; SSDE = sequential strategy difficulty effects (i.e., performance with sentence strategy following Imagery – performance with sentence strategy following Repetition).

mance due to increased recall. In other words, older adults with a high level of processing speed had better recall but a smaller difficulty index (i.e., negative correlation).

Next, we calculated correlations between inhibition failure score, updating, processing speed, and SSDE, again separately in each age group and under each ISI condition (see Table 3). SSDE in young adults correlated with inhibition failure score and updating when they were tested under the short ISI condition, and with no factor when they were tested under the long ISI condition. In older adults, SSDE correlated positively with inhibition failure score and negatively with imagery under the short ISI condition. Under the long ISI condition, SSDE correlated negatively with the proportion of words recalled and learnt with the imagery strategy and with the difficulty index and positively with inhibition failure score. These correlations indicate that (a) young individuals with more efficient inhibition and updating capacities showed smaller SSDE under the short ISI condition, (b) individual differences in young adults' processing resources resulted in no individual differences in SSDE under the long ISI condition, (c) older individuals tested under both the short and long ISI conditions who had poorer inhibition capacities and for whom executing the imagery strategy was more demanding showed larger SSDE, and (d) older individuals for whom imagery was much more difficult than repetition were also those who showed larger SSDE under long ISI.

### 3.4. Variables accounting for SSDE

Hierarchical regression analyses were conducted to determine which variables contributed most to variations in SSDE magnitudes in the young and older groups and under the short and long ISI conditions. In each regression analysis, the variables correlating with SSDE in each group were tested (see Table 4).

In young adults, under the short ISI condition, inhibition accounted for 14% ( $p < 0.05$ ) of the variance in SSDE. Updating added a nonsignificant 1%. Participants with the best inhibition capacities showed the smallest SSDE. In other words, the influence of the difficult strategy on performance on subsequent items was smallest in individuals with the highest inhibition resources. Under the long ISI condition, no variables correlated with SSDE.

The same analyses conducted in older adults showed that the SSDE mediator was imagery, accounting for 20% of the variance in SSDE ( $p < 0.05$ ) under short ISI conditions; inhibition added nonsignificant 5%

**Table 4**

Proportions of variance explained in the SSDE by each variable in each group and under each ISI condition.

		Variables	R <sup>2</sup>	R <sup>2</sup> changed
<b>Young participants</b>				
Short ISI	Step 1	Inhibition	0.14	0.14*
	Step 2	Up-dating	0.17	0.03
Long ISI	–	–	–	–
<b>Older participants</b>				
Short ISI	Step 1	Imagery	0.20*	0.20*
	Step 2	Inhibition	0.25	0.05
Long ISI	Step 1	Difficulty index	0.28	0.28**
	Step 2	Inhibition	0.4	0.12*

of variance accounted for. Under the long ISI condition, difficulty index added 28% ( $p < 0.01$ ) of the variance in SSDE, and inhibition accounted for significant 12% additional variance ( $p < 0.05$ ). Thus, implementing the harder imagery strategy influenced performance on subsequent items less in older individuals with the most efficient inhibition capacities, under long ISI conditions.

## 4. Discussion

The aim of the present study was to improve our understanding of (a) relative strategy difficulty in episodic memory, (b) strategy sequential difficulty effects, and (c) age-related differences in these effects. We manipulated the inter-stimulus interval (ISI) when young and older adults were asked to encode lists of words by providing strategy cues (i.e., “image”, “sentence”, or “repetition”). The data enabled us to determine whether giving participants more time between items would affect age-related differences in strategy execution and in trial-to-trial modulations of strategy execution. Moreover, assessing individuals' processing resources enabled us to examine the role played by these resources in age-related differences in strategy execution and in strategy sequential difficulty effects under each ISI condition. Consistent with previous findings, we found effects of age, strategy, and strategy sequential difficulty on recall performance. More specifically, young participants recalled more words than older adults, especially when they used a mental imagery strategy. The effect of strategy was significant in both groups, indicating that words encoded



with a sentence construction strategy were recalled better when the previous strategy was repetition than when it was the harder mental imagery. Also, more originally, the present findings showed that SSDE were significant under the short but not the long ISI condition in young adults, whereas they were significant under both short and long ISI conditions in older adults. Finally, we found that age-related differences in both relative strategy performance and SSDE were correlated with inhibition. These findings further our understanding of the mechanisms underlying SSDE, but should be replicated with much larger samples.

#### 4.1. Efficiency of the strategies as a function of their difficulty

Our results replicate previous findings of the effects of relative strategy difficulty and the age-related differences in these effects. In line with previous studies, we found that participants performed better using a strategy of mental imagery than repetition, even though the former is harder to execute, and that the benefit of mental imagery over repetition was less for older than young adults (Dirkx & Craik, 1992; Plaie & Isingrini, 1999). An unexpected finding revealed by our data is that strategy performance was influenced by ISI only in young adults, for whom the difference in recall performance between words learnt with imagery and those learnt with repetition was greater with long than short ISI. In older adults, this difference decreased, indicating that longer ISI did not lead to more efficient use of the imagery strategy. Our hypothesis was not corroborated, as longer ISI increased the difference between correct recall of words learnt with imagery and with repetition in younger adults; this was not the case in older adults, who increased their correct recall of words learnt with the repetition strategy only. Moreover, only the interaction between strategies and ISI was significant. In fact, the greater difference in performance between imagery and repetition strategies with long ISI in young participants resulted from a non-significant 3% decrease in performance when they used the repetition strategy combined with a non-significant 4% increase in performance when they used the imagery strategy. It is possible that this difference was not significant because the increased interval length was insufficient to highlight different profiles of strategy use. The imagery strategy would require longer to be correctly implemented. Interestingly, we found significant correlations between performance with mental imagery and measures of inhibition and processing speed in older adults under the short ISI condition. Processing speed and inhibition are known to decline with age (e.g., Daniels et al., 2006; Park & Hedden, 2001; see Rabbitt, 2004 for executive function, and Salthouse, 1996 for processing speed specifically). This may contribute to older adults' difficulty to use mental imagery efficiently, as this strategy requires more processing resources than repetition; this may be particularly apparent with short ISI.

#### 4.2. Variations of SSDE in memory as a function of ISI during aging

Furthermore, we replicated previous findings of strategy sequential difficulty effects in young and older adults in memory (Uittenhove et al., 2015) and in arithmetic problem solving (Uittenhove & Lemaire, 2012). Participants recalled fewer words encoded with a sentence construction strategy after execution of a harder mental imagery strategy than after an easier repetition strategy. It should be recalled that these SSDE have been interpreted as resulting from fewer available resources and/or the possibility of interference due to the execution of the previous strategy. Thus we validated our hypothesis.

One of the most original findings of the present study is that SSDE changed with ISI in young but not in older adults. In young adults, SSDE were significant under the short ISI condition and disappeared under the long ISI condition. It is likely that the longer interval gave them sufficient time to replenish their resources, so that the harder imagery strategy used on the immediately preceding words no longer interfered with execution of the sentence construction strategy on the current words. By contrast, older adults' strategy execution continued to suffer

from interference under the long ISI condition, suggesting that they may still have had insufficient time to recharge their processing resources. An alternative account of this Age x ISI x SSDE interaction is that young and older adults make different use of ISI. Young adults may use it to recover from the just executed strategy (i.e., they inhibit that strategy, their cognitive system recharges mental resources for the next item). By contrast, the older adults may continue to execute the imagery strategy (i.e., generating more salient images of each word) under the long ISI condition, interfering with implementation of the sentence construction strategy cued for the following item.

#### 4.3. Variables contributing to SSDE variability

The pattern of correlations between SSDE and processing resources in young and older adults sheds further light on the processes underlying SSDE. In young adults, SSDE did not correlate with any processing resources in the long ISI condition. This is consistent with Uittenhove et al.'s proposal (and previous findings) on the sources of SSDE and with the suggestion that once a strategy has been executed it needs to be inhibited in order to activate the following cued strategy. These operations take time. With insufficient time (i.e. short ISI), execution of a new strategy is influenced by the strategy used to solve the immediately preceding problem. With more time (i.e. longer ISI), there is no interference between successive strategies. However, our hypothesis that the correlations between processing resources and strategy performance would decrease under long ISI condition was not validated in older adults, as correlations between processing resources and SSDE remained significant under the long ISI condition. Under that condition, ISIs were still not long enough to give older adults time to recover completely from executing the hard strategy on the previous problems. This is consistent with the correlation between SSDE and inhibition under both short and long ISI conditions in older but not younger adults.

Note that this is the first study to find differences in SSDE between young and older adults. Previous studies only tested short ISI conditions, which probably accounts for the fact that the two age groups showed similar SSDE. In our study, age-related differences occurred under the long ISI condition, in which older adults' less efficient inhibition capacities prevented them from recovering from the previous hard imagery strategy while encoding current items. By contrast, long ISI enabled young adults to use their efficient inhibitory mechanisms and recharge their processing resources, enabling them to execute the sentence construction strategy equally well after the harder mental imagery or the easier repetition strategy. At a more general (and currently speculative) level, it is interesting to note that sequential modulations of strategy execution interact during aging only under certain timing conditions, here long ISI. These conditions may correspond to situations where the age-related decline in processing resources interferes most with the cognitive performance of older adults.

#### 4.4. Future directions

In addition to furthering our understanding of relative strategy performance, SSDE, and their age-related differences, the present findings have important implications regarding the role of strategy variations in episodic memory and other cognitive tasks, and age-related changes in these variations. As in many other cognitive tasks, both young and older participants are known to use several memory strategies when asked to memorize lists of items, and their performance depends on which strategy they use (see Lemaire, 2015, for a recent overview). In memory, although mental imagery is harder to execute than repetition, it is also more efficient. Previous research found that this relative strategy efficiency depends on stimulus characteristics (e.g., differences in strategy performance between mental imagery and repetition is larger on concrete than on abstract words; Dirkx & Craik,

1992), type of task (e.g., differences in strategy performance between shallow and deep encoding strategies are larger in recognition than in recall tasks; Forger, Taconnat, Landré, Beigneux, & Isingrini, 2009), and strategy transitions (e.g., differences in strategy performance between a better and a poorer memory strategy are larger on items following items encoded with a poorer strategy relative to after items encoded with a better strategy; Hinault, Lemaire & Touron, 2017). Points of interest here are that (a) relative strategy performance in this experiment was not influenced by how much time participants had between stimulus presentations, and (b) by contrast, the influence of relative strategy performance on execution of the strategy for the next item changed with ISI in young adults (but not in older adults). This suggests that relative strategy performance on current items depends on how long young and older participants have to execute strategy-switching mechanisms (including inhibiting the strategy just executed in order to activate and execute the following one most efficiently). The influence of strategy post-execution processes differs in young and

older adults, as they require processing resources that decline with age. In other words, the present results suggest that age-related differences in relative strategy performance depend not only on previously documented factors characterizing stimulus, task, and strategy characteristics, but also on temporal parameters of stimulus transitions. Clearly, the effects of such temporal parameters are unlikely to be specific to the episodic memory tasks (i.e., learning lists of words) used in the present experiment. It would be interesting in future research to investigate whether they generalize to other memory tasks and other cognitive domains.

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### Appendix 1. Lists of words used in the experiment (in French and in English). The words were randomly mixed to create four sublists (1a, 1b, 1c, 1d; 2a, 2b, 2c, 2d).

List 1		List 2	
French	English	French	English
toucan	Toucan	encre	Ink
cornet	Cornet	anneau	Ring
élan	Elk	mite	Mite
aimant	Magnet	massue	Mace
filtre	Filter	poulpe	Poulpe
poumon	Lung	crochet	Hook
colonne	Column	morse	Morse
coupe	Cut	célieri	Celery
archet	Bow	corne	Horn
mèche	Wick	baril	Barrel
étalage	Showcase	cor	Cor
piolet	Pick	toque	Toque
bosse	Bump	lynx	Lynx
sole	Sole	auvent	Awning
navette	Shuttle	burin	Burin
dièse	Sharp	caisse	Crate
écrou	Nut	laque	Shellac
cabine	Cabin	pion	Pawn
pois	Peas	cargo	Cargo
plan	Plan	rabot	Rabot
paume	Palm	renne	Reindeer
harpon	Harpoon	druide	Druid
cadran	Dial	casier	Locker
crête	Crest	bascule	Bascule
pompe	Pump	binette	Binette
lance	Spear	hyène	Hyena
barre	Rod	anse	Bight
rouet	Rouet	boucle	Buckle
banjo	Banjo	mètre	Metre
circuit	Circuit	hachoir	Chopper

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