

# Delayed reactive distractor suppression in aging populations

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## Delayed Reactive Distractor Suppression in Aging Populations

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This paper is based on chapter 3 of author B.K.A.'s dissertation (Ashinoff, 2017). All raw data and experimental code for this study is publicly available on the Open Science Framework (OSF):

<https://osf.io/3h7ux/>

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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

## Introduction

1 It is generally accepted that normal aging can lead to declines in cognitive performance  
2 (Braver and Barch, 2002; Craik and Salthouse, 2011; Andrews-Hannah et al, 2007; Geerligs et al,  
3 2014a; 2014b; Grady, 2012; Larson et al, 2016; Li et al, 2001; 2016; Persson et al, 2006; Zanto et al,  
4 2010). More specifically, there is a plethora of evidence highlighting impairments in inhibition  
5 mechanisms (Hasher and Zacks, 1988; Bauer et al, 2012; Mayas et al, 2012; Gazzaley et al, 2005; but  
6 see Frings et al, 2015 for contrasting findings). Previous studies have highlighted the increased  
7 interference experienced from irrelevant distractors in old age across different experimental  
8 paradigms such as global/local tasks (Tsvetanov et al, 2013; Mevorach et al, 2016), reading with  
9 distractor tasks (Darowski et al, 2008), response inhibition (Anguera and Gazzaley, 2012), as well as  
10 inhibition in the context of WM tasks (Gazzaley et al, 2005). These findings and others fit with the  
11 notion that aging is associated with a general impairment in a central inhibition mechanism (the  
12 inhibitory deficit theory; Hasher and Zacks, 1988), which manifests in various inhibition related  
13 scenarios. The focus on inhibitory processes in old age is especially relevant because there is  
14 evidence that distractor inhibition is crucial in mediating cognitive control in general (Darowski et al.,  
15 2008). It should be noted that although it is often assumed that inhibition deficits result in impaired  
16 cognition, there is some evidence to suggest that it may improve cognition under some  
17 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 Ax-CPT 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 an 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.

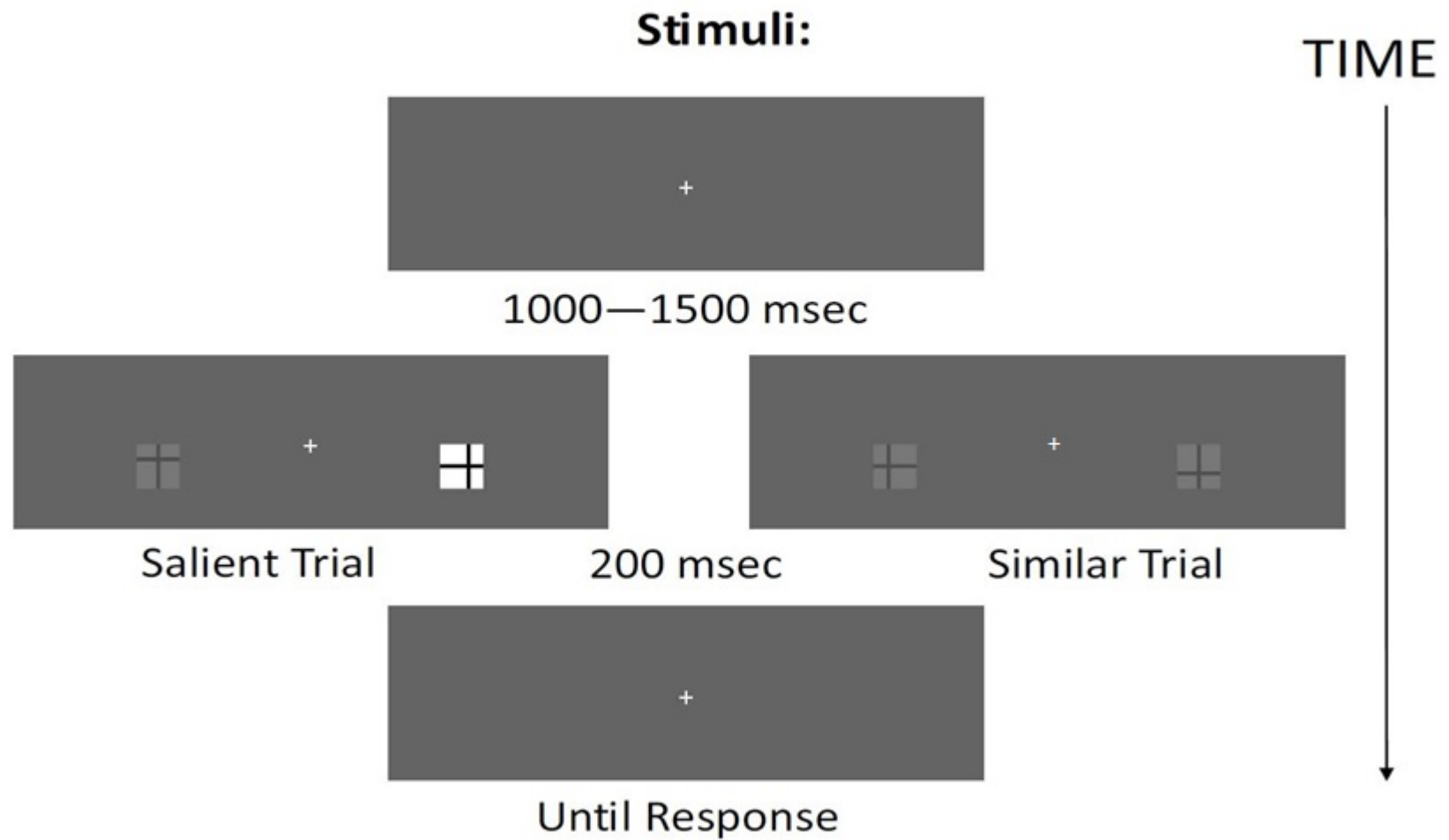
229 *Stimuli and Procedure*

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.



268

269 Figure 1. Diagram of the reactive distractor inhibition 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.

## Results & Discussion

272  
 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.



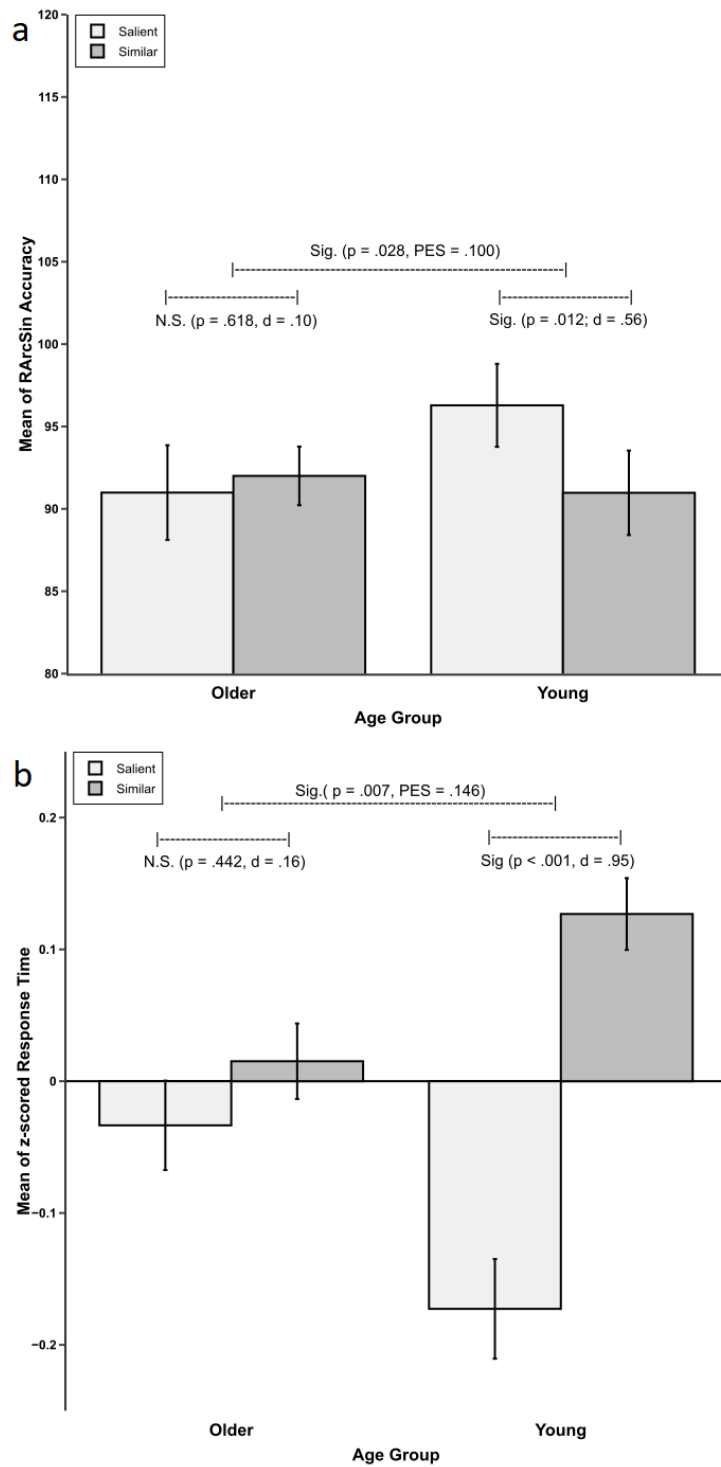
296 Transformed accuracy values (Figure 2a) were analysed using a repeated measures ANOVA  
297 with Saliency (salient distractor vs similar distractor) as within subject factor and participants age  
298 group (Young vs Older) as a between subject factor. The main effects of salience ( $F(1,46) = 2.368$ ,  $p =$   
299  $.131$ ,  $\eta_p^2 = .049$ ) and age group ( $F(1,46) = .446$ ,  $p = .508$ ,  $\eta_p^2 = .010$ ), were not significant, but there  
300 was a significant interaction between salience and age group ( $F(1,46) = 5.132$ ,  $p = .028$ ,  $\eta_p^2 = .100$ ).  
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 ( $90.99 \pm 2.88$ ) and similar trials ( $92.00 \pm 1.78$ ,  $t(23) = -.505$ ,  $p =$   
304  $.618$ ,  $d = .10$ ). In contrast, young participants were more accurate on salient trials ( $96.28 \pm 2.52$ )  
305 than on similar trials ( $90.98 \pm 2.56$ ;  $t(23) = 2.739$ ,  $p = .012$ ;  $d = .56$ ).

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 ( $90.98 \pm 2.56$ ) and  
308 older ( $92.00 \pm 1.78$ ), 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 (Craig and Salthouse, 2011; Salthouse, 1994; 1996; 2000;  
315 Salthouse and Mein, 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    $15.173$ ,  $p < .001$ ,  $\eta_p^2 = .248$ ), where participants were quicker to respond to salient trials ( $z\text{-RT} = -.103$   
325    $\pm .025$ ) than to similar trials ( $z\text{-RT} = .071 \pm .020$ ; 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 ( $F(1,46) = 2.629$ ,  $p = .112$ ,  $\eta_p^2 =$   
329    $.054$ ), but there was an interaction between salience and age group ( $F(1,46) = 7.881$ ,  $p = .007$ ,  $\eta_p^2 =$   
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:  $z\text{-RT} = -.033 \pm .034$ ;  
334   Similar:  $z\text{-RT} = .015 \pm .029$ ). However, younger participants responded significantly quicker ( $t(23) =$   
335    $-4.665$ ,  $p < .001$ ,  $d = .95$ ) in the salient condition ( $z\text{-RT} = -.17 \pm .038$ ) compared with the similar  
336   condition ( $z\text{-RT} = .127 \pm .027$ ). 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.



339

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

343

## 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 ( $\geq 26$  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 ( $\geq 96\%$ ) 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 ( $\geq 26$   
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.

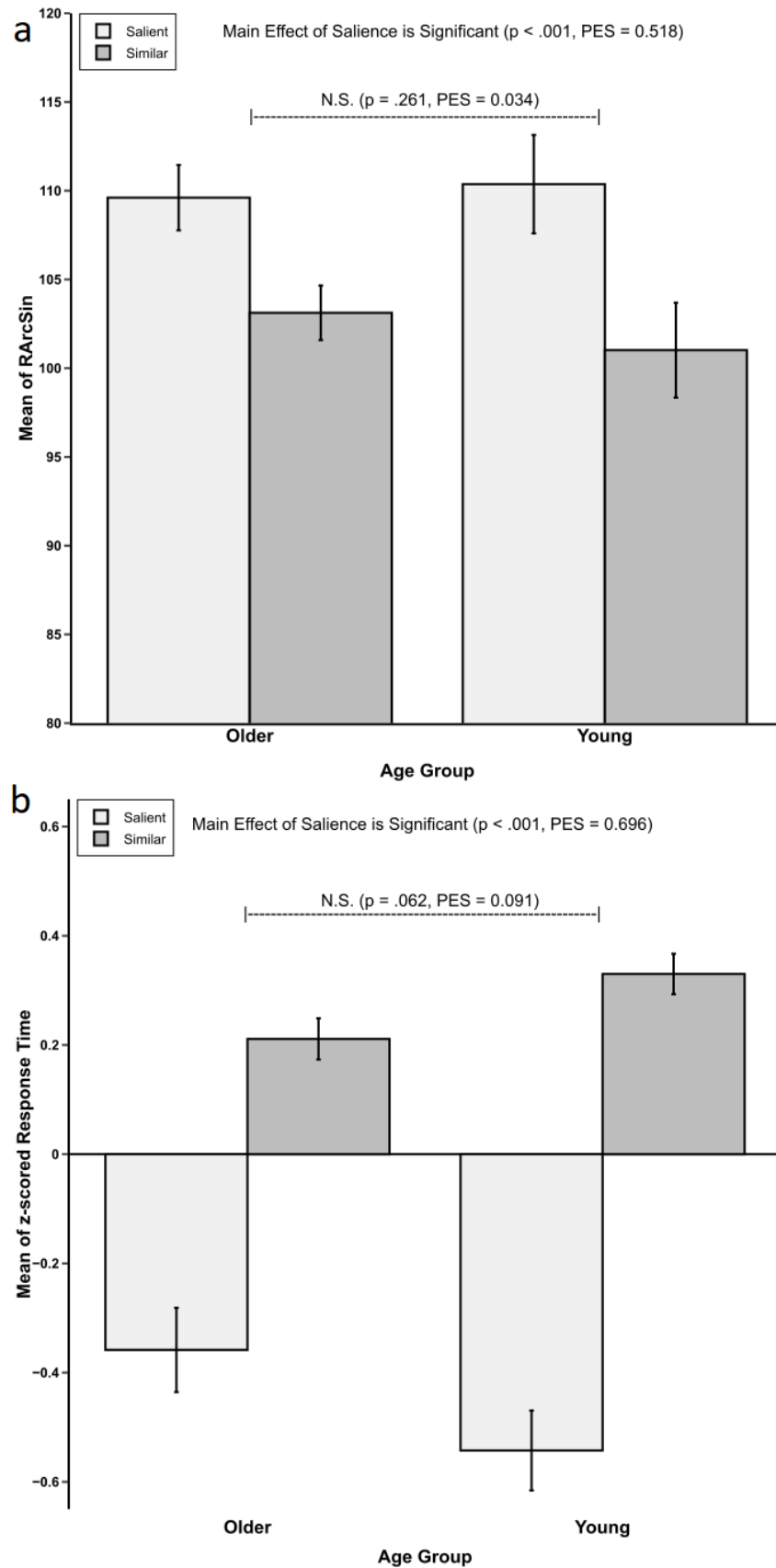
457 Accuracy data was rationalized arcsine (RArcSine) transformed and response time data was  
458 z-transformed using the same procedures as in experiment 1a. RArcSine transformed accuracy and z-  
459 transformed response time were analysed using a repeated measures ANOVA with Saliency (salient  
460 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 ( $F(1,37) = 39.75, p < .001, \eta_p^2 = 0.518$ ), driven by more accurate responses during salient trials  
464 ( $109.99 \pm 1.68$ ) relative to similar trials ( $102.07 \pm 1.56$ ). However, the main effect of age group  
465 ( $F(1,37) = .05, p = .824, \eta_p^2 = 0.001$ ) and the interaction ( $F(1,37) = 1.3, p = .261, \eta_p^2 = 0.034$ ) 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  $< .001$ ,  $\eta_p^2 = 0.696$ ) driven by relatively faster responses during salient trials ( $zRT: -.451 \pm .053$ )  
471 compared to similar trials ( $zRT: .271 \pm .026$ ), suggesting that the salient distractor provided a  
472 benefit to performance. However, the main effect of age group ( $F(1,37) = 1.211$ ,  $p = .278$ ,  $\eta_p^2 =$   
473  $0.032$ ), and the interaction were not significant ( $F(1,37) = 3.696$ ,  $p = .062$ ,  $\eta_p^2 = 0.091$ ). 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 ( $p < .001$ ,  $\eta_p^2 = 0.632$ ; Salient:  $-.542$ ; Similar:  $.330$ ) and older ( $p < .001$ ,  $\eta_p^2 = 0.411$ ; 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 ( $p = .093$ ,  $\eta_p^2 = 0.075$ ;  
481 Older:  $-.359$ ; Younger:  $-.542$ ), but there was a difference in performance for the similar trials ( $p =$   
482  $.031$ ,  $\eta_p^2 = 0.120$ ; 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.



490

491 Figure 3. (a) Graph reflecting mean RArcSine transformed accuracy for salient and similar conditions  
 492 across age groups. (b) Graph reflecting z-scored response time data (msec) for salient and similar  
 493 conditions across age groups.

## 494 **General Discussion**

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 difficulty 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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