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Delayed Reactive Distractor Suppression in Aging Populations

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Abstract

Previous studies have tended to infer that reactive control is intact in aging populations because of evidence that proactive control is impaired and that older participants appear to favor reactive control strategies. However, most of these studies did not compare reactive control in young and older participants directly. In our study, a young (18-21 years old) and older (60 + years old) cohort engaged in a task that assesses reactive distractor suppression where subjects had to discriminate between an upright and inverted t-shape in the presence of a salient or non-salient distractor. In previous studies using this paradigm (DiQuattro and Geng, 2010) young participants reactively used the salient distractor as an anti-cue and performed better (faster RT and higher accuracy) when it was present. It was found that older participants were not able to reactively suppress the salient distractor with a 200 msec display but were able to do so with a 600 msec display. It was concluded that the initiation of reactive suppression is delayed for older participants, but that effective suppression is possible given enough time.

Keywords: Cognitive Aging, Cognitive Control, Distractor Suppression, Reactive Control, Salience Suppression

1 **Introduction**

2   It is generally accepted that normal aging can lead to declines in cognitive performance

3 (Braver and Barch, 2002; Craik and Salthouse, 2011; Andrews-Hannah et al, 2007; Geerligs et al,

4 2014a; 2014b; Grady, 2012; Larson et al, 2016; Li et al, 2001; 2016; Persson et al, 2006; Zanto et al,

5 2010). More specifically, there is a plethora of evidence highlighting impairments in inhibition

6 mechanisms (Hasher and Zacks, 1988; Bauer et al, 2012; Mayas et al, 2012; Gazzaley et al, 2005; but

7 see Frings et al, 2015 for contrasting findings). Previous studies have highlighted the increased

8 interference experienced from irrelevant distractors in old age across different experimental

9 paradigms such as global/local tasks (Tsvetanov et al, 2013; Mevorach et al, 2016), reading with

10 distractor tasks (Darowski et al, 2008), response inhibition (Anguera and Gazzaley, 2012), as well as

11 inhibition in the context of WM tasks (Gazzaley et al, 2005). These findings and others fit with the

12 notion that aging is associated with a general impairment in a central inhibition mechanism (the

13 inhibitory deficit theory; Hasher and Zacks, 1988), which manifests in various inhibition related

14 scenarios. The focus on inhibitory processes in old age is especially relevant because there is

15 evidence that distractor inhibition is crucial in mediating cognitive control in general (Darowski et al.,

16 2008). It should be noted that although it is often assumed that inhibition deficits result in impaired

17 cognition, there is some evidence to suggest that it may improve cognition under some

18 circumstances (Amer, Campbell, and Hasher, 2016).

19   In contrast, the notion that an all-encompassing inhibition impairment is associated with age

20 has been challenged by studies showing impairments only on subsets of inhibition tasks (Rey-

21 Mermet et al, 2018a; 2018b). For instance, Kramer et al (1994) found age related inhibition deficits

22 in a stop-signal task, but not in a response competition or spatial pre-cueing task. Furthermore, even

23 when inhibition impairments occur across tasks, evidence suggests they may be independent. For

24 instance, Anguera and Gazzaley (2012; Sebastian et al, 2013) assessed motor inhibition in a stop

25 signal task and sensory filtering within the context of a delayed recognition task in young and old

26 participants. Critically, they showed that motor and sensory inhibition were independently impaired

27   as a function of aging. More recent studies have built upon this conclusion, further highlighting

28   distinct age effects on different cognitive inhibitory functions and their potential neural correlates

29   (Vadaga et al, 2015; Bloemendaal et al, 2016).

30   The dual mechanisms theory of proactive and reactive cognitive control (Braver, 2012)

31   suggests a potential explanation for the failure to identify a general inhibition impairment in old age.

32   Rather than a single inhibition mechanism, the DMC differentiates between two modes of control:

33   Proactive, an attentional biasing mechanism which mediates behavioral responses to a given

34   stimulus in advance; and reactive, which is a "late correction" mechanism that allows one to alter

35   behavioral plans "in the moment" when suddenly presented with new and relevant information.

36   Consequently, it is possible that only one of these inhibition mechanisms is affected by age, or that

37   they are affected to different degrees. Indeed, previous studies have identified a proactive pattern

38   of performance in young participants and a reactive one in old participants (Braver et al., 2005;

39   Paxton et al, 2008). Interestingly, even when performance across age groups was equivalent, brain

40   activity that was consistent with impairments to proactive control (Vadaga et al, 2015) and increased

41   reliance on reactive control (Paxton et al., 2008) was documented in the older cohorts. Similar brain

42   dynamics have also been recorded in the context of a task switching paradigm as older participants

43   (relative to younger participants) showed reduced sustained activation, a hallmark of proactive

44   control (Braver, 2012), and increased transient activation, a hallmark of reactive control (Braver,

45   2012), during switch trials in the anterior prefrontal cortex (Jimura and Braver 2010). These findings

46   are consistent with the idea that older participants show more reactive control related- and less

47   proactive control related activity than younger participants.

48   The above evidence points to a selective impairment in inhibition in old age – proactive

49   processes appear to decline with age, while reactive processes may be intact. However, there are

50   two major issues with this interpretation. First, most studies of the DMC and aging have highlighted

51   the activation of reactive processes in older participants and proactive process in young participants

52   in the same task, but did not directly compare reactive processes across age groups. Second, in many

53   of these studies (typically using the AxCPT paradigm; Braver et al, 2005; Paxton et al, 2008; Braver et

54   al, 2009) utilising either proactive or reactive control yield different performance benefits. As such, it

55   is possible that the increased use of reactive control in old age represents an unconscious strategic

56   bias rather than specific impairment in proactive control and intact reactive control. For example,

57   one of the early examples for inhibition deficits was reported by Hasher et al (1991) in a study

58   measuring inhibitory function in young and older participants using a negative priming task

59   (assessing the persistence of inhibition of a distractor by switching its role to a target on subsequent

60   trials). Hasher et al (1991) found that young participants showed persistence of inhibition from one

61   trial to the next, but older participants showed no effects, suggesting impaired inhibitory function.

62   They argued that this reflected impairment in a central inhibition mechanism. However, an

63   alternative interpretation is that the younger participants were engaging proactive control and that

64   the persistence of inhibition was an artifact of their anticipating the state of the target and distractor

65   items, whereas older participants engaged reactive control and therefore did not show negative

66   priming because they didn't anticipate their state. Crucially, this arguably conferred a strategic

67   benefit to the older participants in this context since they were not biased away from the target on

68   switch trials.

69   A few notable studies have addressed the issue of comparing reactive control between age

70   groups. One set of studies have focused on "proportion congruence" manipulations in conflict

71   resolution tasks, such as Stroop tasks where congruent (no-conflict) and incongruent (conflict)

72   displays are contrasted (Bugg and Crump, 2012; also see Bugg, 2015 for examples using a flanker

73   task). Proportion congruence studies manipulate the ratio of congruent and incongruent trials within

74   a block (list-wise) or for a specific target type (item-specific; e.g., dogs within a list of animals) and

75   measure how such changes in frequency modulate performance differences between the congruent

76   and incongruent conditions. The typical finding in such studies with young adults is that the

77   congruency effects (difference in performance between congruent and incongruent displays) are

78   larger in the condition with more congruent trials, than in the condition with more incongruent trials

79   (Bugg and Chahani, 2011; Bugg, Jacobi, and Chahani, 2011; Bugg, Jacoby, and Toth, 2008).

80   Importantly, the two versions of this paradigm (list-wide and item-specific) arguably tap proactive

81   and reactive control mechanisms, separately. List-wide manipulations enable participants to adopt a

82   more stringent control in anticipation of trials throughout a block (proactive), while item-specific

83   versions do not. In the latter case, the proportion congruence manipulation is applied to different

84   items that are randomly intermixed and therefore, whether more or less stringent control is needed

85   cannot be predicted before and item is presented (reactive). In fact, Gonthier et al (2016) showed

86   distinct doubly-dissociated behavioral signatures for item-specific (reactive) vs list-wise (proactive)

87   proportion congruence manipulations, supporting the notion that item-specific proportion

88   congruence manipulations tap into reactive control mechanisms. Using such paradigms, Bugg et al

89   (2014a; 2014b) compared performance of young and old adults. Specifically, Bugg et al., (2014b)

90   found that both young and older participants exhibited the standard item-specific proportion

91   congruence effect, where the mostly congruent items had larger congruency effects than the mostly

92   incongruent items. Since reactive control was argued to be necessary to produce this effect, Bugg et

93   al (2014b) concluded that reactive control was spared in older participants.

94   Much like the "item-specific" proportion congruency effect, "sequential" congruency effects

95   have also been used as a measure of reactive control. "Sequential" congruency effects refer to the

96   phenomenon that congruency effects for trials immediately following an incongruent trial are

97   reduced compared to congruency effects for trials immediately following a congruent trial (In other

98   words, analyzing trials n+1 and grouping them based on trial n). Typically, both young and older

99   participants show these sequential congruency effects of equal magnitude, but older participants

100   show overall larger congruency effects and longer overall response times (even after accounting for

101   speed of processing deficits; Puccioni & Vallesi, 2012; West & Moore, 2005; but see Aschenbrenner

102   and Balota, 2016 for a study where older participants showed a larger sequential congruency effect).

103   In other words, although older participants seem to take longer to complete the task, these studies

104   have suggested that reactive control is effectively intact in older cohorts. In contrast, Xiang et al

105   (2016) found no "sequential" congruency effects for older participants, with respect to both

106   response time and accuracy, arguing that reactive control might be impaired in aging. However, they

107   did not account for generalized slowing effects or speed-accuracy trade-offs, which makes their

108   results difficult to interpret.

109   The purpose of this study is to further assess reactive distractor suppression in aging

110   populations. It should be noted here that reactive and proactive cognitive control are essentially

111   umbrella terms that can refer to two different mechanisms of engaging a wide range of similar

112   cognitive abilities, including distractor suppression, target selection, conflict resolution, and so on.

113   Despite this, most studies tend to use the general term of proactive or reactive control, rather than

114   specify the cognitive mechanisms being investigated. This is relevant because it may be that

115   proactive and reactive control of some cognitive abilities may be intact, while others may be

116   impaired. Although the DMC generally argues for a general impairment within proactive control

117   mechanisms, it may be valuable to adopt a more precise perspective. Therefore, we refer to the

118   process of reactive distractor suppression throughout our study, rather than reactive control.

119   In order to stringently assess age-related differences in reactive distractor suppression,

120   performance should be compared in a task that yields clear benefits when reactive distractor

121   suppression is engaged and eliminates or significantly reduces the role of proactive distractor

122   suppression in young participants too. Here, we describe such a task which specifically taps reactive

123   distractor suppression mechanisms. DiQuattro and Geng (2011) investigated the brain mechanisms

124   that are involved in processing contextually relevant, but not task relevant stimuli. While in an fMRI

125   scanner, they had participants (Mean age = 23.8; Age Range: 18 – 39 yrs) perform a visual search

126   task for a low contrast target in the presence of either a high or low contrast non-target (50%

127   predictability), each of which would appear in one of two pre-defined locations; participants could

128   not predict the location of the distractor on a given trial. Despite being task irrelevant, the salient

129   non-target was contextually relevant as the presence of the high contrast non-target informed the

130   participant that the target was in the other location, effectively triggering a reactive distractor

131   suppression. They found that participants were both faster and more accurate on trials with a salient

132   distractor, compared to a similar (to the target) distractor.

133   Geng and DiQuattro (2010; experiment 1) used a variant of this paradigm with eye tracking

134   showing that, when the distractor was unpredictable, participants made a saccade to distractor first

135   on ~68% of trials, necessitating reactive rapid rejection instead of proactively inhibiting the

136   distractor (saccading towards the target first; for similar trials, it was ~50% rapid rejection and ~50%

137   inhibition). They argued that rapid rejection was only needed when inhibition failed. In other words,

138   the engagement of reactive control in this task pre-supposes a failure of proactive control (Geng,

139   2014). Crucially though, even when a saccade was first made towards the distractor, there was still a

140   performance benefit on salient trials. Even when proactive inhibition failed, young participants were

141   able to reactively rapidly reject the distractor in a beneficial manner. Therefore, the presence of a

142   performance benefit (i.e. better performance on salient trials) in this task must be attributed to both

143   a failure of proactive (inhibition) and the engagement of reactive (rapid rejection) processes.

144   The fMRI analysis in DiQuattro and Geng (2011) provided converging evidence for the notion

145   that this task engages reactive distractor suppression. It revealed that the left TPJ and left inferior

146   frontal gyrus (IFG) were significantly more active when there was a high salience non-target

147   compared to a low salience non-target. Dynamic causal modelling revealed a network in which left

148   TPJ projects to left IFG that, in turn projects to the frontal eye fields (FEF). The authors interpreted

149   this to mean that the ventral attention network (TPJ and IFG in this study) that is typically associated

150   with bottom up attention (Corbetta and Shulman, 2002), updates control signals to the dorsal

151   attentional network (FEF in this study). They refer to this network as an attentional circuit breaker

152   that can reorient attention when top-down (i.e. proactive) attentional processes don't work or lead

153   to counterproductive outcomes. Importantly, they further suggest that the TPJ and IFG are

154   effectively generating a "reactive" control signal as a consequence of the stimulus presentation

155 (Braver et al, 2009; Braver, 2012). Additional converging evidence comes from studies of young

156 adults with high expression of psychosis proneness, who have been shown to favor reactive

157 distractor suppression relative to proactive distractor suppression (Abu-Akel et al, 2016a; 2016b;

158 2016c). In the t-task described above, performance benefits from the presence of the salient

159 distractor scale with the expression of psychosis proneness (Abu-Akel et al., 2018), highlighting that

160 this paradigm is sensitive enough to detect variations in the magnitude of engagement of reactive

161 distractor suppression.

162 Moreover, another advantage of this task is that it avoids engaging general non-perceptual

163 inhibition processes. The stimuli within the distractor is never a valid response option (a sideways t

164 shape instead of upright or inverted), so participants won't be primed to make a specific response if

165 they do process the distractor, which would then need to be inhibited. In addition (unlike stop-signal

166 tasks), the "correct" response never changes within the course of a trial so they never have to switch

167 responses. Indeed, older participants appear to be impaired in a stop-signal task (Kramer et al,

168 1994), which tests participants' ability to cancel a motor response while it is already being executed

169 (and therefore presumably measures reactive inhibition). However, the requirement to cancel an

170 already executable motor response may relate to other processes (primarily motor

171 cancelation/response inhibition) which may be independent or more complex than reactive

172 inhibition per se. (Swick, Ashley, and Turken, 2011; Kolodny, Mevorach, and Shalev, 2017). In fact,

173 Anguerra and Gazzaley (2012) have highlighted the independence of impairments in response

174 inhibition and perceptual inhibition (but not exclusively reactive inhibition) in old age. In our study,

175 by design, only differences in perceptual inhibition are likely to change behavior.

176 This paradigm is distinct from the proportion congruence studies in two important ways.

177 First, proportion congruence effects rely on the implicit learning of the associations between

178 different items and their likelihood of conflict (Blais et al, 2012). It is possible that proportion

179 congruence effects may be less susceptible to age-related decline due to their reliance on implicit

180 learning (Cohen-Shikora, Diede, & Bugg, 2018). However, in our task, there is an even probability of

181   all trial types and making a correct response does not depend on any element of previous trials.

182   Thus, our task may tap into a more temporally bounded form of reactive control. Second, our

183   paradigm manipulated stimulus presentation duration to assess the timing of reactive control. As far

184   as we know, no previous studies have done this.

185   In the present study we compared old and young participants' performance on the T-search

186   task to directly assess if reactive inhibition is impaired or intact in old age. If in older participants

187   reactive distractor inhibition is indeed intact (irrespective of a possible proactive impairment), it is

188   expected they will derive a benefit from the presence of the salient distractor compared to a similar

189   distractor. Conversely, if older participants have impaired reactive distractor suppression, it is

190   expected that they show minimal benefit from the presence of a salient distractor.

191

192   **Experiment 1a**

193   **Methods**

194   *IRB Approval*

195   All experiments in this study were approved by the Science, Technology, Engineering and

196   Mathematics Ethical Review Committee at the University of Birmingham.

197   *Participants*

198   25 young participants and 26 older participants participated in two successive behavioral

199   experiments. Three subjects (2 older, 1 younger) were excluded from the analysis due to poor

200   performance (Overall accuracy across conditions < 60%; A cut-off of 60% was chosen to balance

201   between exclude participants who were guessing or did not understand the task, and including

202   participants who simply had low accuracy), resulting in 24 young participants (Mean Age: 18.8, SEM

203   of Age: .19, Age Range: 18 -21; 23 Females) and 24 older participants' (Mean Age: 70.1, SEM of Age:

204   1.63, Age Range: 60 - 82; 13 Females) data being analysed. All participants had normal or corrected

205   to normal vision. The order of the tasks was counterbalanced to account for possible fatigue and

206   order effects. The other experiment is reported elsewhere and has no relevance to the current

207   investigation. Young participants were recruited from the undergraduate population in the school of

208   psychology at the University of Birmingham, UK. They were compensated for their participation with

209   course credits. The older participants were recruited from a volunteer pool maintained by the School

210   of Psychology at the University of Birmingham. They were compensated for 1.5 hours of their time

211   with a one-time payment of £7. All participants had to sign an informed consent form prior to the

212   study. Participants' were healthy with no history of head injury, mental health issues or neurological

213   disorders. The old participants were screened for decline in cognitive functions using the Montreal

214   Cognitive Assessment (MoCA). All of the older participants scored within the normal range (Mean

215   Score: 27.5, SEM of Score: .23).

216   *Power Analysis*

217   An a priori statistical power analysis was performed for sample size estimation, based on data from

218   DiQuattro and Geng (2011; N = 21). They found that the presence of a salient distractor significant

219   improved both response time and accuracy for healthy young participants, with an effect size of

220   cohen's d = 2.9 and d = 1.7, respectively. These are considered to be extremely large using Cohen's

221   (1988) criteria. With an alpha = .05 and power = 0.95, the projected sample size needed to detect an

222   effect size of 1.7 (GPower 3.1.9.2; Faul et al, 2007; 2009) is approximately N = 6 for a repeated

223   measures ANOVA with a within-between subjects interaction. However, one possibility is that the

224   effect size will be much smaller for the older participants. Therefore, as an additional check the

225   projected sample size needed to detect an effect size of .3 (with all the same other parameters) is

226   approximately N = 40 (20 per group). Thus, our sample size of 51 should be adequate to assess the

227   main objectives of this study, unless the effect size for older participants is lower than .3. This power

228   analysis also applies to experiment 2 which has a sample size of 39.

229   *Stimuli and Procedure*

230   Participants were presented with five blocks of 46 trials each. Color was defined using RGB

231   color coordinates. The background color of the display was grey [100 100 100]. On all trials, target

232   and non-target stimuli were displayed. Each stimulus was a square whose center was 6.5 degrees of

233   visual angle (horizontally 6.3 degrees; vertically 1 degree; all measures of visual angle were

234   calculated assuming a viewing distance of 50 cm) diagonally left or right and below the center of the

235   screen. Each square subtended 1.8 degrees of visual angle. The target square was dark grey [120 120

236   120]. In the target square, a vertical line with a width of .224 degrees of visual angle bisected the

237   square. A second horizontal line also appeared to create a 'T'-like shape (Figure 1). These lines were

238   a dark grey [80 80 80]. On half of trials, the horizontal line was .281 degrees of visual angle above

239   the center of the square, creating an 'Upright' T (Figure 1) and on the other half, the horizontal line

240   was .281 degrees of visual angle below the center of the square creating an 'Inverted' T. The color of

241   the non-target square depended on the trial type. On 'Similar' trials, the color was the same as the

242   target square. On 'Salient' trials, the non-target square was white [255 255 255]. In the non-target

243   square, an horizontal line with a height of .224 degrees of visual angle bisected the square. A second

244   vertical line also appeared to create a sideways 'T'-like shape (Figure 1). On 'Similar' trials, the line

245   color was the same as inside the target square. On 'Salient' trials, the line color was black [0 0 0]. On

246   50% of trials, the vertical line was .281 degrees of visual angle right of the center of the square,

247   creating a clockwise rotated "T". On 50% of the trials, the vertical line was .281 degrees of visual

248   angle left of the center of the square creating a counter-clockwise rotated "T".

249   In each block there were 50% "Salient" trials and 50% "Similar" trials, randomly intermixed.

250   On any given trial there was a 50% chance that the target would appear in the left position and 50%

251   chance that it would appear in the right position. Participants had to identify if there was an upright

252   or inverted "T" stimulus on each trial by pressing the "H" or "B" keys, respectively. These buttons

253   were chosen because the "H" key is positioned above the "B" key on the keyboard, mimicking the

254   spatial orientation of the target stimuli, where the upright "T" stimulus has a horizontal line above

255   the center of the stimulus square and the inverted "T" stimulus has a horizontal line below the

256   center of the stimulus square.

257   Every trial began with a white [255 255 255] fixation cross presented at the center of the

258   screen, which persisted throughout the trial (including during 'blank' screens). Each trial began with

259   blank screen. The "fixation" time was randomly selected based on a uniform distribution of times

260   between 1500 – 2000 msec (Figure 1). Next, the appropriate stimulus (depending on the trial) was

261   displayed for 200 msec. Participants could respond starting when the stimulus was presented. After

262   the stimulus was removed, the participant was presented with blank screen until they made a

263   response. Once a response was made, the next trial would begin. Participants were given the

264   chance to take short breaks in between blocks (< 5 min). Each session began with 20 practice trials.

265   During the practice, participants received visual feedback such that if they made an identification

266   error, the fixation cross changed to red for 250 msec before turning back to white for the rest of the

267   fixation time.

Stimuli:

TIME

1000—1500 msec

Salient Trial   200 msec   Similar Trial

Until Response
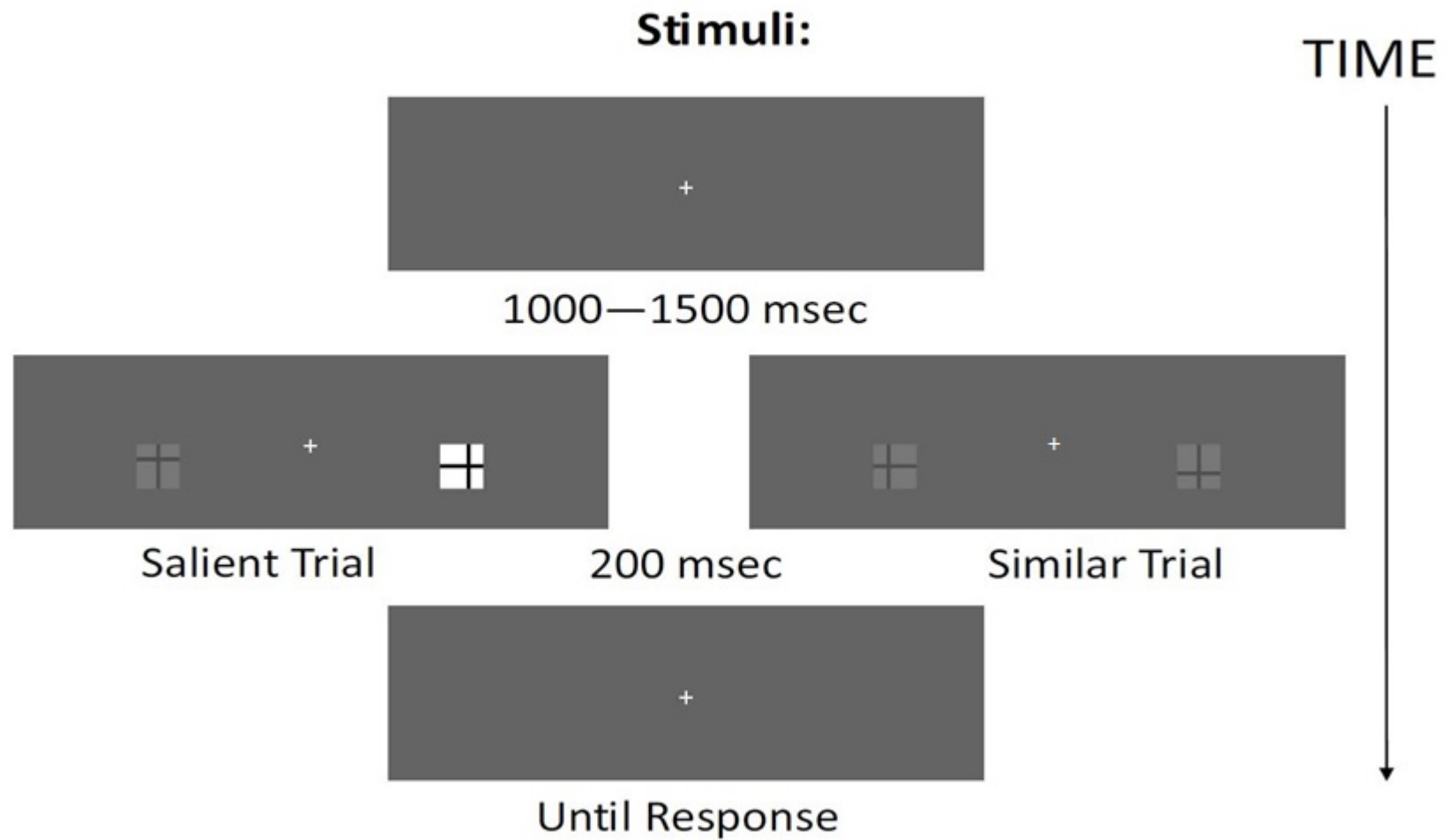
268

269 Figure 1. Diagram of the reactive distractor inhibtion t-task. Participants were presented with either a salient or similar stimulus on any give trial. In the
270 salient example the correct response would be to press the H-key to indicate an upright target. In the similar example the correct response would be to
271 press the B-key to indicate an inverted target.

272   **Results & Discussion**

273   Response time in msec (RT) and accuracy rate (i.e. proportion of correct responses) were

274   measured as dependent variables. All values are presented as mean +/- standard error of the mean.

275   The data was cleaned to account for outliers. For each participant, response time data that was

276   greater than and less than 2 standard deviations from the participants' individual mean was

277   excluded from all analyses. The individual mean response time was calculated separately for each

278   salience condition (salient trials and similar trials). This resulted in the loss of an average of 4.37%

279   (SEM = .22%) of the response time data per older participant and 3.71% (SEM = .23%) per young

280   participant. An independent samples t-test revealed that these values were significantly different

281   (t(46) = -2.039, p = .047, d = .58). This is attributable to the notion that older participants tend to

282   exhibit greater variability in cognitive performance (Hultsch and MacDonald, Chapter 4 in Dixon et

283   al, 2004; Morse, 1993) than younger participants. As such, their response time distributions would

284   be wider and they would have more trials that would fall outside of 2 standard deviations from the

285   mean.

286   For the accuracy data, a rationalized arcsine transformation (Equation 1) was applied to each

287   participants' overall accuracy in each salience condition. This was done to account for possible

288   violations of normality that can arise in binomially distributed data. The rationalized arcsine

289   transformation was designed to normalize the data in accordance with the arcsine transformation

290   while maintaining a more intuitive scale for interpretation of results (Studebaker, 1985). Since the

291   transformation don't reflect true probabilities, they will not be reported with a % symbol, but for

292   interpretation purposes the values do approximate the raw data, albeit skewed towards larger

293   values than the raw data.

$$RArcSine = \left(46.47324337 * \left(2 * arcsin(\sqrt{Accuracy})\right)\right) - 23$$

294   Equation 1. This rationalized arcsine transformation calculates the standard arcsine transformation,
295   then adjusts the value such that a proportion of .5 will have a transform of 50, rather than 1.5708.

296   Transformed accuracy values (Figure 2a) were analysed using a repeated measures ANOVA

297   with Saliency (salient distractor vs similar distractor) as within subject factor and participants age

298   group (Young vs Older) as a between subject factor. The main effects of salience (F(1,46) = 2.368, p =

299   .131, η_p^2 = .049) and age group (F(1,46) = .446, p = .508, η_p^2 = .010), were not significant, but there

300   was a significant interaction between salience and age group (F(1,46) = 5.132, p = .028, η_p^2 = .100).

301   Planned comparisons with paired samples t-tests comparing performance in the salient and similar

302   conditions within each age group revealed that for older participants there was no significant

303   difference in accuracy for salient (90.99 +/- 2.88) and similar trials (92.00 +/- 1.78, t(23) = -.505, p =

304   .618, d = .10). In contrast, young participants were more accurate on salient trials (96.28 +/- 2.52)

305   than on similar trials (90.98 +/- 2.56; t(23) = 2.739, p = .012; *d* = .56).

306   Moreover, an independent samples t-test revealed there was no significant difference in

307   RArcSine transformed accuracy during the similar condition between the young (90.98+/- 2.56) and

308   older (92.00 +/- 1.78), participants (t(46) = -.329, p = .744, d = .09), which highlights that the group

309   differences we observed were not due to greater difficulty in identifying the stimuli by the older

310   group. It also confirms that the benefit effect for the young participants was specifically due to

311   enhanced performance in the presence of a salient distractor.

312   For the Response Time data, the raw response times were transformed into z-scores to

313   account for generalized speed of processing deficits reported in aging populations that can be

314   confounded with inhibition deficits (Craik and Salthouse, 2011; Salthouse, 1994; 1996; 2000;

315   Salthouse and Meinz, 1995). We applied a z-score transformation to each individual subject's

316   response time data by subtracting their overall mean response time from their condition mean

317   (Salient or Similar), then dividing by the standard deviation of their condition means. To be clear, this

318   was done separately for their salient and similar condition data. This procedure has been used

319   previously to account for speed of processing deficits (Tsvetanov et al, 2013) in aging populations

320   and is described in more detail in Faust et al (1999).

321   The z-RT data were analysed using a repeated measures ANOVA with Saliency (salient

322 distractor vs similar distractor) as within subject factor and participants age group (Young vs Older)

323 as a between subject factor (Figure 2b). The analysis revealed a main effect of saliency (F(1,46) =

324 15.173, p < .001, η_p^2 = .248), where participants were quicker to respond to salient trials (z-RT = -.103

325 +/- .025) than to similar trials (z-RT = .071 +/- .020; Smaller values reflect faster response times). This

326 effect is a typical result for this paradigm and supports the notion that participants are engaged in

327 reactive cognitive control and utilise the salient distractor as an anti-cue (DiQuattro and Geng, 2011;

328 Geng and DiQuattro, 2010). There was not a main effect of age group (F(1,46) = 2.629, p =.112, η_p^2 =

329 .054, but there was an interaction between salience and age group (F(1,46) = 7.881, p = .007, η_p^2 =

330 .146).

331   We conducted planned comparisons using a paired samples t-test to compare z-RTs for the

332 two salience conditions in each group. For the older participants, there was no significant difference

333 in z-RT across salience conditions (t(23) = -.782, p = .442, d = .16; Salient: z-RT = -.033 +/- .034;

334 Similar: z-RT = .015 +/- .029). However, younger participants responded significantly quicker (t(23) =

335 -4.665, p < .001, *d* = .95) in the salient condition (z-RT = -.17 +/- .038) compared with the similar

336 condition (z-RT = .127 +/- .027). These results suggest that the main effect of saliency was primarily

337 driven by the younger participants and that the older participants showed no benefit in performance

338 when the salient distractor appeared.
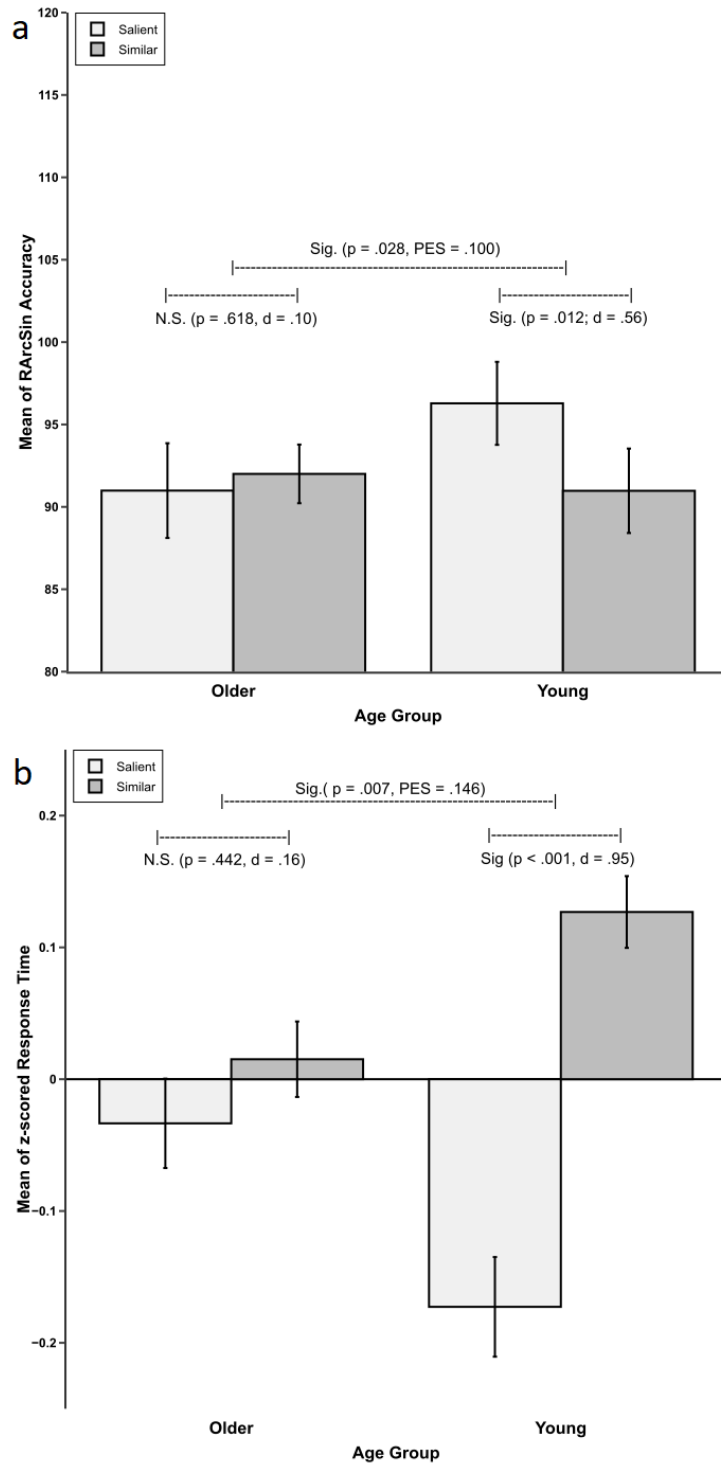
Figure 2. (a) Graph reflecting mean of RArcSine transformed accuracy for salient and similar conditions across age groups. (b) Graph reflecting z-scored response time data (msec) for salient and similar conditions across age groups. PES stands for partial eta squared and d stands for cohen's d.

344   **Experiment 1b**

345   The identical performance we documented for older participants in the similar and salient

346   trials could potentially stem from reduced visual contrast sensitivity in this age group (Roberts and

347   Allen, 2016; Pardhan, 2004; Owsley et al, 1983; Sekuler et al, 1980). One possible complication in

348   any aging study of higher order cognitive abilities – such as reactive cognitive control – is that low

349   quality information due to age-related impairments to lower level perceptual abilities may cascade

350   through the information processing stream affecting performance (the information degradation

351   hypothesis; Monge and Madden, 2016; but see Houston et al, 2016 for a counter-perspective).

352   Notably, Porto et al (2016) found that controlling for visual acuity scaled and/or eliminated an age-

353   related reduction in posterior P3b amplitude during a visual oddball task. The posterior P3b

354   amplitude is generally presumed to be indicative of higher-level decision making and executive

355   functions, although it should be noted that the specific role of the posterior P3b amplitude is still

356   under a great deal of debate (See Polich, 2007 for a more in-depth discussion).

357   Indeed, if our older participants were not sensitive to the contrast differences between

358   salient and similar non-targets then their performance in the two conditions would be equivalent. To

359   exclude this possibility, we invited a subset of the older participants who took part in experiment 1a

360   back and assessed whether or not they are able to distinguish between the two contrast conditions

361   (Salient vs Similar). In experiment 1b we presented the exact same stimuli to a set of older

362   participants, but instead of responding to the t-shapes, they had to indicate if the box colors of the

363   two elements of the display (target and non-target) were the same or different. If the participants

364   can successfully distinguish between the salient and non-salient stimuli, then we can be confident

365   that age-related impairments to visual contrast sensitivity are not influencing our results.

366   **Methods**
367   *Participants*
368   5 older participants (Mean Age: 70.8, SEM of Age: 2.35, Age Range: 65 - 78; 1 Female)

369   participated in the experiment. The older participants were recruited from the initial cohort who

370   participated in Experiment 1a. They were compensated for 1.5 hours of their time with a one-time

371   payment of £7. All participants had to sign an informed consent form prior to the study. Participants'

372   were healthy with no history of head injury, mental health issues or neurological disorders. The

373   older participants were screened for decline in cognitive functions using the Montreal Cognitive

374   Assessment (MoCA). All of the older participants scored within the normal range (>= 26 out of 30).

375   *Stimuli and Procedure*

376   The stimuli and procedure were exactly the same as in experiment 1a except that instead of

377   indicating if the target were upright or inverted, participants pressed the "h" key to indicate if the

378   two stimulus boxes were the same color (similar trials) and the "b" key if they were different (salient

379   trials).

380   **Results and Discussion**

381   Overall raw accuracy across the 5 participants was very high (Mean = 98% +/- .68%). The

382   data was transformed to a rationalized arcsine measure, consistent with experiment 1a. To assess

383   the RArcSine transformed accuracy results, a one-way one-sample t-test was conducted to

384   determine if a statistically significant difference existed between the average RArcSine and an

385   RArcSine of 50 (equivalent to a proportion correct of .5). The t-test was significant, $t(4) = 19.8$, $p <$

386   .001, $d = 8.85$, suggesting that older participants were able to successfully distinguish between the

387   salient and non-salient stimulus boxes.

388   The response time was not z-transformed like in experiment 1a since there is only an older

389   participants group and we do not need to account for group differences. However, the response

390   time data was cleaned to account for outliers using the same procedure described in experiment 1a.

391   This resulted in the loss of an average of 4.69% (SEM = .59%) of the response time data for salient

392   trials and 3.82% (SEM = .89%) of the response time data for similar trials. A paired samples t-test

393   revealed that these were not significantly different ($t(4) = 1.12$, $p = .326$, $d = .5$). The ability to

394   distinguish successfully between these scenarios was evidenced by virtually identical response times

395   for same (Mean = 592 +/- 37.4 msec) and different (593 +/-37.5 msec) trials (t(4) = -.029, p = .977, d

396   = .013), confirming that older participants were not simply increasing accuracy during different trials

397   by taking more time.

398   Overall, these results exclude the possibility that the lack of benefit for older participants,

399   observed in Experiment 1a was attributed to impairments to visual contrast sensitivity yielding the

400   salient and similar trials identical for our older participants. It should be noted that although there is

401   a small sample size in this study, the consistently high accuracy (≥ 96%) across all participants and

402   their age range allows us to be relatively confident that these results are a reasonable estimation of

403   our participants' visual contrast sensitivity.

404   **Experiment 2**
405   Although we show that general age-related processing speed deficits can't fully account for

406   our data (as overall RTs were not associated with the benefit measure for older participants), it is

407   still possible that certain aspects of processing speed affect older participants ability to utilise

408   reactive distractor suppression this task. For instance, if older adults take longer to accumulate

409   evidence that will yield a disengagement decision from a non-target element, it might be the case

410   that even though they are sensitive to the contrast differences it takes them similar amount of time

411   to reach a decision to disengage. In experiment 1b, it took the older participants 592 msec to simply

412   discriminate between the salient and similar conditions, whereas in experiment 1a they were only

413   given 200 msec to use the salient distractor. Thus, it is possible that in old age effective reactive

414   distractor suppression is possible given enough time.

415   This idea would fit with the argument that older participants favor reactive control in the

416   first place because it takes longer to accumulate neural resources in old age and reactive control

417   typically requires fewer resources over a shorter period of time compared to proactive control

418   (Grady, 2012). Consequently, slow resource accumulation could theoretically impact reactive control

419   as well. In particular, it would result in a delayed initiation of reactive inhibition. If the initiation of

420 reactive distractor suppression is delayed in older cohorts, then we would expect them to be able to

421 effectively utilise reactive distractor suppression as long as they are given enough time to engage

422 reactive suppression mechanisms.

423 To address the possibility that there is an age-related delay in the initiation of reactive

424 inhibition processes, Experiment 2 was conducted in which the stimulus presentation time was

425 extended from 200 msec to 600 msec. If the initiation of reactive inhibition takes longer in old age,

426 then a longer presentation time should allow older participants to take advantage of the salient

427 distractor, and we would expect to see a performance benefit. Alternatively, if reactive inhibition is

428 simply less effective in old age we expect to replicate the results from experiment 1a and find no

429 performance benefit for the old participants.

430   **Methods**

431 *Participants*

432 20 young participants (Mean Age: 19.2, SEM of Age: .20, Age Range: 18 -21; 18 Females) and

433 19 older participants (Mean Age: 69.47, SEM of Age: 1.12, Age Range: 62 - 78; 11 Females)

434 participated in the experiment. Like experiment 1a, we planned to exclude any participants with less

435 than 60% overall accuracy, but no participants met this criterion and none were excluded from

436 analysis. Young participants were recruited from the undergraduate population in the school of

437 psychology at the University of Birmingham, UK. They were compensated for their participation with

438 course credits. The older participants were recruited from a volunteer pool maintained by the School

439 of Psychology at the University of Birmingham. They were compensated for 1.5 hours of their time

440 with a one-time payment of £7. All participants had to sign an informed consent form prior to the

441 study. Participants' were healthy with no history of head injury, mental health issues or neurological

442 disorders. The older participants were screened for decline in cognitive functions using the Montreal

443 Cognitive Assessment (MoCA). All of the older participants scored within the normal range (>= 26

444 out of 30).

445 *Stimuli and Procedure*

446   The stimuli and procedure were exactly the same as in experiment 1a, except that the

447 stimulus was presented for 600 msec instead of 200 msec.

448   **Results and Discussion**

449   Response time in msec (RT) and accuracy rate (i.e. proportion of correct responses) were

450 measured as dependent variables. The response time data was cleaned to account for outliers. For

451 each participant, response time data that was greater than and less than 2 standard deviations from

452 the mean was excluded from all analyses. The mean response time was calculated separately for

453 each salience condition (salient trials and similar trials). This resulted in the loss of an average of

454 3.64% (SEM = .22%) of the response time data, per older participant and 3.61% (SEM = .24%) per

455 young participant. An independent samples t-test revealed that these values were not significantly

456 different (t(37) = -.093, p = .927). All values are presented as mean +/- standard error of the mean.

457   Accuracy data was rationalized arcsine (RArcSine) transformed and response time data was

458 z-transformed using the same procedures as in experiment 1a. RArcSine transformed accuracy and z-

459 transformed response time were analysed using a repeated measures ANOVA with Saliency (salient

460 distractor vs similar distractor) as within subject factor and participants age group (Young vs Older)

461 as a between subject factor. Data is reported as mean +/- standard error of the mean.

462   For RArcSine transformed accuracy (Figure 3a), the main effect of salience was significant

463 (F(1,37) = 39.75, p < .001, η_p^2 = 0.518), driven by more accurate responses during salient trials

464 (109.99 +/- 1.68) relative to similar trials (102.07 +/- 1.56). However, the main effect of age group

465 (F(1,37) = .05, p = .824, η_p^2 = 0.001) and the interaction (F(1,37) = 1.3, p = .261, η_p^2 = 0..034) were not

466 significant. This data suggests that, in terms of RArcSine transformed accuracy, the young and older

467 participants were equally effective at using the salient distractor as an anti-cue when the stimulus

468 presentation time was extended.

469   For response time (Figure 3b), the main effect of salience was significant (F(1,37) = 84.654, p

470   < .001, η_p^2 = 0.696) driven by relatively faster responses during salient trials (zRT: -.451 +/- .053)

471   compared to similar trials (zRT: .271 +/- .026), suggesting that the salient distractor provided a

472   benefit to performance. However, the main effect of age group (F(1,37) = 1.211, p = .278, η_p^2 =

473   0.032), and the interaction were not significant (F(1,37) = 3.696, p = .062, η_p^2 = 0.091). Given the

474   marginal p-value for the interaction, we conducted an exploratory analysis to assess whether there

475   is potential evidence the interaction is driven by a lack of performance benefit (i.e. the difference

476   between salient and similar performance) for the older adults. Crucially, simple effects revealed that

477   the difference in performance between the salient and similar conditions was significant for both the

478   young (p < .001, η_p^2 = 0.632; Salient: -.542; Similar: .330) and older (p < .001, η_p^2 = 0.411; Salient: -

479   .359; Similar: .212) cohorts. Further simple effects revealed that there was no difference in

480   performance between older and younger participants for the salient trials (p = .093, η_p^2 = 0.075;

481   Older: -.359; Younger: -.542), but there was a difference in performance for the similar trials (p =

482   .031, η_p^2 = 0.120; Older: .212; Younger: .330; Older participants were less slowed during similar

483   trials). This verifies that despite the trending interaction, both age groups showed a clear

484   performance benefit in the presence of a salient distractor, even if it is attenuated in the older

485   cohort.

486   These data suggest that given enough time older participants are able to use the salient

487   distractor as an anti-cue as effectively as the younger participants. This suggests that older

488   participants may take longer to initiate reactive inhibition, possibly due to the slower accumulation

489   of neural resources, but that given enough time reactive inhibition can be effectively implemented.
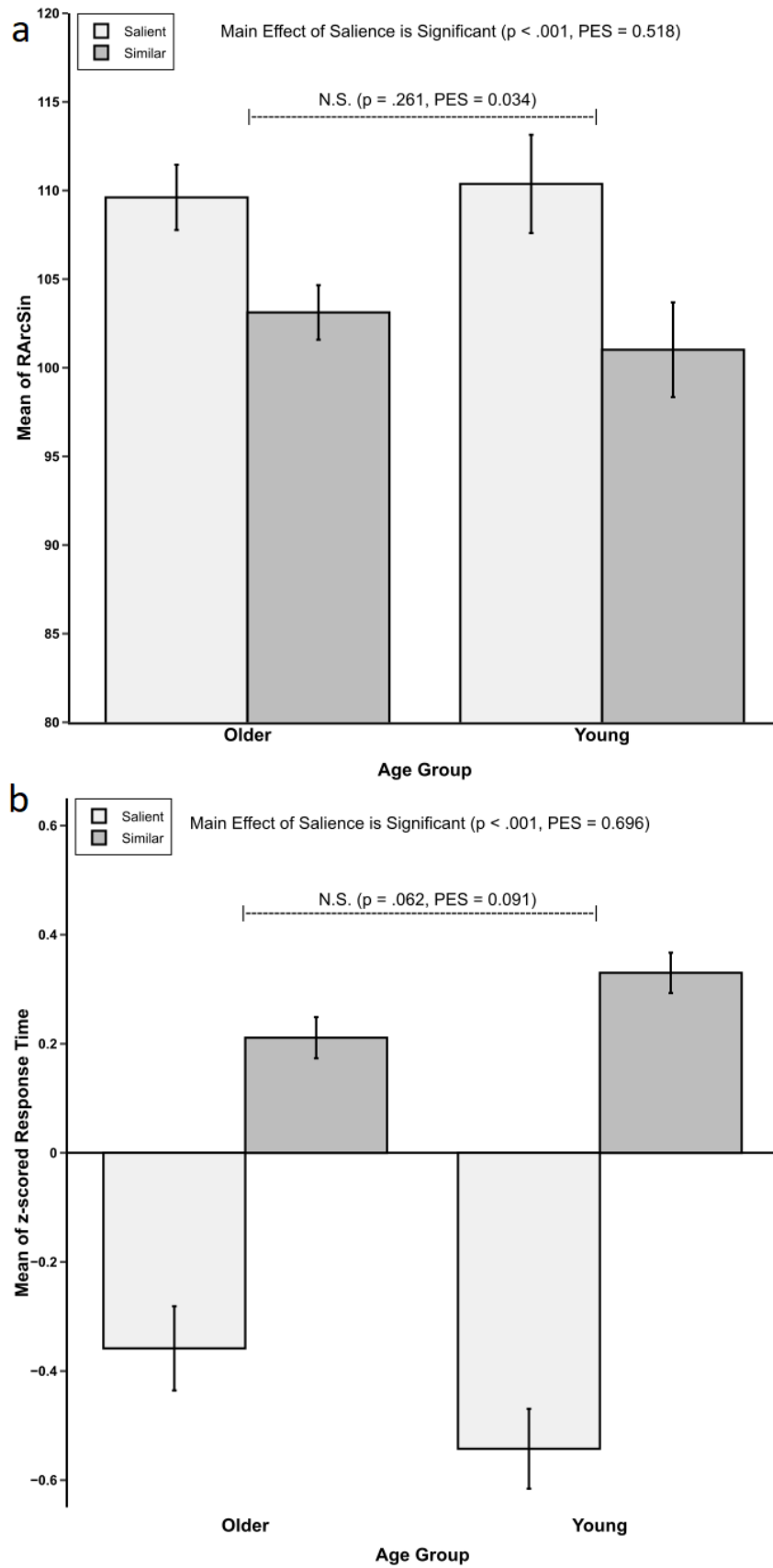
Figure 3. (a) Graph reflecting mean RArcSine transformed accuracy for salient and similar conditions across age groups. (b) Graph reflecting z-scored response time data (msec) for salient and similar conditions across age groups.

General Discussion

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495   The purpose of this study was to assess the effect of aging on reactive suppression in older

496   populations by comparing performance in a task that relies on reactive suppression in young

497   participants too. In experiment 1a, with a 200 msec display, we found that young participants were

498   able to effectively use a salient distractor as an anti-cue to benefit performance in terms of both

499   accuracy and response time, demonstrating effective reactive distractor suppression. Older

500   participants on the other hand showed no change in performance when the salient distractor was

501   present in the display. Importantly, the lack of performance benefit for old participants could not be

502   attributed to reduced contrast sensitivity as a subset of the older participants were shown to be able

503   to distinguish between low and high contrast items in experiment 1b. However, experiment 2

504   showed that older participants could engage reactive inhibition if given enough time. When the

505   stimulus presentation time was extended to 600 msec, older participants showed better

506   performance during salient trials than similar trials (in both accuracy and response time) at an

507   equivalent magnitude to the young participants. These data suggest that older participants have a

508   delayed initiation of reactive inhibition processes that scales with age, but that given enough time

509   effective reactive inhibition is possible. Prior literature typically shows a) impairments to proactive

510   control in aging and b) a shift from proactive to reactive mechanisms in aging. Despite the dearth of

511   studies directly investigating reactive control deficits, this has led to an implicit (and sometimes

512   explicit) assumption throughout prior literature that older participants shift to reactive control

513   because proactive control is impaired and reactive control is intact. Our study challenges this notion

514   as we did find an age-related deficit in a measure reflecting reactive distractor inhibition. That being

515   said, it is possible that reactive control is less impaired than proactive control, which induces a shift,

516   but that is a different issue than shifting due to no deficit.

517   One concern for this type of research in general is that inhibition deficits may in fact be

518   attributed to a generalized deficit in processing speed (Salthouse and Meintz, 1995; Salthouse, 2000;

519   Verhaeghen and De Meersman; 1998). Since most studies that identify inhibition deficits measure

520   response time, it could appear as if there were impaired response times in a specific inhibition task

521   for older participants, when in fact they are simply overall slower. However, even after accounting

522   for this possibility, inhibition deficits still persist in many inhibition tasks (Verhaeghen and Cerella,

523   2002). In our study, we z-transformed the response time data to account for this possibility and still

524   found no performance benefit in the 200 msec condition (Experiment 1a). As such, we would argue

525   that the age-related lack of a benefit we report cannot be attributed to general speed of processing

526   deficits and is more likely associated with a delay in reactive distractor suppression specifically.

527   A second concern with respect to this specific study is that the deficit observed may in fact

528   be completely or partially due to age-related impairments in attentional orienting rather than

529   reactive inhibition. The nature of orienting attention is complex and there are many variables to

530   consider, particularly with respect to aging (see Erel and Levy, 2016 for a comprehensive review),

531   but the most relevant aspects in the context of our study are covert and overt orienting, and

532   exogenous and endogenous orienting. Participants in the current study were instructed to keep their

533   eyes focused on the fixation point throughout the trials ostensibly to encourage covert attention (no

534   eye movements) which is also likely given the short presentation times in experiment 1a, however

535   eye tracking was not employed so the use of overt attention cannot be ruled out. Regardless,

536   research shows that older participants typically do not have impairments in covert attentional

537   orienting (Jennings et al, 2007), and that while deficits in overt attention tasks have been reported

538   (Kingstone et al, 2002), it has been argued that they can be attributed to deficits in motor control

539   over eye movements (Chen and Machado, 2016; Dowiasch et al, 2015; Warren et al, 2013; Crawford

540   et al, 2013; Klein et al, 2000, Ross et al, 1999) rather than attentional control (Erel and Levy, 2016).

541   With regard to exogenous and endogenous orienting during trials with a salient distractor, it

542   is arguable that this study engages both. Geng and DiQuattro (2010) showed that salient distractors

543   could facilitate performance (using a similar t-task paradigm to our study) using a combination of

544   two attentional strategies: inhibition, where saccades toward the salient distractor are actively

545   inhibited, and rapid rejection, where a saccade toward the salient distractor is quickly disengaged

546   and redirected towards the target. Inhibition took place on target-first trials, when the first saccade

547   went towards the target, and rapid rejection followed by inhibition took place on distractor-first

548   trials, when the first saccade went towards the salient distractor. Within the t-task, the process of

549   rapid rejection essentially consists of three phases: Orienting attention towards the salient

550   distractor, disengaging attention from the salient distractor, and reorienting attention towards the

551   target/inhibiting the salient distractor. The initial orienting of eye movements towards the salient

552   distractor is a classic example of overt exogenous orienting. However, disengaging, reorienting, and

553   inhibiting only begins because the participants recognize the distractor as such, making the target no

554   longer in an unpredictable location. This suggests that endogenous orienting is an integral part of

555   reactive distractor suppression processes which are likely important for performance in our task.

556   Previous studies have typically reported intact (Waszak et al, 2010; Iarocci et al, 2009;

557   Jennings et al, 2007; Folk and Hoyer, 1992; Craik and Byrd, 1982) or even enhanced (Langley et al,

558   2011a; 2011b; Mahoney et al, 2010) exogenous orienting in aging. In contrast, endogenous attention

559   is sometimes reported to be impaired (Olk and Kingstone, 2009; Bojko et al, 2004; Brodeur and Enns,

560   1997; Greenwood et al, 1993; see also Erel and Levy, 2016). Furthermore, impaired (i.e. slow)

561   attentional disengagement (Owsley, 2016; Greenwood and Parasuraman, 1994) has also been

562   documented in older populations. Consequently, if spatial endogenous disengagement and orienting

563   is impaired in old age it may well be the case that these impairments also manifest in impaired

564   reactive distractor suppression.

565   Nevertheless, disengagement and endogenous orienting are likely engaged in both salient

566   and similar trials in our task as both trials may involve the initial selection of the non-target item

567   (Geng & DiQuattro, 2010). Thus, an impairment in these processes should have affected

568   performance in both trial types. However, the older participants in Experiment 1a did not show such

569   a general impaired performance. In fact, accuracy was the same for both young (86%) and older

570   (86.2%) participants during the similar condition in experiment 1a. As such, the performance

571   patterns we report point to a difference in the efficiency of processes that are specifically utilised

572   when a salient distractor is present. One reason behind this could simply be a slower processing

573   capacity for salient items in old age (that is overcome when the input is presented for longer). This

574   seems unlikely as Experiment 1b demonstrated that the older participants showed virtually no

575   difference in response time when discriminating between similar (two low contrast stimuli) and

576   salient (one low and one high contrast stimuli) conditions. If salient stimuli required more processing

577   time in old age, we would have expected to see longer response times on trials where a salient item

578   was present in the display. A second, and seemingly more likely explanation, is that old participants

579   are exhibiting impairments in the reactive suppression of salient information (rather than having

580   difficultly processing salient information in the first place). In fact, impaired suppression of salient

581   information in old age has previously been reported by Tsvetanov et al (2013) in the context of a

582   proactive inhibition task. It is therefore possible that older adults exhibit impairments in salience

583   suppression in general, regardless of whether reactive or proactive inhibition is called upon.

584   A final possibility is that 600 msec is too long to still be considered "reactive." According to

585   Irlbacher et al (2014), reactive control can be parsed into an early and late mechanism and that each

586   mechanism provides a unique method of identifying and resolving conflict. In the context of working

587   memory inhibition, both mechanisms resolve interference that occurs when a familiar stimulus is

588   identified but must be ignored. Familiarity-inhibition models favor speed over accuracy and are

589   considered to be a quick and early acting reactive control mechanism, engaging around 300-450 ms

590   after stimulus presentation (Du et al, 2008). In these models, the interference is resolved through

591   the inhibition of the familiar stimulus (Mecklinger et al, 2003). On the other hand, context retrieval

592   models favor accuracy over speed and are considered to be a slower and late acting reactive control

593   mechanism, engaging around 550 ms after stimulus presentation (Zhang et al, 2010). In these

594   models, the interference is resolved by selecting for the relevant target features more strongly (by

595   retrieving the appropriate contextual information; Badre and Wagner, 2005; 2007). Based on this, it

596   is reasonable to believe that reactive processes were used by participants with a presentation time

597   of 600 msec.

598   However, despite indications that our data reflect an impairment in reactive distractor

599   suppression, a major limitation was that we did not use eye-tracking and therefore cannot tease

600   apart the relative contribution of proactive and reactive distractor suppression during this task. In

601   other words, there is no direct evidence that young and old participants are completing the task in a

602   similar manner (i.e. specifically via reactive control mechanisms). That being said, Geng and

603   DiQuattro (2010) showed that young participants had a failure of proactive control mechanisms (i.e.

604   a saccade was made to the salient distractor) on ~68% of trials, leading necessarily to the

605   engagement of reactive control mechanisms (i.e. rapid rejection). Importantly, performance on

606   these "reactive" trials was still better than on control trials on which the first saccade went to a non-

607   salient distractor, suggesting that the reactive rejection of the salient distractor was facilitated even

608   when it initially captured attention. Based on this we can infer that a similar proportion of "proactive

609   failure" trials likely occurred in our study for the young participants. Further, in conjunction with

610   well-characterized prior literature that has shown age-related deficit across proactive control

611   mechanisms, we also infer that "proactive failures" are probably more common in our older cohort.

612   This would suggest that our older cohort likely relied more on reactive control mechanisms to

613   complete the task than the younger cohort. However, this is ultimately speculative and must be

614   confirmed in future research with other methods.

615   Overall, this study suggests that older participants exhibit an age-related delay in the

616   initiation of reactive inhibition. The nature of this impairment is hypothesized to be specific to

617   reactive salience suppression, since the underlying rapid rejection and inhibition processes appear

618   intact when there is no salient distractor present (as evidenced by equivalent performance across

619   age groups in experiment 1a during similar trials). Future research will have to investigate the

620   underlying impairment that leads to this delay in the initiation of reactive distractor suppression. For

621 example, reactive distractor suppression may be engaged late because of the slower accumulation

622 of neural resources (Grady, 2012), or because the attentional capture process is intact but the delay

623 is in the transition to inhibition/rapid rejection, or because both attentional capture and

624 inhibition/rapid rejection are independently delayed. Of course, these possibilities are not

625 necessarily mutually exclusive. An alternative explanation that could account for this data is that

626 there is a "fast" and a "slow" reactive control mechanism and that only the faster reactive

627 mechanism is impaired. Future research will have to distinguish between these possibilities.

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