A Cross-sectional Study on Interference Control: Age Affects Reactive Control but not Proactive Control

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Background. Working memory updating (WMU), a controlled process to continuously adapt to the changing task demand and environment, is crucial for cognitive executive function. Although previous studies have shown that the elderly were more susceptible to cognitive interference than the youngsters, the picture of age-related deterioration of WMU is incomplete due to lack of study on people at their middle ages. Thus, the present study investigated the impact of age on the WMU among adults by a cross-sectional design to verify whether inefficiency interference control accounts for the aging of WMU. **Methods.** In total, 112 healthy adults were recruited for this study; 28 old adults (21 female) ranging from60-78 years of age; 28 middle-age adults (25 female) ranging from 45-59 years of age; 28 adults (11 female) ranging from 26-44 years of age; and 28 young adults (26 female) ranging from 18-25 years of age. Each participant completed a 1-back task. The inverse efficiency score (IES) was calculated in various sequences of 3 trials in a row to quantify the performance of WMU for adults of various ages. **Results.** Inverse efficiency score (IES) of both young groups (young adult and adult) were significantly shorter than the old group in both Repeat-Alternate (RA, including□□○ and○○□) and Alternate-Alternate (AA, including ○□○ and □○□) sequential patterns and they were additionally better than the middle-age group in AA sequential pattern . **Conclusion.** With the increase of difficulty in the task, the difference in reactive interference control between young and middle age was gradually revealed, while the difference between young and old remained to apparent. The degradation of WMU aging may begin from middle-age and presents selective impairment in that only reactive interference control, but not proactive interference control, shows pronounced age-related decline. The preliminary results can inform future studies to further explore the whole lifespan trajectories of cognitive

functions.

1 **A Cross-sectional Study on Interference Control: Age Affects**

2 **Reactive Control but not Proactive Control**

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Abstract

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20 the youngsters, the picture of age-related deterioration of WMU is incomplete due to a lack of

21 study on people at their middle ages. Thus, the present study investigated the impact of age on

22 the WMU among adults by a cross-sectional design to verify whether inefficiency interference

23 control accounts for the aging of WMU.

24 **Methods.** In total, 112 healthy adults were recruited for this study; 28 old adults (21 female)

25 ranging from 60-78 years of age; 28 middle-age adults (25 female) ranging from 45-59 years of

26 age; 28 adults (11 female) ranging from 26-44 years of age; and 28 young adults (26 female)

27 ranging from 18-25 years of age. Each participant completed a 1-back task. Inverse efficiency

28 score (IES) was calculated in various sequences of 3 trials in a row to quantify the performance

29 of WMU for adults of various ages.

30 **Results.** Inverse efficiency score (IES) of both young groups (young adult and adult) were

31 significantly shorter than the old group in both Repeat-Alternate (RA,including□□○ and○

32 ○□) and Alternate-Alternate (AA,including ○□○ and □○□) sequential patterns and

33 they were additionally better than the middle-age group in AA sequential pattern.

34 **Conclusion.** With the increase of difficulty in the task, the difference in reactive interference

35 control between young and middle age was gradually revealed, while the difference between

36 young and old remained to be apparent. The degradation of WMU aging may begin from middle-

37 age and presents selective impairment in that only reactive interference control, but not proactive

38 interference control shows pronounced age-related decline. The preliminary results can inform

39 future studies to further explore the whole lifespan trajectories of cognitive functions.

40

Introduction

42 Cognitive aging has been a central theme (Anderson & Craik, 2017) of the growing global aging

43 because the compromised cognitive functioning in later life is a risk factor for increased

44 morbidity and mortality (Bruce, Hoff, Jacobs, & Leaf, 1995). Effective cognitive function can

45 help old adults to maintain independence and promote quality of life in old age (Royall, Palmer,

46 Chiodo, & Polk, 2005). The purpose of exploring age-related cognitive changes is to discover an

47 aging mechanism and to provide preventative interventions. In the past two decades, a

48 substantial body of research has documented the decline of cognition for old adults compared to

49 young adults. The progression of aging is unclear because middle age has been understudied,

50 however, investigating this period of the lifespan is important for the understanding of

51 senescence.

52 Since WM is capacity-limited, working memory updating (WMU) is used to continuously

53 adapt to changing task demands and environment (Morris & Jones, 1990), and is crucial for

54 cognitive executive function. Updating is a process of dismantling and recreating associations

55 between content and context (Artuso & Palladino, 2018). That is, unbinding the outdated

56 contents from their contexts in time and establishing new bindings (Oberauer, 2009). It is hard to

57 distinguish between outdated and new items particularly when they're similar. Many studies

58 have proved that the WMU of young adults over older adults was better, because older adults

59 decreased the ability to modulate brain activation and they could not maintain a better

60 availability of attention representations to efficiently inhibit irrelevant information (Arjona,

61 Escudero, & Gómez, 2016; Fiore, Borella, Mammarella, & Cornoldi, 2011; Podell et al., 2012;

62 Sambataro et al., 2015). Old adults need larger accuracy cost and an additional focus-switch cost,

63 which is the cost of switching attention to relevant information (Schmiedek, Li, & Lindenberger,

64 2009; Verhaeghen & Basak, 2005), especially old-old adults (Borella, Carretti, Cornoldi, & De

65 Beni, 2007; De Beni & Palladino, 2004; Kato et al., 2016). The inefficient inhibition of irrelevant

66 information was thought to be the crucial reason for WMU aging. But Borella, Carretti, and De

67 Beni (2008) recruited 304 subjects age-range 20-86 to measure 4 kinds of WM tasks and 2 kinds

68 of inhibition tasks. Results showed that inhibition was not as a crucial contributor to age-related

69 decline in the functional capacity of WM across the adult life-span as previously thought.

70 Recently, Dagry, Vergauwe, and Barrouillet (2017) suggested that during WMU, attention was

71 allocated to capture current goals but not to inhibit stimulus that should be ignored.

72   Control processes are a critical component of the WM function (Braver, Gray, & Burgess,

73   2012). When the task contains high interference, the task will tax more cognitive control

74   resources to protect the contents of memory against interference (Szmalec, Verbruggen,

75   Vandierendonck, & Kemps, 2011). Control processes in WMU are responsible for selecting

76   relevant information; preventing interference; updating at appropriate junctures and so on

77   (Braver et al., 2012). Kessler and Meiran (2006, 2008) pointed out there are two dissociable

78   independent components contributing to WMU, one is used to modify the relevant

79   representations in memory, the other one is used to protect the contents of WM against

80   interference. Some empirical studies also embraced this view (Artuso & Palladino, 2011; Rac-

81   Lubashevsky & Kessler, 2016b). For example, in the n-back task, the mismatch trials containing

82   a switch cost was performed slower than the match trials, and the lure trials (no-longer/no-yet

83   relevant item corresponds to the currently presented item) were performed slower than the

84   mismatch trials due to more similarity-based interference they caused (Szmalec et al., 2011). The

85   memory of previous trials affected the current performance (Rac-Lubashevsky & Kessler, 2016b;

86   Szmalec, Demanet, Vandierendonck, & Verbruggen, 2009). How does the control process work?

87   The Dual Mechanisms of Control (DMC) theory stated that two types of cognitive control are

88   dynamically interacting with each other. One is reactive control, which is a transient stimulus-

89   driven. It is responsible for "just-in-time" selection by detecting and solving interference after it

90   occurs. The other one is proactive control, which is anticipatory goal-driven. It is responsible for

91   early selection by anticipating and preventing interference before it occurs (Braver, 2012; Braver

92   et al., 2012). Which cognitive control is the crucial contributor to WMU aging? Some evidence

93   showed that age selectively impaired cognitive control. Recent studies reported that old adults

94   had selective difficulty in memorizing content-context associations but not in isolated contents

95   (Artuso, Cavallini, Bottiroli, & Palladino, 2017; Artuso & Palladino, 2011; McCormick-Huhn,

96   Chen, Wyble, & Dennis, 2018; Old & Naveh-Benjamin, 2008; Pelegrina, Borella, Carretti, &

97   Lechuga, 2012) and the delays in selection were longer with a function of memory load (Artuso

98   et al., 2017), implying that proactive control was impaired with aging. But Xiang et al. (2016)

99   reported that older adults had selective deficits in reactive control.

100   Previous literature comparing young with old adults found an aging effect on WMU,

101   however, the progression of age-related changes and the crucial element causing WMU aging

102   were unknown because of the exclusion of middle-age adults in the previous studies. Previous

103   studies suggested that besides vocabulary knowledge, which increases with aging (Miller &

104   Lachman, 2003; Salthouse, 2010; Singh-Manoux et al., 2012), most cognitive functions decline

105   with aging and present variant recession cycles. For example, content-context binding (Cowan,

106   Naveh-Benjamin, Kilb, & Saults, 2006; Hommel, Kray, & Lindenberger, 2011; Siegel, 1994;

107   Swanson, 2017) and switch (Kray, Eber, & Lindenberger, 2004; Reimers & Maylor, 2005)

108   decrease approximately linearly across the adult life-span. The decline of memory, process speed,

109   inhibition and reasoning begin from middle age (Anstey, Sargent-Cox, Eramudugolla, Magliano,

110   & Shaw, 2015; Borella et al., 2008; Davis et al., 2017; M. L. Hughes, Agrigoroaei, Jeon,

111   Bruzzese, & Lachman, 2018; Persad, Abeles, Zacks, & Denburg, 2002; Singh-Manoux et al.,

112   2012; Zimprich & Mascherek, 2010). Although the timing of age-related decline of cognitive

113   functions varies, middle age looks like an important age boundary.

114   This study focused on verifying whether inefficient interference control is a crucial

115   contributor to WMU aging across the adult life span and employed 1-back test, which includes

116   two stimuli. The interference difficulty was manipulated by adjusting the sequence relationship.

117   Sequential interference had an accumulative effect in N-back test (Oberauer, Souza, Druey, &

118   Gade, 2013; Salmi et al., 2018; Soetens, Boer, & Hueting, 1985) and only lure trial N-1 showed

119   a significant sequence effect in 1-back test (Rac-Lubashevsky & Kessler, 2016b), which had

120   been proved by previous studies. Four sequence patterns were distinguished by the sequence of 3

121   trials in a row. The main objective is to assess age-changes of WMU in four sequence patterns. If

122   WMU aging is attributed to inefficient interferent control, the age-related decline was steeper as

123   interference increases. The hypotheses stated that 1) WMU performance will decline with

124   interference increase, 2) the WMU degradation begins from middle-age and becomes steeper in

125   old age, and 3) age-related decline is getting steeper as interference increases.

126   ## Methods and materials

127   ## Ethical approval

128   This study received approval from the Ethics Committee of Shanghai University of Sport (No.

129   2017044).

130   ## Participants

131   The sample consisted of 112 adult participants, 28 older adults (*21 female*) ranging from 60-78

132   years of age (*M=67.68, SD=4.23*); 28 middle-age adults (*25 female*) ranging from 45-59 years of

133   age (*M=54.25, SD=4.84*); 28 adults (*11 female*) ranging from 26-44 years of age (*M=31.68,*

134   *SD=4.63*); and 28 young adults (*26 female*) ranging from 18-25 years of age (*M=22.71,*

135   *SD=1.67*), recruited through Shanghai University of Sport and local communities. Participants

136   were compensated for a small gift for their participation. All participants didn't have cognitive

137   impairment as tested by the Mini-mental State Examination and signed the informed consent (*see*

138   *Table 1*).

139   *(Insert table 1 about here)*

Stimuli

141   The 1-back task was adopted from Rac-Lubashevsky and Kessler (2016a, 2016b) to observe a

142   participant's ability to update information. This task involved the continuous presentation of a

143   solid gray square "□" (side length 38 mm) or a solid gray circle "○" (the diameter of 38 mm).

144   A Lenovo computer with a 17-inch VGA display (frequency 60 Hz, resolution 1366 × 768) was

145   used for stimulus presentation, and the Matlab2015 software package (Psychtoolbox 3.0) was

146   used for response sampling. All stimuli were presented on a white background.

Task

148   Participants were instructed to monitor stimuli subtended a visual angle of 5.73° horizontally and

149   5.73° vertically from viewing distance 55 cm and decided whether the presented shape was the

150   same as the one that had been presented immediately before by pressing one of two keys on a

151   response box: "3" for "yes" and "1" for "no". The test consisted of a practice block and two

152   formal experimental blocks. The practice block contained 20 trials with feedback to familiarize

153   the participant with the task. The system automatically transitions to the formal experimental

154   session until the accuracy reached up to 66.7% in the practice session, otherwise, the system

155   remained in the practice session. The data of the practice session was not recorded.

156   Each block of the formal test included 42 trials and started with a blank fixation screen

157   presented for 500 ms, the stimulus "□" or "○" was then presented for 500 ms randomly,

158   followed by a white display for 1500 ms. Participants were required to respond quickly and

159   accurately as soon as the target stimuli appeared. The maximum duration for a response to be

160   made was 2000 ms (the presentation of the stimulus 500 ms + the presentation of white display

161   1500 ms). Reaction time and accuracy were automatically recorded by Matlab2015. If the

162   participant didn't respond in time (RT > 2000 ms), the reaction time was recorded as an error.

163   Participants were assured with adequate rest between 2 blocks of the experiment (Fig. 1).

164   (*Insert Figure 1 about here*)

Statistical Analysis

166   Previous studies reported that only the lure trial (trial N-1) influenced the current performance

167   (Trial N+1) in the 1-back task (Rac-Lubashevsky & Kessler, 2016b, 2016a; Soetens et al., 1985;

168   Szmalec et al., 2011). Accordingly, the data were classified by the sequence of 3 trials in a row,

169   and 4 sequence patterns could be identified: 1) Repeating the same stimulus three times (named

170   as RR; including □□□ and ○○○); 2) Repeating the same stimulus twice followed by a

171   different stimulus, (named as RA; including○○□ and □□○); 3) Altering the stimulus in the

172   first two followed by repeating the second stimulus on the third (named as AR; including○□□

173   and □○○); 4) Altering the stimuli twice in the 3 trials (named as AA; including○□○

174   and□○□) (Fig. 2).

175   (*Insert Figure 2 about here*)

176   RT data were cleaned by removing inaccurate and no response trials. RT below 100 ms was

177   treated as response error, and outlying trials which were more than 3 standard deviations above

178   each sequence patter condition mean were removed. Time cost and accuracy are known to be

179   negatively related (Pachella, 1974). Particularly, with increasing difficulty, participants may

180   decide to emphasize either speed or accuracy. Disregard accuracy or analyzing the accuracy and

181   RTs separately impair the power to detect relationships and interactions (Hughes, Linck, Bowles,

182   Koeth, & Bunting, 2014). Consequently, inverse efficiency score (IES), RT with consideration of

183   response accuracy, has been proposed as a good way (Bruyer & Brysbaert, 2011; Townsend &

184   Ashby, 1978) and be used to evaluate updating in this study. IES is calculated as RT divided by

185   PC (the proportion of correct responses). The formula is IES = RT/PC. Performance and IES are

186   negatively related, a lower IES corresponds to better performance. A 4×4 (Sequence

187   pattern×Age) mixed-design ANOVA with sequence pattern (RR, RA, AR, AA) as within-

188   subjects factor and Age (18-25 age, 26-44 age, 45-59 age, ≥60 age) as a between-subjects factor

189   was employed to examine the effects of interference and age on WMU.

190   **Results**

191   The 2-way ANOVA showed significant main effects for Age [F $(3, 108) = 17.43$, $p < 0.001$, η_p^2

192    $=0.326$], Pattern [F $(3, 108) = 132.27$, $p < 0.001$, $\eta_p^2 = 0.551$]. Tukey post-hoc comparisons

193   showed that young adults outperformed middle-age ($p < 0.001$) and old ($p < 0.001$), the same

194   results appeared between adults and middle-age ($p < 0.01$) and old ($p < 0.001$); the difference

195   were not observed both between young adults and adults group (p = 0.725) and middle-age and

196   old group (p = 0.554). That implied the serious degradation of WMU began in middle-age. The

197   significant differences among the 4 sequence patterns were also observed, implying the declined

198   performance with increasing interference, IES of RR was the lowest, then RA, and then AR, AA

199   was the highest ($p < 0.001$).

200   The interaction between Age and Pattern [F $(3, 324) = 6.55$, $p < 0.001$, $\eta_p^2 = 0.121$] reached

201   significance. The simple main effect analysis showed a significant age effect in RA [F $(3, 432) =$

202   3.87, $p < 0.01$] and AA [F $(3, 432) = 35.79$, $p < 0.001$], the post hoc Tukey's HSD test showed

203   that both young groups outperformed the old group in RA, and they outperformed both middle-

204   age and old groups in AA (*see Table 2*). In summary, WMU declined with increasing age,

205   however, the selective age-related impaired was presented (*see Fig 3*).

206   *(Insert table 2 about here)*

207   (*Insert Figure 3 about here*)

208   **Discussion**

209   The study aimed to analyze the impact of age on WMU interference control by a cross-sectional

210   comparison. Updating requires holding temporary binding between contents and contexts and

211   unbinding outdated contents in time because WM capacity is limited. Cognitive control should

212   hold maximal flexibility to find an optimal balance between maintaining and replacing to ensure

213   performance, especially on a strong interference task. In this study, the interference difficulty

214   was manipulated by adjusting the sequence relationship, four sequence patterns including RR,

215   RA, AR, AA patterns were classified by 3 trials in a row. The participants were divided into the

216   youngster, middle-aged and the elderly. Besides, the young participants were subdivided into

217   young adults and adults, because middle-aged had been understudied in previous aging studies,

218   potentially due to that the difference between middle age and other groups was not observed

219   (Phillips et al., 2011). Subdivision of youth groups could help us to acquire a better

220   understanding of the progression of age-related changes across adult life-span particularly from

221   young to middle age. Our results showed two young groups outperformed the old group in both

222   RA and AA and they were additionally better than the middle-age group in AA sequential

223   pattern.

224   Four sequential patterns were classified by 3 trials in a row. As we expected, the

225   performance declined with interference increase. Rac-Lubashevsky and Kessler (2016a, 2016b)

226   separated several contributions to updating by reference-back task. The reference-back task

227   contains reference trials, which is presented inside a red frame, and comparison trials, which is

228   presented inside a blue frame. The participants are required to judge whether the presented

229   stimulus is the same as, or different from, the previous reference trials. In other words, the

230   comparison trials should be compared to the previous reference trails, but should not be updated.

231   Compared with comparison trials, reference trials contain an additional updating cost. In this

232   study, repetition trials as comparison trials should not be updated, the cost was smaller than

233   alternation trials (RR < RA; AR < AA). The previous study of 2-alternative forced-choice task or

234   1-back choice task found AR elicited a stimulus-response (S-R) conflict response which contains

235   additional time cost and accurate cost than other patterns (Rac-Lubashevsky & Kessler, 2016b;

236   Szmalec et al., 2009). But the response of 1-back depended on the relationship between the

237   previous trial and the current stimulus. AA requires the participant to switch focus to relevant

238   information and to prevent similarly interference in terms of ensuring a currently appropriate

239 action (Wylie & Allport, 2000). In this study, an accumulative effect of the sequence interference

240 was observed, especially in AA (RR < AR; RA < AA), suggesting two independent sources of

241 contribution to updating. That was consistent with previous studies (Artuso & Palladino, 2011;

242 Kessler & Meiran, 2006, 2008; Rac-Lubashevsky & Kessler, 2016b).

243   A better WMU of young adults over older adults was proved in this study as well as in

244 many previous studies (Artuso et al., 2017; Guerreiro, Murphy, & Van Gerven, 2013; Hommel et

245 al., 2011; Pelegrina et al., 2012; Phillips et al., 2011; Schmiedek et al., 2009). And the superior

246 performance of young groups to the middle age group was observed in this study. No difference

247 was found between young adult and adult. No difference was found between middle-aged and

248 old adults on total mean IES. Only two stimuli were employed in this study to induce larger

249 similarity-based interference, used IES to increase the detection power, and shortened ISI to

250 prevent participators from refreshing during free time. Even under the circumstances, the

251 difference between young and middle age was observed only in the pattern with the biggest

252 interference (AA). The task of previous studies was possibly too easy to observe the early onset

253 of cognitive impairment at middle age. This is possibly the reason why middle-aged

254 understudied in previous aging studies.

255   Age-related changes varied among 4 sequential patterns and only appeared in RA and AA.

256 The difference between young and old adults was observed in RA and AA. RA and AA contain a

257 characteristic that requires updating the new item and replacing the outdated one after the onset

258 of new items. The age-related decline was observed in alternation trials disregarding prior

259 sequence characteristics, suggesting that age only affected just-in-time selection. The reactive

260 control, but not proactive control, declined with aging (Xiang et al., 2016). That challenged

261 earlier views of age can only affect proactive control (Botvinick, Carter, Braver, Barch, & Cohen,

262 2001; Braver & West, 2015). The difference between young and middle-aged was observed in

263 AA, but not in RA. Compared with RA, AA elicits more similarity-based interference and

264 requires more cognitive control than RA. The difference between young and middle-aged was

265 gradually revealed with the increase of interference, while the difference between young and old

266 remained to be apparent, reflecting the degradation of WMU begins from the middle-age. The

267 age-related decline only appeared in mismatch trials, implying age-related switch deficit might

268 be a crucial contributor to WMU aging across the adult lifespan. However, previous switch aging

269 studies suggested that special switch cost, which represented the differences between switch and

270 nonswitch trials within a block as in this study, were largely unrelated to age; only the global

271 switch, the ability to efficiently coordinate multiple tasks, was negatively affected by age (Kray

272 & Lindenberger, 2000; Mayr & Liebscher, 2001). Using varied tasks may cause different results.

273 The N-back task may be a measure of cognitive control when it involves higher interference

274 (Szmalec et al., 2011). And its interference can continuously increase by manipulating the

275 sequence relationship. The task-induced huge similarity-based interference due to employing

276 only 2 stimuli in this study and the IES index was adopted to ensure the power. All of this may

277 prompt some new findings. Age-related decline in reactive interference control but not in

278 proactive control was gradually revealed after middle age and the decline got steeper with age. In

279 the future, research, particularly including middle age, should consider the impact of task

280 difficulty and the power of indexing on the result. And future studies should explore further the

281 relationship between updating, interference, and aging using the N-back task.

282 Limitations

283 The present study had a few limitations. Firstly, the main motivation of the study is to explore

284 the progression of WMU aging by including the middle age group, but the sample size of the

285 cross-sectional design was too small to further explore timing detail of onset of aging and the

286 progression of aging after 60 age. Secondly, the cross-sectional design could not avoid individual

287 differences within age groups. A larger sample of participants should be recruited in future

288 studies and combine with cross-sectional and longitudinal follow-up design, which may offset

289 the defect of the present study. Finally, the lack of information on education and other socio-

290 economic variables of the studied population may limit the generalization of the findings.

291 Conclusions

292 In conclusion, with the increase of difficulty in the task, the difference in reactive cognitive

293 control between young and middle age was gradually revealed, while the difference between

294 young and old remained to be apparent. The results reflected that WMU degradation may begin

295 from the middle age and become steeper in old age. WMU aging presents selective impairment.

296 Only reactive interference control, but not proactive interference control, shows pronounced age-

297 related decline, which mainly reflects a larger special switch cost. Age-related switch decline

298 may be a crucial contributor to WMU in aging. The preliminary results can inform future studies

299 to further explore the whole lifespan trajectories of cognitive functions.

300

301 **References**

302 Anderson, N. D., & Craik, F. I. M. (2017). 50 Years of Cognitive Aging Theory. *Journals of*
303   *Gerontology - Series B Psychological Sciences and Social Sciences*, *72*(1), 1–6.
304   https://doi.org/10.1093/geronb/gbw108

305 Anstey, K. J., Sargent-Cox, K., Eramudugolla, R., Magliano, D. J., & Shaw, J. E. (2015).
306   Association of cognitive function with glucose tolerance and trajectories of glucose
307   tolerance over 12 years in the AusDiab study. *Alzheimer's Research and Therapy*, *7*(1), 48.
308   https://doi.org/10.1186/s13195-015-0131-4

309 Arjona, A., Escudero, M., & Gómez, C. M. (2016). Cue validity probability influences neural
310   processing of targets. *Biological Psychology*, *119*, 171–183.
311   https://doi.org/10.1016/j.biopsycho.2016.07.001

312 Artuso, C., Cavallini, E., Bottiroli, S., & Palladino, P. (2017). Updating working memory:
313   memory load matters with aging. *Aging Clinical and Experimental Research*, *29*(3), 371–
314   377. https://doi.org/10.1007/s40520-016-0581-y

315 Artuso, C., & Palladino, P. (2011). Content-context binding in verbal working memory updating:
316   On-line and off-line effects. *Acta Psychologica*, *136*(3), 363–369.
317   https://doi.org/10.1016/j.actpsy.2011.01.001

318 Artuso, C., & Palladino, P. (2018). How sublexical association strength modulates updating:
319   Cognitive and strategic effects. *Memory and Cognition*, *46*(2), 285–297.
320   https://doi.org/10.3758/s13421-017-0764-6

321 Borella, E., Carretti, B., Cornoldi, C., & De Beni, R. (2007). Working memory, control of
322   interference and everyday experience of thought interference: When age makes the
323   difference. *Aging Clinical and Experimental Research*, *19*(3), 200–206.
324   https://doi.org/10.1007/BF03324690

325 Borella, E., Carretti, B., & De Beni, R. (2008). Working memory and inhibition across the adult
326   life-span. *Acta Psychologica*, *128*(1), 33–44. https://doi.org/10.1016/j.actpsy.2007.09.008

327 Botvinick, M. M., Carter, C. S., Braver, T. S., Barch, D. M., & Cohen, J. D. (2001). Conflict
328   monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652.
329   https://doi.org/10.1037/0033-295X.108.3.624

330   Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework.
331   *Trends in Cognitive Sciences*, *16*(2), 106–113. https://doi.org/10.1016/j.tics.2011.12.010

332   Braver, T. S., Gray, J. R., & Burgess, G. C. (2012). Explaining the Many Varieties of Working
333   Memory Variation: Dual Mechanisms of Cognitive Control. In C. A. Conway, M. K.
334   Jarrold, A. Miyake, & J. Towse (Eds.), *Variation in Working Memory* (pp. 76–106). Oxford:
335   Oxford University Press. https://doi.org/10.1093/acprof:oso/9780195168648.003.0004

336   Braver, T. S., & West, R. (2015). Working Memory, Executive Control, and Aging. In F. I. M.
337   Craik & T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (pp. 311–372). New
338   York and Hove. https://doi.org/10.4324/9780203837665.ch7

339   Bruce, M. L., Hoff, R. A., Jacobs, S. C., & Leaf, P. J. (1995). The effects of cognitive
340   impairment on 9-year mortality in a community sample. *Journals of Gerontology - Series B*
341   *Psychological Sciences and Social Sciences*, *50 B*(6), P289–P296.
342   https://doi.org/10.1093/geronb/50B.6.P289

343   Bruyer, R., & Brysbaert, M. (2011). Combining Speed and Accuracy in Cognitive Psychology:
344   Is the Inverse Efficiency Score (IES) a Better Dependent Variable than the Mean Reaction
345   Time (RT) and the Percentage Of Errors (PE)? *Psychologica Belgica*, *51*(1), 5.
346   https://doi.org/10.5334/pb-51-1-5

347   Cowan, N., Naveh-Benjamin, M., Kilb, A., & Saults, J. S. (2006). Life-span development of
348   visual working memory: When is feature binding difficult? *Developmental Psychology*,
349   *42*(6), 1089–1102. https://doi.org/10.1037/0012-1649.42.6.1089

350   Dagry, I., Vergauwe, E., & Barrouillet, P. (2017). Cleaning working memory: The fate of
351   distractors. *Journal of Memory and Language*, *92*, 327–342.
352   https://doi.org/10.1016/j.jml.2016.08.002

353   Davis, D., Bendayan, R., Muniz Terrera, G., Hardy, R., Richards, M., & Kuh, D. (2017). Decline
354   in Search Speed and Verbal Memory over 26 Years of Midlife in a British Birth Cohort.
355   *Neuroepidemiology*, *49*(3–4), 121–128. https://doi.org/10.1159/000481136

356   De Beni, R., & Palladino, P. (2004). Decline in working memory updating through ageing:
357   Intrusion error analyses. *Memory*, *12*(1), 75–89.
358   https://doi.org/10.1080/09658210244000568

359   Fiore, F., Borella, E., Mammarella, I. C., & Cornoldi, C. (2011). Mental imagery in a
360   visuospatial working memory task and modulation of activation. *Journal of Cognitive*
361   *Psychology*, *23*(1), 52–59. https://doi.org/10.1080/20445911.2011.454497

362   Guerreiro, M. J. S., Murphy, D. R., & Van Gerven, P. W. M. (2013). Making sense of age-
363   related distractibility: The critical role of sensory modality. *Acta Psychologica*, *142*(2),
364   184–194. https://doi.org/10.1016/j.actpsy.2012.11.007

365   Hommel, B., Kray, J., & Lindenberger, U. (2011). Feature integration across the lifespan:
366   Stickier stimulus-response bindings in children and older adults. *Frontiers in Psychology*, *2*,
367   268. https://doi.org/10.3389/fpsyg.2011.00268

368   Hughes, M. L., Agrigoroaei, S., Jeon, M., Bruzzese, M., & Lachman, M. E. (2018). Change in
369   Cognitive Performance from Midlife into Old Age: Findings from the Midlife in the United
370   States (MIDUS) Study. *Journal of the International Neuropsychological Society*, *24*(8),

371   805–820. https://doi.org/10.1017/S1355617718000425

372 Hughes, M. M., Linck, J. A., Bowles, A. R., Koeth, J. T., & Bunting, M. F. (2014). Alternatives

373   to switch-cost scoring in the task-switching paradigm: Their reliability and increased

374   validity. *Behavior Research Methods*, *46*(3), 702–721. https://doi.org/10.3758/s13428-013-

375   0411-5

376 Kato, K., Nakamura, A., Kato, T., Kuratsubo, I., Iwata, K., Yamagishi, M., & Ito, K. (2016).

377   Age-Related Changes in Attentional Control Using an N-Back Working Memory Paradigm.

378   *Experimental Aging Research*, *42*(4), 390–402.

379   https://doi.org/10.1080/0361073x.2016.1191867

380 Kessler, Y., & Meiran, N. (2006). All updateable objects in working memory are updated

381   whenever any of them are modified: Evidence from the memory updating paradigm.

382   *Journal of Experimental Psychology: Learning Memory and Cognition*, *32*(3), 570–585.

383   https://doi.org/10.1037/0278-7393.32.3.570

384 Kessler, Y., & Meiran, N. (2008). Two Dissociable Updating Processes in Working Memory.

385   *Journal of Experimental Psychology: Learning Memory and Cognition*, *34*(6), 1339–1348.

386   https://doi.org/10.1037/a0013078

387 Kray, J., Eber, J., & Lindenberger, U. (2004). Age differences in executive functioning across

388   the lifespan: The role of verbalization in task preparation. *Acta Psychologica*, *115*(2–3),

389   143–165. https://doi.org/10.1016/j.actpsy.2003.12.001

390 Kray, J., & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and*

391   *Aging*, *15*(1), 126–147. https://doi.org/10.1037/0882-7974.15.1.126

392 Mayr, U., & Liebscher, T. (2001). Is there an age deficit in the selection of mental sets?

393   *European Journal of Cognitive Psychology*. https://doi.org/10.1080/09541440042000214

394 McCormick-Huhn, J. M., Chen, H., Wyble, B. P., & Dennis, N. A. (2018). Using attribute

395   amnesia to test the limits of hyper-binding and associative deficits in working memory.

396   *Psychology and Aging*, *33*(1), 165–175. https://doi.org/10.1037/pag0000213

397 Miller, L. M. S., & Lachman, M. E. (2003). Cognitive Performance and the Role of Control

398   Beliefs in Midlife. *Aging, Neuropsychology, and Cognition*, *7*(2), 69–85.

399   https://doi.org/10.1076/1382-5585(200006)7:2;1-u;ft069

400 Morris, N., & Jones, D. M. (1990). Memory updating in working memory. *The Role of the*

401   *Central Executive*, *81*(2), 111–121. https://doi.org/10.1111/j.2044-8295.1990.tb02349.x

402 Oberauer, K. (2009). Design for a Working Memory. *Psychology of Learning and Motivation*,

403   *57*(09), 45–100. https://doi.org/10.1016/B978-0-12-394293-7.00002-9

404 Oberauer, K., Souza, A. S., Druey, M. D., & Gade, M. (2013). Analogous mechanisms of

405   selection and updating in declarative and procedural working memory: Experiments and a

406   computational model. *Cognitive Psychology*, *66*(2), 157–211.

407   https://doi.org/10.1016/j.cogpsych.2012.11.001

408 Old, S. R., & Naveh-Benjamin, M. (2008). Differential Effects of Age on Item and Associative

409   Measures of Memory: A Meta-Analysis. *Psychology and Aging*, *23*(1), 104–118.

410   https://doi.org/10.1037/0882-7974.23.1.104

411 Pachella, R. G. (1974). The interpretation of reaction time in information processing research.

412   *Human Information Processing: Tutorials in Performance and Cognition*, (November), 41–
413   82.
414 Pelegrina, S., Borella, E., Carretti, B., & Lechuga, M. T. (2012). Similarity-based interference in
415   a working memory numerical updating task: Age-related differences between younger and
416   older adults. *Experimental Psychology*, *59*(4), 183–189. https://doi.org/10.1027/1618-
417   3169/a000142
418 Persad, C. C., Abeles, N., Zacks, R. T., & Denburg, N. L. (2002). Inhibitory changes after age 60
419   and their relationship to measures of attention and memory. *Journals of Gerontology -
420   Series B Psychological Sciences and Social Sciences*, *57*(3), P223–P232.
421   https://doi.org/10.1093/geronb/57.3.P223
422 Phillips, L. H., Bull, R., Allen, R., Insch, P., Burr, K., & Ogg, W. (2011). Lifespan aging and
423   belief reasoning : Influences of executive function and social cue decoding. *Cognition*,
424   *120*(2), 236–247. https://doi.org/10.1016/j.cognition.2011.05.003
425 Podell, J. E., Sambataro, F., Murty, V. P., Emery, M. R., Tong, Y., Das, S., … Mattay, V. S.
426   (2012). Neurophysiological correlates of age-related changes in working memory updating.
427   *NeuroImage*, *62*(3), 2151–2160. https://doi.org/10.1016/j.neuroimage.2012.05.066
428 Rac-Lubashevsky, R., & Kessler, Y. (2016a). Decomposing the n-back task: An individual
429   differences study using the reference-back paradigm. *Neuropsychologia*, *90*, 190–199.
430   https://doi.org/10.1016/j.neuropsychologia.2016.07.013
431 Rac-Lubashevsky, R., & Kessler, Y. (2016b). Dissociating working memory updating and
432   automatic updating: The reference-back paradigm. *Journal of Experimental Psychology:
433   Learning Memory and Cognition*, *42*(6), 951–969. https://doi.org/10.1037/xlm0000219
434 Reimers, S., & Maylor, E. A. (2005). Task switching across the life Span: Effects of age on
435   general and specific switch costs. *Developmental Psychology*, *41*(4), 661–671.
436   https://doi.org/10.1037/0012-1649.41.4.661
437 Royall, D. R., Palmer, R., Chiodo, L. K., & Polk, M. J. (2005). Normal rates of cognitive change
438   in successful aging: The freedom house study. *Journal of the International
439   Neuropsychological Society*, *11*(7), 899–909. https://doi.org/10.1017/S135561770505109X
440 Salmi, J., Soveri, A., Rodríguez-Fornells, A., Laine, M., Lehtonen, M., & Vilà-Balló, A. (2018).
441   Neural signatures for active maintenance and interference during working memory updating.
442   *Biological Psychology*, *132*, 233–243. https://doi.org/10.1016/j.biopsycho.2018.01.007
443 Salthouse, T. A. (2010). Selective review of cognitive aging. *Journal of the International
444   Neuropsychological Society*, *16*(5), 754–760. https://doi.org/10.1017/S1355617710000706
445 Sambataro, F., Podell, J. E., Murty, V. P., Das, S., Kolachana, B., Goldberg, T. E., … Mattay, V.
446   S. (2015). A variable number of tandem repeats in the 3′-untranslated region of the
447   dopamine transporter modulates striatal function during working memory updating across
448   the adult age span. *European Journal of Neuroscience*, *42*(3), 1912–1918.
449   https://doi.org/10.1111/ejn.12956
450 Schmiedek, F., Li, S. C., & Lindenberger, U. (2009). Interference and Facilitation in Spatial
451   Working Memory: Age-Associated Differences in Lure Effects in the N-Back Paradigm.
452   *Psychology and Aging*, *24*(1), 203–210. https://doi.org/10.1037/a0014685

453   Siegel, L. S. (1994). Working Memory and Reading: A Life-span Perspective. *International*
454   *Journal of Behavioral Development*, *17*(1), 109–124.
455   https://doi.org/10.1177/016502549401700107
456   Singh-Manoux, A., Kivimaki, M., Glymour, M. M., Elbaz, A., Berr, C., Ebmeier, K. P., …
457   Dugravot, A. (2012). Timing of onset of cognitive decline: Results from Whitehall II
458   prospective cohort study. *BMJ (Online)*, *344*(7840). https://doi.org/10.1136/bmj.d7622
459   Soetens, E., Boer, L. C., & Hueting, J. E. (1985). Expectancy or Automatic Facilitation?
460   Separating Sequential Effects in Two-Choice Reaction Time. *Journal of Experimental*
461   *Psychology: Human Perception and Performance*, *11*(5), 598–616.
462   https://doi.org/10.1037/0096-1523.11.5.598
463   Swanson, H. L. (2017). Verbal and visual-spatial working memory: What develops over a life
464   Span? *Developmental Psychology*, *53*(5), 971–995. https://doi.org/10.1037/dev0000291
465   Szmalec, A., Demanet, J., Vandierendonck, A., & Verbruggen, F. (2009). Investigating the role
466   of conflict resolution in memory updating by means of the one-back choice RT task.
467   *Psychological Research*, *73*(3), 390–406. https://doi.org/10.1007/s00426-008-0149-3
468   Szmalec, A., Verbruggen, F., Vandierendonck, A., & Kemps, E. (2011). Control of Interference
469   During Working Memory Updating. *Journal of Experimental Psychology: Human*
470   *Perception and Performance*, *37*(1), 137–151. https://doi.org/10.1037/a0020365
471   Townsend, J. T., & Ashby, F. G. (1978). Methods of modeling capacity in simple processing
472   systems. In I. J. Castellan & F. Restle (Eds.), *Cognitive theory (Vol. 3)* (pp. 200–239).
473   Hillsdale, NJ: Erlbaum. https://doi.org/10.1163/_q3_SIM_00374
474   Verhaeghen, P., & Basak, C. (2005). Ageing and switching of the focus of attention in working
475   memory: Results from a modified N-Back task. *Quarterly Journal of Experimental*
476   *Psychology Section A: Human Experimental Psychology*, *58*(1), 134–154.
477   https://doi.org/10.1080/02724980443000241
478   Wylie, G., & Allport, A. (2000). Task switching and the measurement of "switch costs."
479   *Psychological Research*, *63*(3–4), 212–233. https://doi.org/10.1007/s004269900003
480   Xiang, L., Zhang, B., Wang, B., Jiang, J., Zhang, F., & Hu, Z. (2016). The Effect of Aging on
481   the Dynamics of Reactive and Proactive Cognitive Control of Response Interference.
482   *Frontiers in Psychology*, *7*, 1–10. https://doi.org/10.3389/fpsyg.2016.01640
483   Zimprich, D., & Mascherek, A. (2010). Five views of a secret: Does cognition change during
484   middle adulthood? *European Journal of Ageing*, *7*(3), 135–146.
485   https://doi.org/10.1007/s10433-010-0161-5
486

Participant demographics

1 Table1:

2 Participant demographics

Age group	N	Mean age	BMI	Females	MMSE score
Yong-adults	28	22.71 (1.67)	20.4(1.8)	26	--
Adults	28	31.68 (4.63)	22.8(2.8)	11	--
Middle-aged adults	28	54.21 (4.06)	23(2.7)	25	--
Old	28	67.68 (4.37)	23(2.2)	21	27.8 (2.2)

3 Note. SD in brackets. MMSE = Mini-Mental State Examination.

Age group comparison between Young-young (Y-y), Old-young (O-y), Middle-age (M-a), Old age (O-a) about four sequential patterns.

Inverse efficiency score calculating as RT divided by PC (the proportion of correct responses) was evaluated on the performance in 4 patterns.

1 Table 2:

2 Age group comparison between Young adult (18-25 age), adult (26-44 age), Middle-age (45-59

3 age), Old age (60- age) about four sequential patterns.

4 Inverse efficiency score calculating as RT divided by PC (the proportion of correct responses)

5 was evaluated on the performance in 4 patterns.

Sequential Pattern	Age Groups (ms)				simple main effect of Age (F)	post hoc Tukey HSD test
	18-25 ①	26-44 ②	45-59 ③	60- ④		
RR	538.2 (24.2)	608.9 (37.4)	685 (37.3)	843.2 (73.2)	1.5	
RA	686.2 (30.1)	716.7 (46.4)	1004.6 (56.4)	1110 (64.2)	3.87**	①<④* ②<④*
AR	807.9 (42.3)	965.6 (77.5)	1030 (48.2)	1210.2 (90.6)	2.42	
AA	1340.8 (93.2)	1406.5 (106.9)	2488.1 (256.6)	2472.7 (243.8)	35.79**	①<③** ②<③** ①<④** ②<④**

6 *: $p<0.05$; **: $p<0.01$

Figure 1

The 1-back task procedure

The task started with a blank fixation screen presented for 500ms , the stimulus "□" or "○" was then presented for 500ms randomly, followed by a white display for 1500ms. Participants were required to respond quickly and accurately as soon as the target stimuli appeared. If it was the same as the previous trial pressing "1" (same), if not pressing "3" (difference) The maximum duration for response to be made was 2000ms (the presentation of the stimulus 500ms + the presentation of white display 1500ms) .
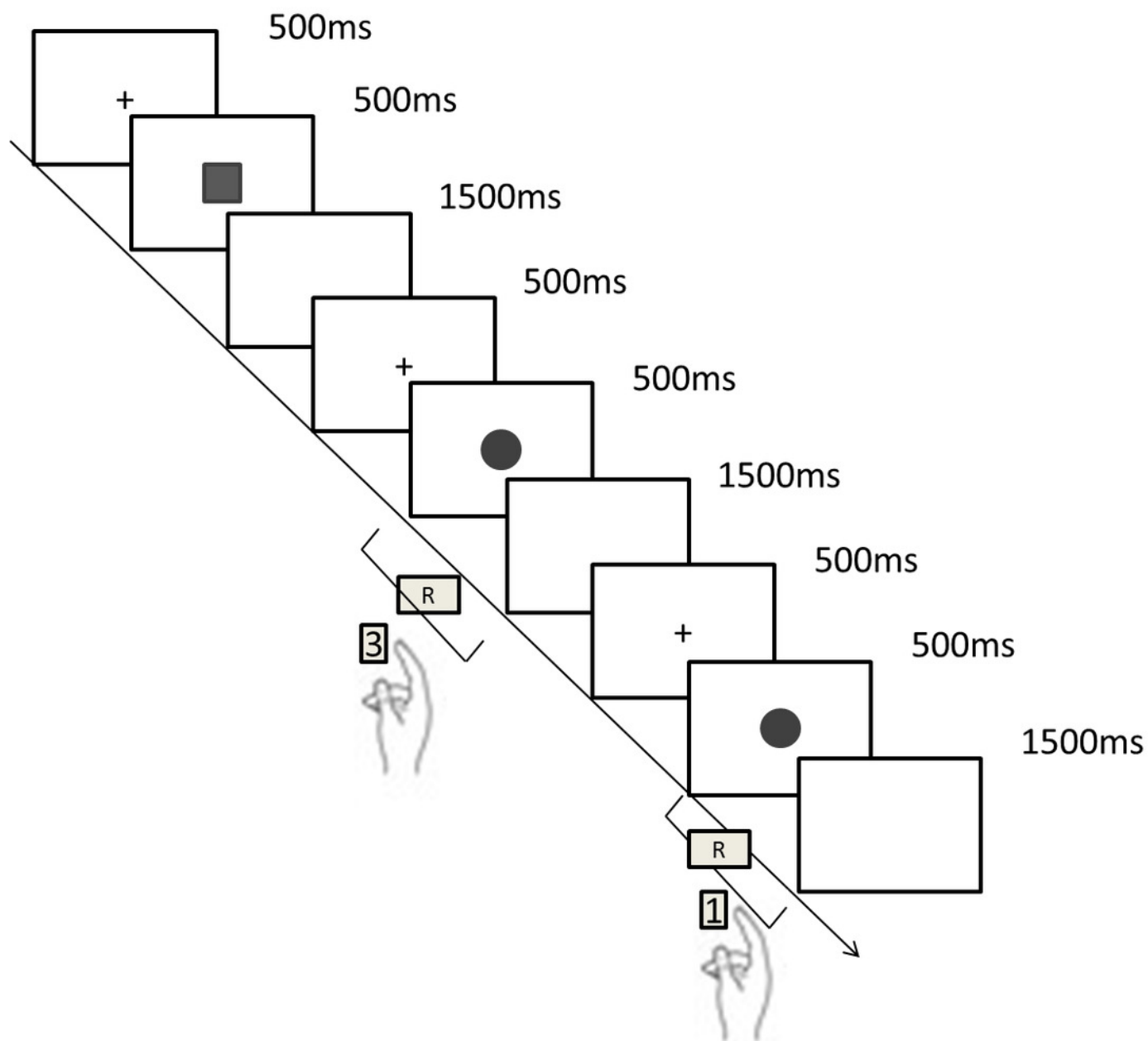
Figure 2

Four different sequential patterns with the sequence of 3 trials in a row

A: Repeating the same stimulus three times is named as RR; B: Repeating the same stimulus twice followed by a different stimulus, (named as RA; including ○○□ and □□○); C: Altering the stimulus in first two followed by repeating the second stimulus on the third (named as AR; including ○□□ and □○○); D: Altering the stimuli twice in the 3 trials (named as AA ; including ○□○ and□○□)
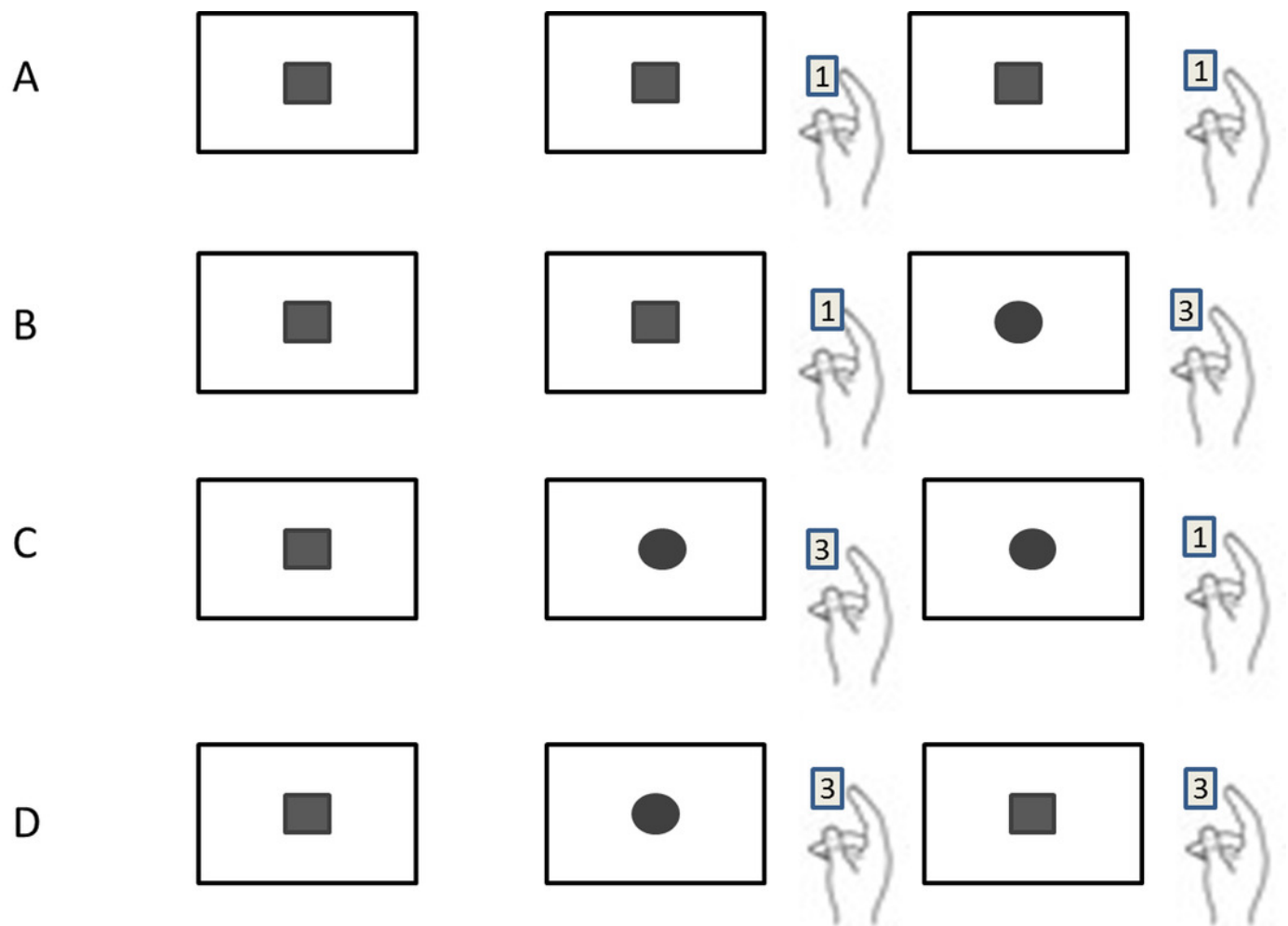
Figure 3

The age-related change during various sequence patterns

X axis is sequence pattern, Y axis is the inverse efficiency score (RTc / PC). Error bars represent standard error.