

Debroux-Method of loci and semantic link in aging

1 Method of loci and semantic link: Assessment of memory benefits in healthy aging

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15 **Abstract**

16 Objective: Episodic memory naturally declines with age. The method of loci is an encoding
17 strategy that has been shown to enhance episodic memory. However, it relies heavily on
18 associative memory, as it consists in associating each item of a to-be-learned list with a location
19 along a familiar route, and associative memory is thought to be the source of the episodic age-
20 related decline. However, when associative memory is supported by semantic knowledge, older
21 adults can compensate for this decline. This study aims to explore the use of the method of loci,
22 that we adapted to leverage pre-existing knowledge in semantic memory, to improve episodic
23 memory in aging. Methods: Word recall performance of young (18–30 years old) and older
24 (60–75 years old) participants was tested after encoding word lists using the method of loci
25 under two conditions: congruent or incongruent with pre-existing knowledge, compared to a
26 control condition. Results: The results showed significant memory performance improvement
27 in both groups when the method of loci was used with congruent associations. In contrast, in
28 older adults, performance in the incongruent condition did not improve compared with that
29 observed during encoding without a specific strategy, highlighting the importance of semantic
30 links for associative memory. Furthermore, using the method of loci with congruent
31 associations, older adults displayed recall performance equivalent to young adults, while it was
32 not the case with incongruent associations. Conclusions: The method of loci applied in
33 conditions of semantic congruence thus appears to be a promising compensatory strategy for
34 older adults.

35 **Keywords**: episodic memory; associative memory; semantic memory; mnemonic strategy;
36 congruence effect; cognitive aging.

37

38 **Statement of Research Significance**

39 Research Question(s) or Topic(s):

40 This study investigates whether older adults benefit even more from a mnemonic strategy (the
41 method of loci) when it is combined with semantic congruence (associating words with familiar
42 and related locations), as semantic relatedness has been shown to improve memory in aging.

43

44 Main Findings:

45 Both young and older adults significantly improved their memory performance when using the
46 method of loci combined with semantically congruent associations (e.g., associating "cake"
47 with "kitchen"). However, in older adults, no benefit was observed when associations were
48 incongruent compared to encoding without specific strategies.

49

50 Study Contributions:

51 These results demonstrate that relying on pre-existing semantic knowledge can effectively
52 compensate for age-related memory decline, making the method of loci particularly beneficial
53 for older adults. This finding opens an avenue to a practical approach for enhancing memory
54 during normal aging.

55 **Introduction**

56 Episodic memory is particularly vulnerable to aging (Angel et Collette, 2015; Craik et Byrd,
57 1982; Salmaso et al., 1993). Some encoding strategies known to improve episodic memory
58 could however help improve the age-related decline.

59 *The method of loci*

60 Among those, the method of loci is a well-established mnemonic strategy, experimentally
61 validated, and based on the principles of associative memory. It consists of associating each
62 item to be remembered with a specific location within a familiar space, such as the steps of a
63 well-known route (for example, a path through one's own house). This imaginary route—also
64 referred to as a “mental palace”—serves as a guide during memory retrieval: by mentally
65 retracing the path, the individual can reactivate, in order, the items originally associated with
66 each location. This encoding strategy contributes to reinforcing the organizational structure of
67 the memory trace. It promotes deeper and more elaborative processing of the information (cf.
68 Levels of Processing theory, Craik and Lockhart, 1972) and provides powerful contextual cues
69 that facilitate retrieval (Legge et al., 2012; Maguire et al., 2003; Raz et al., 2019; Ruchkin et
70 al., 2022; Strandberg et al., 2020).

71 This technique primarily relies on visuospatial mental imagery, as suggested by findings
72 showing increased activation in occipital brain regions—key areas involved in visual
73 processing (Nyberg et al., 2003). It also involves the ability to associate information with a
74 familiar spatial context, and sequential planning, thereby supporting structured encoding and
75 ordered recall of elements (Bower, 1970, cited in Gross et al., 2014; Nyberg et al., 2003; Singer,
76 Lindenberger et Baltes, 2003).

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77 Several empirical studies have confirmed the effectiveness of this approach in young
78 adults, especially compared to free recall conditions without specific strategies (Bellezza et
79 Reddy, 1978; Blunt et VanArsdall, 2021; Legge et al., 2012). For instance, in two experiments
80 conducted by Blunt and VanArsdall (2021), participants using the method of loci recalled
81 significantly more words, with reduced interference during recall, than those in a control
82 condition in which they were asked to evaluate the pleasantness of the words. According to
83 these authors, several features contribute to the effectiveness of this method: the use of mental
84 imagery, temporal planning, as well as the personalized and actively engaging nature of the
85 technique (Blunt et VanArsdall, 2021; Sanchez et al., 2019). Moreover, the method is robust
86 across different types of words (living vs. non-living) and remains effective even when using
87 unfamiliar environments, such as those explored virtually (Legge et al., 2012).

88 This method is of particular interest for older adults, as it mobilizes memory functions
89 that are relatively preserved, such as visuospatial memory, to support more vulnerable functions
90 like episodic memory, as well as certain attentional and executive processes involved in
91 retrieval (Engvig et al., 2010). However, aging is also characterized by a specific decline in
92 associative memory, on which the method of loci relies heavily.

93 *Associative memory in aging*

94 An influential hypothesis indeed suggests that the age-related episodic decline is largely due to
95 specific difficulties forming and recognizing links between arbitrary units of information, in the
96 face of relatively preserved recognition of individual elements (associative deficit hypothesis,
97 Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003).

98 However, the exact nature of this deficit remains a matter of debate. Traditionally, the
99 associative deficit hypothesis attributes this difficulty to inefficient encoding of associations:
100 older adults struggle to initiate or apply controlled encoding strategies that actively link the

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101 elements of an episode (Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2003). Yet, other
102 studies have shown that older adults can encode certain associations, but experience difficulty
103 retrieving them strategically. From this perspective, the associative deficit is also attributable
104 to retrieval failures, such as ineffective access to contextual cues, increased interference, or a
105 lack of retrieval strategies (Hwang et al., 2024; Dew et Giovanello, 2010; Naveh-Benjamin et
106 al., 2007; Troyer et al., 2006). So, on one hand, older adults exhibit a **strategic production**
107 **deficit**, in that they do not spontaneously generate effective relational encoding strategies. On
108 the other hand, they demonstrate a **strategic efficiency deficit**: even when applying suggested
109 strategies, their performance remains lower than that of younger adults due to a generally less
110 efficient implementation. These findings suggest that the associative deficit observed in aging
111 results from both a lack of strategy initiation and a suboptimal use of memory strategies.

112 *The method of loci in aging*

113 Studies examining the effectiveness of the method of loci in older adults remain relatively
114 limited. The available research indicates that this strategy can be beneficial in enhancing
115 memory performance in older individuals (Engvig et al., 2010; Gross et al., 2014; Kliegl, Smith
116 et Baltes, 1990; Nyberg et al., 2003; Singer, Lindenberger et Baltes, 2003). However, the gains
117 observed are generally smaller than those in younger adults (Sandberg et al., 2021; see also the
118 meta-analysis by Gross et al., 2012), even with extended training time (Kliegl, Smith et Baltes,
119 1990). A possible explanation is that, even after specific training, older adults tend to favor
120 simpler mnemonic strategies, such as semantic clustering or storytelling, rather than adopting
121 more complex methods like the method of loci. The latter indeed requires, on top of its reliance
122 on associative memory, the coordination of multiple cognitive processes (mental imagery,
123 planning, serial recall), which can be challenging, despite its potential to compensate for certain
124 functions weakened by aging (Kliegl, Smith et Baltes, 1990; Nyberg et al., 2003, cited in Gross
125 et al., 2014).

126 *Semantic knowledge and unitization in aging*

127 A strategy that has been shown to compensate for episodic memory decline in older adults
128 involves relying on pre-existing semantic knowledge, particularly through thematic
129 associations between elements (for example, between a toothbrush and toothpaste; Delhayé et
130 al., 2019a, 2019b; Folville et al., 2016). This benefit is thought to rely in part on a unitization
131 mechanism, an encoding strategy whereby an object and its semantic associate are fused into a
132 single memory representation—for example, instead of encoding “a cat” and “a couch”
133 separately, one could imagine, based on preexisting knowledge, “a cat sleeping on a couch” as
134 a coherent and integrated representation.

135 Unitization promotes familiarity-based retrieval rather than recollection, in contrast to
136 memory for arbitrary associations or free recall that primarily rely on recollection (Yonelinas,
137 2002). Familiarity—the ability to recognize information without recalling the contextual
138 details of its learning episode—is a process that remains relatively preserved with age (Koen
139 et Yonelinas, 2014). In contrast, recollection, which involves active and controlled retrieval of
140 the encoding context, is particularly vulnerable to aging (Light et al., 2000). Thus, by
141 facilitating unitization through pre-existing semantic knowledge, it is possible to enhance older
142 adults’ associative memory by leveraging memory mechanisms that are less affected by aging.

143 *Interference in aging*

144 Healthy aging, often associated with a decline in executive functions, is accompanied by a
145 weakening of inhibitory mechanisms, which increases susceptibility to interference, notably in
146 the context of learning and episodic memory retrieval. Notably, the **inhibitory deficit**
147 **hypothesis** (Hwang et al., 2024) proposes that older adults display an increased tendency to
148 involuntarily bind irrelevant elements together due to a decline in inhibitory mechanisms. In
149 implicit encoding tasks, older adults tend to form associations even with distractors, leading to

150 an excess of irrelevant associations and increased interference during retrieval (Hwang et al.,
151 2024). This **hyperbinding** phenomenon (Campbell et al., 2010) would thus reflect **non-**
152 **selective encoding**, in contrast with the lack of relevant associations emphasized by the
153 associative deficit hypothesis.

154 The method of loci is presented as a strategy that can help compensate for certain
155 executive difficulties by providing a structured system for retrieving information from episodic
156 memory (Roediger, 1980; Wang et Thomas, 2000). However, this perspective is nuanced in the
157 literature: some authors point out that when the same mental palace is used for multiple
158 memorization episodes, interference effects may arise, both as proactive interference —where
159 previously memorized lists hinder the learning of new ones— and retroactive interference —
160 where new lists impair the recall of earlier ones (Massen et Vaterrodt-Plünnecke, 2006; De Beni
161 et Cornoldi, 1988). These effects appear to be particularly pronounced among novice users of
162 the method of loci (Berha, 2013). Given older adults' decline in controlled resources (Hwang
163 et al., 2024), they could be more susceptible to such interference when applying the method of
164 loci.

165 However, some studies have shown that certain mnemonists are able to reuse the same
166 mental path repeatedly without any decline in episodic memory performance, likely due to their
167 ability to inhibit or quickly erase previous associations (De Beni et Cornoldi, 1988; O'Brien,
168 1993). Other research suggests that rigorous training in the method of loci could enhance its
169 effectiveness (Berha, 2013). Indeed, Berha (2013) demonstrated that training in spatial
170 navigation and mental imagery significantly improves memory performance while reducing
171 interference effects.

172

173

174 *Study design and hypotheses*

175 To improve episodic memory performance in older adults while engaging cognitive functions
176 that are relatively well preserved with age, such as visuo-spatial and semantic memory, we used
177 a strategic encoding approach based on the method of loci, that we combined with the use of
178 preexisting semantic knowledge to foster the formation of richer, more coherent, and more
179 structured—and possibly unified— mental images.

180 Two groups of participants were recruited: a group of older adults and a group of young
181 adults. Word list recall performance was compared in three experimental conditions. In the first
182 condition, called “baseline” condition, participants encoded and recalled a list of words without
183 any specific instructions or mnemonic technique to structure encoding. In the second condition,
184 referred to as the “congruent method of loci,” participants were asked to encode a list of words
185 by mentally navigating a familiar route through their home, with each word being semantically
186 linked to a specific location (for example, “cake” with “stove”). We hypothesize that the
187 presence of semantic links facilitates the unitization of word-location associations, allowing
188 older adults to rely on preserved familiarity during episodic memory retrieval.

189 In contrast, in the third condition, called the “incongruent method of loci”, word
190 encoding was also done while mentally navigating a route in their home, but words were
191 associated with places in an incongruent manner (e.g., “doll” associated with “refrigerator”).
192 Of note, this last condition corresponds to the traditional method of loci, with no specific
193 semantic link between words and places.

194 We hypothesize that participants' performance would follow a gradual progression, with
195 the lowest scores in the baseline condition, intermediate scores in the incongruent method of
196 loci condition and the highest scores in the congruent method of loci condition. Furthermore,
197 we anticipated that age-related differences should appear in the baseline and incongruent
198 method of loci conditions, but should be reduced, if not suppressed, in the congruent method

199 of loci condition, given that older subjects' pre-existing semantic knowledge should support and
200 enhance their performance (Greenberg et Verfaellie, 2010; Greve et al., 2018).

201 **Methods**

202 *Participants*

203 Two groups of participants took part in the study: 24 young adults aged 18 to 30 years and 24
204 older adults aged 60 to 75 years, based on prior studies (e.g., Bridger et al., 2017; Naveh-
205 Benjamin et al., 2005). These groups were matched based on educational level to ensure
206 demographic homogeneity ($t(45) = -0.90; p = 0.37$).

207 Participants were recruited through word-of-mouth, and only those with all the required
208 rooms in their homes necessary for applying the method of loci according to the standardized
209 protocol of this study were selected. All participants reported having no history of neurologic
210 or psychiatric disorder. A score below 23/30 on the MoCA (Montreal Cognitive Assessment;
211 Nasreddine et al., 2005) was an exclusion criterion, as it indicates possible cognitive
212 impairment (Carson et al., 2017). One older adult was excluded from the study for this reason.

213 Each participant provided written informed consent before the study began. The study
214 received approval from the Ethics Committee of the Faculty of Psychology at the University of
215 Liège and was conducted in accordance with the Declaration of Helsinki. Demographic data is
216 presented in Table 1.

217 [Insert Table 1 here]

218 *Materials*

219 The materials included 100 words representing objects (taken from Lists A and B of the 16-
220 items Free and Cued Recall test (RLRI-16) as well as the California Verbal Learning Test
221 (CVLT) for children; **the words from the CVLT were selected because they are constructed to**
222 **represent semantic categories using common, familiar items**) and 16 location names
223 corresponding to rooms or corners of a house. The words were matched to locations in order to

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224 create semantically congruent and incongruent associations with the locations. The exhaustive
225 stimulus list can be found in Table S1 of the Supplementary Materials and examples are
226 provided in Table 2 below.

227 [Insert Table 2 here]

228 Since the use of semantically congruent and incongruent words in this method had never
229 been tested before, the material underwent a validation process. First, a questionnaire was
230 administered to 15 independent participants (13 women and 2 men, with a mean age of 43.6
231 years old; range: 21-62 years old) to verify whether their home contained 21 identified locations
232 for the task and to assess their ability to visualize each location using mental imagery on a
233 Likert scale from 1 (I cannot visualize it) to 5 (I visualize it very clearly). The 16 selected
234 locations, to be used as reference points in the method of loci mental journey, were owned by
235 a minimum of 86% of the sample and rated as easy to imagine.

236 Next, another questionnaire was administered to 8 independent participants (3 women
237 and 5 men, with a mean age of 40.5 years; range: 23-66 years old) to assess the semantic link
238 between created word-location pairs. To associate the words with the locations, we first
239 predefined a list of four words for each specific location (2 *a-priori* more congruent, and 2 *a-*
240 *priori* more incongruent). For each of the four words associated with a given location,
241 participants were asked to rate the level of congruence on a scale from 1 (completely
242 incongruent) to 5 (completely congruent). From this, we selected 28 word-location associations
243 with an average score ≥ 4 to form the congruent associations (i.e., 12 of the 16 locations were
244 presented twice in the congruent condition), and 28 word-location associations with an average
245 score ≤ 2 to form the incongruent associations (i.e., 12 of the 16 locations were presented twice
246 in the incongruent condition), so that we ended up with a total of 56 word-location associations.
247 We selected 28 words from the remaining words to form the study list for our baseline

248 condition. The words did not differ in terms of length and frequency across lists¹. The 16
249 remaining words that were not selected for the main task served for the training during which
250 participants familiarized themselves with the method of loci. The finalized material was tested
251 on 9 pilot participants from both age groups (5 young subjects and 4 older subjects) to ensure
252 the absence of ceiling and floor effects in the recall test.

253 *Procedure*

254 Each participant took part in the study individually in a testing session lasting between 1.5 and
255 2 hours which took place in their home². The tasks were performed on a laptop equipped with
256 the E-Prime software. After providing written informed consent, participants began with the
257 baseline free recall task, which required them to encode 28 words presented successively on
258 the screen, with each word appearing for 4 seconds, followed by a 1-second fixation cross. After
259 the encoding phase, a 1 minute and 30-second countdown distraction task was administered to
260 reduce the effect of immediate repetition. Participants then completed a free recall test, in which
261 they had to recall as many words as possible in any order. This condition established a baseline
262 measure of their memory performance in the absence of mnemonic aid. Afterwards, the Block
263 Tapping Test was administered, serving both as a distraction task and as a measure of
264 visuospatial span (Corsi, 1972).

265 Next, participants underwent training in the method of loci. Detailed instructions,
266 combining written and oral explanations, were provided to guide them in applying this
267 technique. First, participants were asked to perform a structured mental exploration through
268 various rooms in their home following a predefined route, visualizing each room in detail. The

¹ The lists were not matched in terms of imageability ($F(2) = 8.56, p = .014$) and valence ($F(2) = 10.58, p = .005$), which differed significantly across the three encoding conditions, with congruent words having higher valence ($p = .009$) and higher imageability ($p = .049$) than incongruent ones, and incongruent words having lower valence ($p = .021$) and lower imageability ($p = .019$) than baseline words. These lexical differences, which were not controlled for, represent a potential confounding factor in interpreting the effects observed (see supplementary results for more information).

² The overlap between the location where the testing took place in the subjects' home and the locations used along the standardized route of the method of loci was not controlled for.

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269 name of each room appeared on the computer screen in a fixed, predefined order, ensuring that
270 all participants followed the same path. Participants had to confirm the presence of each room
271 in their own home and then rated the vividness of their mental image for each location on a
272 Likert scale from 1 (no image) to 5 (very vivid image), in a self-paced manner.

273 In the next phase, participants completed a training session for the main task, which
274 included a word-location encoding task using the method of loci. This involved memorizing 16
275 words, each paired with a location (regardless of congruency), with each pair presented for 4
276 seconds, followed by a 1-second fixation cross. Locations were always presented in a fixed
277 order along a predefined route, to standardize the protocol across participants. After a 1-minute
278 30-second countdown distracting task, participants completed a free recall test of the words
279 from the list. They were encouraged to use the route in the house to help recall the words, but
280 they were not required to mention the associated locations. Subsequently, the Camel and Cactus
281 Test (Bozeat et al., 2000) was administered, serving both as a distraction task and an assessment
282 of participants' semantic association abilities.

283 Then, 56 words were encoded using the method of loci. These 56 words were distributed
284 across two separate encoding blocks of 28 words each. Importantly, both congruent and
285 incongruent associations were mixed within each block. The block order was counterbalanced
286 across participants. The procedure mirrored that of the training phase, with the only difference
287 being the division into two blocks to reduce participants' cognitive load. Each block included
288 12 locations that were presented twice: once with a congruent word and once with an
289 incongruent word. Additionally, four locations were presented only once—two with congruent
290 words and two with incongruent words. This was done due to the limited number of locations
291 common to most participants' homes, according to our pre-tests. In total, in each block,
292 participants navigated a set of 16 locations arranged along a predefined and standardized mental

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293 route, which remained the same for all participants. After encoding, there was a 1-minute 30-
294 second countdown distraction task, and then participants recalled as many words as possible.

295 In each block, word recall was recorded as 1 or 0 (present or absent), and each intrusion
296 was coded as 1 (the exact nature of the intrusions was not recorded).

297 [Insert Figure 1 here]

298 A mental imagery test was administered to both groups between the two blocks to
299 evaluate their visualization abilities (Bourlon et al., 2009). Finally, the MoCA (Montreal
300 Cognitive Assessment; Nasreddine et al., 2005) was administered to older participants to assess
301 their global cognitive functions. At the end of the study, a compliance questionnaire on the
302 method of loci was given to all participants to verify that they had correctly applied this strategy
303 during encoding. Each participant was asked whether they had used the method of loci during
304 the encoding phase (yes/no). All participants confirmed that they had applied this mnemonic
305 strategy as instructed.

306

307 *Statistical Analyses*

308 We compared performance on cognitive tests (Block Tapping Test, Camel and Cactus Test, and
309 mental imagery test) between the two groups using independent samples t-tests.

310 Then, we conducted a paired samples t-test to compare participants' performance
311 between the first and second blocks of the main task, to assess whether participants improved
312 their use of the method of loci during the second session.

313 Because we found that participants' performance declined between block 1 and block
314 2, which could be explained by a fatigue effect ($t(46) = 3.50; p < 0.001$; Cohen's $d = 0.51$; 95%
315 CI: $[0.20, 0.81]$)³, we calculated the average score across the two blocks, and computed the

³ Additional analyses examining whether this performance difference could be attributed to proactive interference are presented in the Supplementary Analyses.

316 difference between the means of the two blocks (block 1 – block 2). This decline score was
317 introduced in the two-factor (2x3) mixed ANCOVA with the factors: group (young vs. older)
318 and learning condition (no strategy, congruent method of loci, incongruent method of loci) on
319 the proportion of recalled words. Post-hoc tests (Dunn-Bonferroni) were used to compare
320 performance inter-group differences for each experimental condition, and individual repeated-
321 measures ANCOVAs with the factor learning condition (no strategy, congruent method of loci,
322 incongruent method of loci) and the same covariate as previously were used to compare the
323 effect of condition within each group.

324 Correlation analyses between performance on cognitive tests and ‘benefit scores’
325 associated with the method of loci were conducted; details of the computation and results are
326 presented in Supplementary Results (see also Table S2).

327 Finally, a non-parametric 2x2 mixed ANOVA (factors: group: young, older; condition:
328 baseline vs. method of loci) was conducted on intrusion scores to assess interference control.
329 The number of intrusions was recorded separately for each block, during each of the 3 free
330 recall phases and corresponded to recalled words that were not in the study list. Subsequently,
331 we averaged mean intrusions across the two blocks of the method of loci, leading to a single
332 method of loci intrusion score. Of note, intrusions cannot be attributed to the congruent or
333 incongruent conditions, as words were not present at encoding. We predicted that the method
334 of loci could either reduce or increase interference (and thus intrusions) in older adults.

335 To complement our frequentist approach and better quantify the strength of the evidence
336 supporting our results, we also conducted Bayesian analyses by comparing alternative models
337 to the null model. Bayesian analyses are particularly useful, as they make it possible to assess
338 the strength of the evidence either in favor of the null hypothesis or in favor of the alternative
339 hypothesis, or whether the data simply remain inconclusive. Here, we used the Bayes factor
340 (BF_{10}), which quantifies the strength of evidence in favor of the alternative hypothesis over to

341 **the null hypothesis.** We present the results of our Bayesian analyses alongside the frequentist
 342 statistics in the Results section.

343 **Results**

344 *Cognitive tasks*

345 Performance in the cognitive tasks is presented in Table 3. Group comparisons revealed poorer
 346 performance in older adults in the Block Tapping Test, but age invariance in the Camel and
 347 Cactus Test and Mental Imagery Test.

348 [Insert Table 3 here]

349 *Recall performance as a function of group and condition*

350 Performance of the two groups in the three conditions is illustrated in Figure 2. The 2 (Group)
 351 x 3 (Condition) mixed ANCOVA revealed a significant main effect of condition ($F(2,88) =$
 352 $38.59, p < 0.001, \eta^2_p = 0.47, BF_{10} = 2.36 \times 10^{11}$).

353 A significant main effect of group was also observed ($F(1,44) = 14.55, p < 0.001, \eta^2_p =$
 354 $0.25, BF_{10} = 52.21$). Young participants ($M = 0.65$) performed significantly better than older
 355 participants ($M = 0.49$). A significant interaction between conditions and groups was also found
 356 ($F(2,88) = 7.68, p < 0.001, \eta^2_p = 0.15, BF_{10} = 6.54 \times 10^{14}$). In the incongruent method of loci
 357 condition, young participants ($M = 0.64, SD = 0.2$) outperformed older participants ($M = 0.36,$
 358 $SD = 0.17$), with a significant difference ($t(44) = -4.95; p < 0.001, BF_{10} = 1894$). However, no
 359 significant difference was observed between young ($M = 0.77, SD = 0.17$) and older adults (M
 360 $= 0.66, SD = 0.20$) in the congruent method of loci condition ($t(44) = -2.04; p = 0.71, BF_{10} =$
 361 1.62). In the baseline condition, no significant difference was found between young ($M = 0.53,$
 362 $SD = 0.17$) and older adults ($M = 0.44, SD = 0.12; t(44) = -2.10, p = 0.62, BF_{10} = 1.82$).⁴

⁴The ANOVA without the covariate but including the Block variable led to the same pattern of result, with, additionally, the main effect of Block reported in the ‘Statistical analyses’ section, showing better overall performance in block 1 than in block 2. The Block did not interact with any of the variables.

363 To further explore the effect of condition, we conducted separate one-way ANCOVAs
364 within each group. In older adults, the repeated-measures ANCOVA revealed a significant main
365 effect of encoding condition, $F(2, 42) = 26.38, p < .001, \eta_p^2 = 0.56, BF_{10} = 4.61 \times 10^4$, indicating
366 that memory performance differed significantly across the three encoding conditions (baseline,
367 incongruent, congruent). Post hoc comparisons showed that memory performance was
368 significantly higher in the congruent method of loci condition compared to the baseline ($t(21)$
369 $= -5.30, p < .001, BF_{10} = 1199.3$) and compared to the incongruent condition ($t(21) = 7.66, p <$
370 $.001, BF_{10} = 179837.3$). Additionally, performance in the incongruent condition was
371 significantly worse than in the baseline condition ($t(21) = 3.39, p = .007, BF_{10} = 17.5$).

372 In younger adults, the repeated-measures ANCOVA revealed a significant main effect
373 of encoding condition ($F(2, 44) = 16.83, p < .001, \eta_p^2 = 0.43, BF_{10} = 46,132.82$), indicating that
374 memory performance varied significantly across the three encoding conditions (baseline,
375 incongruent, congruent). Post hoc comparisons further clarified this pattern. Performance in the
376 congruent method of loci condition was significantly higher than in the baseline condition ($t(22)$
377 $= -5.74, p < .001, BF_{10} = 3699.62$) and than in the incongruent condition ($t(22) = 5.82, p < .001;$
378 $BF_{10} = 4460.94$). Although performance in the incongruent condition was numerically higher
379 than in the baseline, the difference did not reach significance ($t(22) = -2.29, p = 0.078, BF_{10} =$
380 2.06).

381 [Insert Figure 2 here]

382

383 *Intrusions*

384 The number of intrusions is presented in Figure 3. Since the distribution of intrusion scores
385 violated the assumption of homogeneity of variances across conditions ($p = .05$), a non-
386 parametric test was used whenever possible (there is no non-parametric option for Bayesian
387 analyses). Results revealed that the difference between younger and older participants in the

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388 number of intrusions in the baseline condition was not statistically significant ($\chi^2 = 0.99$, $p =$
389 $.32$, $\varepsilon^2 = .022$, $BF_{10} = 0.658$).

390 However, when examining the number of intrusions following encoding using the method of
391 loci (collapsing across congruent and incongruent conditions, as intrusions involve non-studied
392 items that cannot be uniquely attributed to one encoding strategy), a significant group difference
393 was found ($\chi^2 = 8.268$, $p = .004$, $\varepsilon^2 = .18$, $BF_{10} = 13.15$). This indicates that older adults produced
394 significantly more intrusions than younger adults during recall.

395 [Insert Figure 3 here]

396 Discussion

397 Older adults experience a decline in episodic memory. To mitigate these difficulties, strategies
398 based on the use of semantic knowledge have been proposed (Delhaye et al., 2019). Indeed, it
399 is well established that semantic knowledge is preserved or even strengthened with age
400 (Bellezza et Reddy, 1978). Another recognized strategy for improving episodic memory
401 performance is the method of loci (Blunt et VanArsdall, 2021; Legge et al., 2012; Maguire et
402 al., 2003; Raz et al., 2019; Ruchkin et al., 2022; Strandberg et al., 2020), including in older
403 adults, although the latter were shown to improve to a lesser degree than young adults do, thus
404 exacerbating age differences (Sandberg et al., 2021; for a meta-analysis, see Gross et al., 2012).
405 The main objective of this study was to examine whether combining the method of loci with
406 semantic knowledge would allow older participants to achieve performance comparable to that
407 of young adults, thereby attenuating their episodic memory decline. To address this objective,
408 two groups of participants (young and older) encoded a list of words using the method of loci
409 versus without any strategy. In the method of loci, the words were either congruent (engaging
410 semantic knowledge) or incongruent with the locations to which they were associated.

411 This study yielded three main findings. First, performance of both young and older
412 participants significantly improved when encoding relied on the method of loci in conditions

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413 congruent with semantic knowledge compared with the use of the method of loci with
414 incongruent object-location associations and the baseline condition. This is consistent with the
415 previously reported benefit of semantic congruency in episodic memory, whereby new
416 information is effectively integrated by leveraging preexisting associations to better organize
417 and retrieve them (Bellezza, 1996). However, to our knowledge, this is the first time that this
418 semantic congruency effect has been demonstrated within the framework of the method of loci.
419 Second, older participants performed worse than younger participants in the incongruent
420 condition, but this difference between groups disappeared in the congruent condition. Third,
421 the method of loci led older adults to higher intrusions than young adults, suggesting greater
422 susceptibility to memory interference or reduced source monitoring in the older group,
423 especially when applying this encoding strategy.

424 Surprisingly, the results also revealed comparable performance between young and
425 older participants after encoding without a specific strategy (baseline condition). This contrasts
426 with classical findings of age-related differences in free recall tasks (Light et al., 2000). This
427 could partly be explained by the fact that we selected participants who had at least two
428 bedrooms in their home, which may have introduced a socio-economic bias. Indeed, older
429 adults from more privileged socio-economic backgrounds benefit from greater cognitive
430 reserve. This increased reserve promotes neural plasticity and cognitive resilience, which
431 translates into better cognitive performance at an advanced age (Fratiglioni et Wang, 2007;
432 Narbutas et al., 2021). This could explain the lack of a significant difference between young
433 and older subjects at baseline. Moreover, our baseline condition may have been too
434 undemanding to reveal differences among cognitively healthy adults from relatively
435 advantaged backgrounds (Light et al., 2000).

436 The method of loci in the incongruent condition in this study corresponds to the
437 traditionally studied method of loci, whose effectiveness has previously been demonstrated

438 both in young participants (Blunt et VanArsdall, 2021; Legge et al., 2012; Maguire et al., 2003;
439 Raz et al., 2019; Ruchkin et al., 2022; Strandberg et al., 2020) and in older participants (Engvig
440 et al., 2010; Gross et al., 2014; Kliegl, Smith et Baltes, 1990; Nyberg et al., 2003; Singer,
441 Lindenberger et Baltes, 2003). Surprisingly, no significant improvement in performance was
442 observed in young participants when using the incongruent method of loci. Although their
443 performance was numerically higher compared to baseline, the difference was not statistically
444 significant. In contrast, among older adults, performance in the incongruent method of loci
445 condition was significantly lower than in the baseline condition.

446 Several limitations in this study have however been identified. These may account for
447 the unexpected results. First, the congruent condition was mixed with the incongruent
448 condition, which may have directed participants' attention toward congruent associations at the
449 expense of words from the incongruent condition (Greve et al., 2018), or generated interference
450 between the two conditions. Relatedly, another important divergence from the classical method
451 of loci that generally involves associating only one word per location is that here, most locations
452 were associated with two words, one congruent and one incongruent.

453 Another point is that word-location associations were imposed, preventing participants from
454 benefiting from the spontaneity helping for effective encoding using the method of loci (Berger-
455 Mandelbaum et Magen, 2017). Likewise, the standardized mental route may not have matched
456 their actual home layout, potentially reducing the effectiveness of the method of loci.

457 Also, participants' familiarity with their home environment was not controlled.
458 However, this limitation should be interpreted with caution, as previous research has shown
459 that the method of loci can remain effective even in previously unfamiliar environments (Legge
460 et al., 2012). In addition, conducting the task at home may have influenced performance
461 variably: while it reduced stress and increased ecological validity, it also introduced unequal
462 contextual cues, especially from the room where testing occurred. Third, word lists were not

463 counterbalanced across conditions, and words in the incongruent condition had lower valence
464 and imageability. These lexical differences could partly explain the lack of significant
465 improvement in that condition for older adults, **but also limit interpretations**. Moreover,
466 semantic relatedness between the words - especially congruent ones - to be encoded was not
467 controlled. However, this represents an inherent feature of our experimental paradigm: words
468 that are congruent with home locations tend to be more semantically related to one another.
469 Finally, the specificity of the spatial locations varied (e.g., full rooms vs. sub-areas), introducing
470 possible inconsistencies in mental imagery. This heterogeneity, though reflective of natural
471 variations, may have affected the concreteness of associations and, in turn, performance.

472 However, the fact that our methodological limitations did not compromise encoding via
473 the method of loci in the semantic congruence condition further highlights the strength and
474 robustness of this strategy.

475 To further explore the avenue opened by the current study, future research should record
476 the order of item recall, to help assess whether the method of loci supports temporal
477 organization, particularly in older adults. Finally, examining intrusion errors could reveal
478 whether semantic schema activation interferes with encoding, especially when items are
479 incongruent with familiar locations.

480

481 **Conclusion**

482 Numerous studies have demonstrated the effectiveness of the method of loci as a mnemonic
483 strategy that enhances episodic memory performance and facilitates learning (Blunt et
484 VanArsdall, 2021; McCabe, 2015; Ruchkin et al., 2022; Sandberg et al., 2020). However, few
485 studies have examined its effectiveness in the context of aging, where episodic memory
486 declines while semantic memory remains well preserved (Engvig et al., 2010 ; Gross et al.,

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487 2014 ; Singer, Lindenberger et Baltes, 2003). This study provides insights into this question by
488 exploring the use of the method of loci in connection with semantic knowledge in older adults.

489 This study demonstrated that the method of loci in the congruent condition is an
490 effective tool for improving memory performance in both young adults and older individuals.
491 The results highlight the importance of semantic congruence between word-location
492 associations in optimizing recall performance. Indeed, participants, regardless of age, achieved
493 better performance in the congruent condition, confirming the benefit of semantic knowledge
494 in information retrieval. Furthermore, using the method of loci in the congruent condition, older
495 adults displayed recall performance equivalent to young adults. Additionally, the study
496 highlights several key aspects to consider in future research in this field.

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498 **Declaration of competing interests**

499 The authors declare that they have no competing interests related to this study.

500

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715

716 Table 1. Participants' characteristics

	<i>Young</i>	<i>Older</i>
N	24	23
Sex (M/F)	7 / 17	8 / 15
Age	23.87 (2.98)	65.56 (4.92)
Education level	14.25 (2.74)	13.39 (3.73)
MoCA	/	27.3 (2.22)

717 Note. Standard deviations are indicated in parentheses. Educational level is determined by the
718 mean number of years of formal education and its standard deviation. (Montreal Cognitive
719 Assessment; Nasreddine et al., 2005).

720 Table 2. Description of the experimental material – Three encoding conditions: baseline,
721 congruent word-location associations, and incongruent word-location associations.

Baseline	Congruent	Incongruent
celery	doormat - hall	linden - guest room
harp	book - coffee table	tractor - bed
dentist	lamp - dining room	lemon - wardrobe
stairs	blanket – bed	chainsaw - desk

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740 Table 3. Mean Scores (and standard deviation) young adults and older adults on cognitive test

	<i>Older adults</i>	<i>Young adults</i>	<i>t</i>	<i>p</i>	<i>BF₁₀</i>
Block Tapping Test - direct order	7.45 (2.02)	9.25 (1.42)	-3.38	0.002	22.2
Block Tapping Test - indirect order	7.17 (1.55)	8.79 (1.84)	-3.60	<.001	37.6
Camel and Cactus Test (/64)	58.67 (2.33)	58.04 (3.18)	0.69	0.49	0.352
Mental Imagery Test (/135)	135 (4.08)	135.54 (3.36)	-0.38	0.71	0.307

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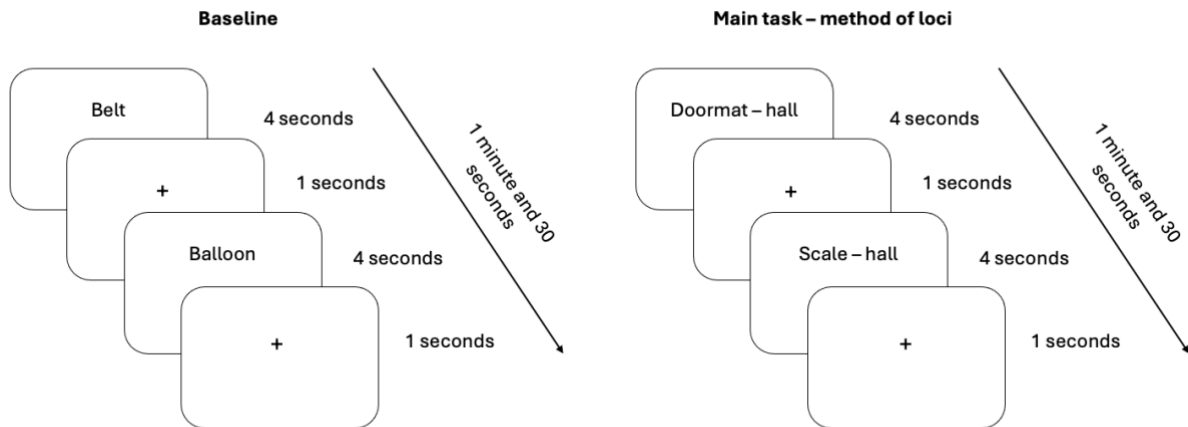
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755 Figure 1. Illustration of our encoding task, showing the encoding conditions: without strategy
756 (baseline, on the left) and with strategy (method of loci, on the right), where, in this example,
757 the congruent condition appears first, followed by the incongruent one.

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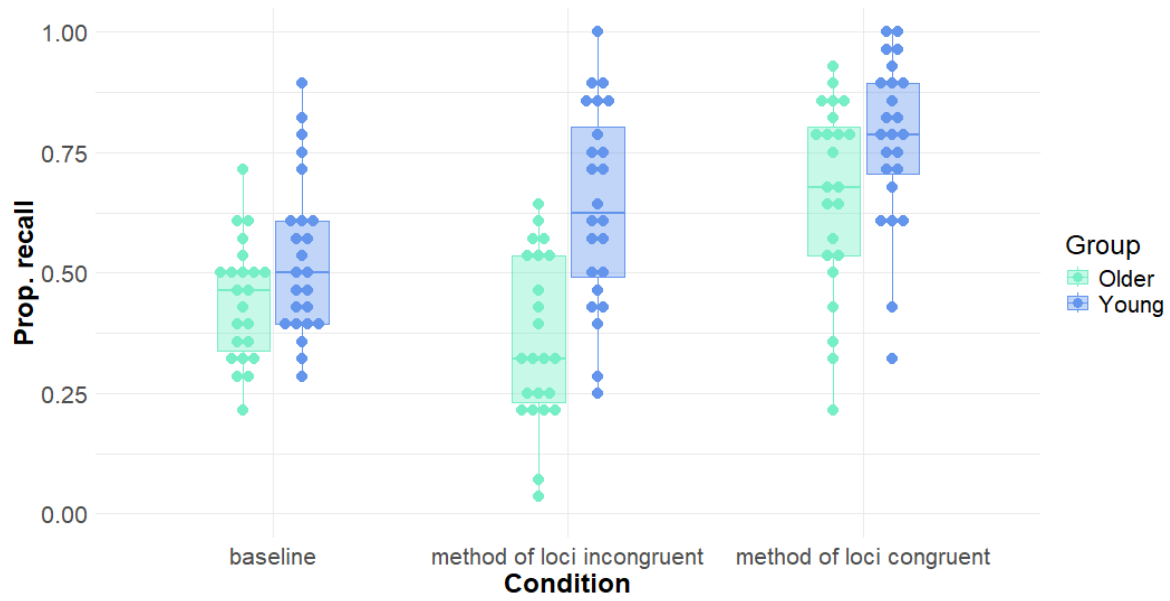
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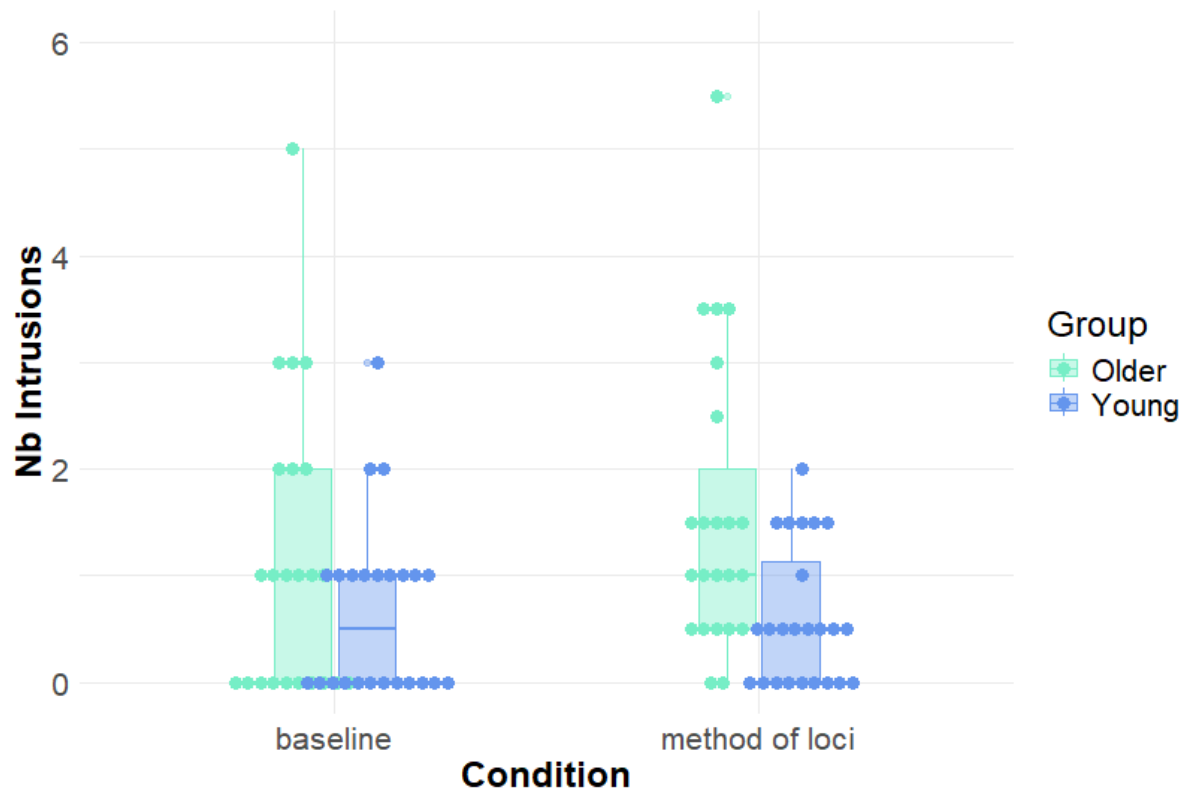
Debroux-Method of loci and semantic link in aging



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767 Figure 2. Recall proportion across the three conditions and the two age groups. Each point

768 corresponds to an individual data value within the respective group and condition.



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770 Figure 3. Number of intrusions according to the condition (baseline vs. method of loci) and the
771 group.

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