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DOI:
10.1037/pag0000336

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The authors would like to thank Denise Clissett for her critical role in the recruitment of older participants, as well as Samantha Ellis, Charlie-Louise Milward, and Leah Supra for their contributions to this project as undergraduate research assistants.

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/

Date: 05/02/2019 – This manuscript has not been published yet.

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

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

In contrast, the notion that an all-encompassing inhibition impairment is associated with age has been challenged by studies showing impairments only on subsets of inhibition tasks (Rey-Mermet et al, 2018a; 2018b). For instance, Kramer et al (1994) found age related inhibition deficits in a stop-signal task, but not in a response competition or spatial pre-cueing task. Furthermore, even when inhibition impairments occur across tasks, evidence suggests they may be independent. For instance, Anguera and Gazzaley (2012; Sebastian et al, 2013) assessed motor inhibition in a stop signal task and sensory filtering within the context of a delayed recognition task in young and old participants. Critically, they showed that motor and sensory inhibition were independently impaired as a function of aging. More recent studies have built upon this conclusion, further highlighting distinct age effects on different cognitive inhibitory functions and their potential neural correlates (Vadaga et al, 2015; Bloemendaal et al, 2016).

The dual mechanisms theory of proactive and reactive cognitive control (Braver, 2012) suggests a potential explanation for the failure to identify a general inhibition impairment in old age. Rather than a single inhibition mechanism, the DMC differentiates between two modes of control: Proactive, an attentional biasing mechanism which mediates behavioral responses to a given stimulus in advance; and reactive, which is a "late correction" mechanism that allows one to alter behavioral plans "in the moment" when suddenly presented with new and relevant information. Consequently, it is possible that only one of these inhibition mechanisms is affected by age, or that they are affected to different degrees. Indeed, previous studies have identified a proactive pattern of performance in young participants and a reactive one in old participants (Braver et al., 2005; Paxton et al, 2008). Interestingly, even when performance across age groups was equivalent, brain activity that was consistent with impairments to proactive control (Vadaga et al, 2015) and increased reliance on reactive control (Paxton et al., 2008) was documented in the older cohorts. Similar brain dynamics have also been recorded in the context of a task switching paradigm as older participants (relative to younger participants) showed reduced sustained activation, a hallmark of proactive control (Braver, 2012), and increased transient activation, a hallmark of reactive control (Braver, 2012), during switch trials in the anterior prefrontal cortex (Jimura and Braver 2010). These findings are consistent with the idea that older participants show more reactive control related- and less proactive control related activity than younger participants.

The above evidence points to a selective impairment in inhibition in old age – proactive processes appear to decline with age, while reactive processes may be intact. However, there are two major issues with this interpretation. First, most studies of the DMC and aging have highlighted the activation of reactive processes in older participants and proactive process in young participants in the same task, but did not directly compare reactive processes across age groups. Second, in many of these studies (typically using the AxCPT paradigm; Braver et al, 2005; Paxton et al, 2008; Braver et al, 2009) utilising either proactive or reactive control yield different performance benefits. As such, it is possible that the increased use of reactive control in old age represents an unconscious strategic bias rather than specific impairment in proactive control and intact reactive control. For example, one of the early examples for inhibition deficits was reported by Hasher et al (1991) in a study measuring inhibitory function in young and older participants using a negative priming task (assessing the persistence of inhibition of a distractor by switching its role to a target on subsequent trials). Hasher et al (1991) found that young participants showed persistence of inhibition from one trial to the next, but older participants showed no effects, suggesting impaired inhibitory function. They argued that this reflected impairment in a central inhibition mechanism. However, an alternative interpretation is that the younger participants were engaging proactive control and that the persistence of inhibition was an artifact of their anticipating the state of the target and distractor items, whereas older participants engaged reactive control and therefore did not show negative priming because they didn’t anticipate their state. Crucially, this arguably conferred a strategic benefit to the older participants in this context since they were not biased away from the target on switch trials.

A few notable studies have addressed the issue of comparing reactive control between age groups. One set of studies have focused on “proportion congruence” manipulations in conflict resolution tasks, such as Stroop tasks where congruent (no-conflict) and incongruent (conflict) displays are contrasted (Bugg and Crump, 2012; also see Bugg, 2015 for examples using a flanker task). Proportion congruence studies manipulate the ratio of congruent and incongruent trials within a block (list-wise) or for a specific target type (item-specific; e.g., dogs within a list of animals) and measure how such changes in frequency modulate performance differences between the congruent and incongruent conditions. The typical finding in such studies with young adults is that the congruency effects (difference in performance between congruent and incongruent displays) are larger in the condition with more congruent trials, than in the condition with more incongruent trials (Bugg and Chahani, 2011; Bugg, Jacobi, and Chahani, 2011; Bugg, Jacoby, and Toth, 2008). Importantly, the two versions of this paradigm (list-wide and item-specific) arguably tap proactive and reactive control mechanisms, separately. List-wide manipulations enable participants to adopt a more stringent control in anticipation of trials throughout a block (proactive), while item-specific versions do not. In the latter case, the proportion congruence manipulation is applied to different items that are randomly intermixed and therefore, whether more or less stringent control is needed cannot be predicted before and item is presented (reactive). In fact, Gonthier et al (2016) showed distinct doubly-dissociated behavioral signatures for item-specific (reactive) vs list-wise (proactive) proportion congruence manipulations, supporting the notion that item-specific proportion congruence manipulations tap into reactive control mechanisms. Using such paradigms, Bugg et al (2014a; 2014b) compared performance of young and old adults. Specifically, Bugg et al., (2014b) found that both young and older participants exhibited the standard item-specific proportion congruence effect, where the mostly congruent items had larger congruency effects than the mostly incongruent items. Since reactive control was argued to be necessary to produce this effect, Bugg et al (2014b) concluded that reactive control was spared in older participants.

Much like the “item-specific” proportion congruency effect, “sequential” congruency effects have also been used as a measure of reactive control. “Sequential” congruency effects refer to the phenomenon that congruency effects for trials immediately following an incongruent trial are reduced compared to congruency effects for trials immediately following a congruent trial (In other words, analyzing trials n+1 and grouping them based on trial n). Typically, both young and older participants show these sequential congruency effects of equal magnitude, but older participants show overall larger congruency effects and longer overall response times (even after accounting for speed of processing deficits; Puccioni & Vallesi, 2012; West & Moore, 2005; but see Aschenbrenner and Balota, 2016 for a study where older participants showed a larger sequential congruency effect). In other words, although older participants seem to take longer to complete the task, these studies have suggested that reactive control is effectively intact in older cohorts. In contrast, Xiang et al (2016) found no “sequential” congruency effects for older participants, with respect to both response time and accuracy, arguing that reactive control might be impaired in aging. However, they did not account for generalized slowing effects or speed-accuracy trade-offs, which makes their results difficult to interpret.

The purpose of this study is to further assess reactive distractor suppression in aging populations. It should be noted here that reactive and proactive cognitive control are essentially umbrella terms that can refer to two different mechanisms of engaging a wide range of similar cognitive abilities, including distractor suppression, target selection, conflict resolution, and so on. Despite this, most studies tend to use the general term of proactive or reactive control, rather than specify the cognitive mechanisms being investigated. This is relevant because it may be that proactive and reactive control of some cognitive abilities may be intact, while others may be impaired. Although the DMC generally argues for a general impairment within proactive control mechanisms, it may be valuable to adopt a more precise perspective. Therefore, we refer to the process of reactive distractor suppression throughout our study, rather than reactive control.

In order to stringently assess age-related differences in reactive distractor suppression, performance should be compared in a task that yields clear benefits when reactive distractor suppression is engaged and eliminates or significantly reduces the role of proactive distractor suppression in young participants too. Here, we describe such a task which specifically taps reactive distractor suppression mechanisms. DiQuattro and Geng (2011) investigated the brain mechanisms that are involved in processing contextually relevant, but not task relevant stimuli. While in an fMRI scanner, they had participants (Mean age = 23.8; Age Range: 18 – 39 yrs) perform a visual search task for a low contrast target in the presence of either a high or low contrast non-target (50% predictability), each of which would appear in one of two pre-defined locations; participants could not predict the location of the distractor on a given trial. Despite being task irrelevant, the salient non-target was contextually relevant as the presence of the high contrast non-target informed the participant that the target was in the other location, effectively triggering a reactive distractor suppression. They found that participants were both faster and more accurate on trials with a salient distractor, compared to a similar (to the target) distractor.

Geng and DiQuattro (2010; experiment 1) used a variant of this paradigm with eye tracking showing that, when the distractor was unpredictable, participants made a saccade to distractor first on ~68% of trials, necessitating reactive rapid rejection instead of proactively inhibiting the distractor (saccading towards the target first; for similar trials, it was ~50% rapid rejection and ~50% inhibition). They argued that rapid rejection was only needed when inhibition failed. In other words, the engagement of reactive control in this task pre-supposes a failure of proactive control (Geng, 2014). Crucially though, even when a saccade was first made towards the distractor, there was still a performance benefit on salient trials. Even when proactive inhibition failed, young participants were able to reactively rapidly reject the distractor in a beneficial manner. Therefore, the presence of a performance benefit (i.e. better performance on salient trials) in this task must be attributed to both a failure of proactive (inhibition) and the engagement of reactive (rapid rejection) processes.

The fMRI analysis in DiQuattro and Geng (2011) provided converging evidence for the notion that this task engages reactive distractor suppression. It revealed that the left TPJ and left inferior frontal gyrus (IFG) were significantly more active when there was a high salience non-target compared to a low salience non-target. Dynamic causal modelling revealed a network in which left TPJ projects to left IFG that, in turn projects to the frontal eye fields (FEF). The authors interpreted this to mean that the ventral attention network (TPJ and IFG in this study) that is typically associated with bottom up attention (Corbetta and Shulman, 2002), updates control signals to the dorsal attentional network (FEF in this study). They refer to this network as an attentional circuit breaker that can reorient attention when top-down (i.e. proactive) attentional processes don’t work or lead to counterproductive outcomes. Importantly, they further suggest that the TPJ and IFG are effectively generating a “reactive” control signal as a consequence of the stimulus presentation

(Braver et al, 2009; Braver, 2012). Additional converging evidence comes from studies of young adults with high expression of psychosis proneness, who have been shown to favor reactive distractor suppression relative to proactive distractor suppression (Abu-Akel et al, 2016a; 2016b; 2016c). In the t-task described above, performance benefits from the presence of the salient distractor scale with the expression of psychosis proneness (Abu-Akel et al., 2018), highlighting that this paradigm is sensitive enough to detect variations in the magnitude of engagement of reactive distractor suppression.

Moreover, another advantage of this task is that it avoids engaging general non-perceptual inhibition processes. The stimuli within the distractor is never a valid response option (a sideways t shape instead of upright or inverted), so participants won't be primed to make a specific response if they do process the distractor, which would then need to be inhibited. In addition (unlike stop-signal tasks), the "correct" response never changes within the course of a trial so they never have to switch responses. Indeed, older participants appear to be impaired in a stop-signal task (Kramer et al, 1994), which tests participants' ability to cancel a motor response while it is already being executed (and therefore presumably measures reactive inhibition). However, the requirement to cancel an already executable motor response may relate to other processes (primarily motor cancelation/response inhibition) which may be independent or more complex than reactive inhibition per se. (Swick, Ashley, and Turken, 2011; Kolodny, Mevorach, and Shalev, 2017). In fact, Anguerra and Gazzaley (2012) have highlighted the independence of impairments in response inhibition and perceptual inhibition (but not exclusively reactive inhibition) in old age. In our study, by design, only differences in perceptual inhibition are likely to change behavior.

This paradigm is distinct from the proportion congruence studies in two important ways. First, proportion congruence effects rely on the implicit learning of the associations between different items and their likelihood of conflict (Blais et al, 2012). It is possible that proportion congruence effects may be less susceptible to age-related decline due to their reliance on implicit learning (Cohen-Shikora, Diede, & Bugg, 2018). However, in our task, there is an even probability of all trial types and making a correct response does not depend on any element of previous trials. Thus, our task may tap into a more temporally bounded form of reactive control. Second, our paradigm manipulated stimulus presentation duration to assess the timing of reactive control. As far as we know, no previous studies have done this.

In the present study we compared old and young participants' performance on the T-search task to directly assess if reactive inhibition is impaired or intact in old age. If in older participants reactive distractor inhibition is indeed intact (irrespective of a possible proactive impairment), it is expected they will derive a benefit from the presence of the salient distractor compared to a similar distractor. Conversely, if older participants have impaired reactive distractor suppression, it is expected that they show minimal benefit from the presence of a salient distractor.

Experiment 1a

Methods

IRB Approval

All experiments in this study were approved by the Science, Technology, Engineering and Mathematics Ethical Review Committee at the University of Birmingham.

Participants

25 young participants and 26 older participants participated in two successive behavioral experiments. Three subjects (2 older, 1 younger) were excluded from the analysis due to poor performance (Overall accuracy across conditions < 60%; A cut-off of 60% was chosen to balance between exclude participants who were guessing or did not understand the task, and including participants who simply had low accuracy), resulting in 24 young participants (Mean Age: 18.8, SEM of Age: .19, Age Range: 18 -21; 23 Females) and 24 older participants' (Mean Age: 70.1, SEM of Age: 1.63, Age Range: 60 - 82; 13 Females) data being analysed. All participants had normal or corrected to normal vision. The order of the tasks was counterbalanced to account for possible fatigue and

order effects. The other experiment is reported elsewhere and has no relevance to the current investigation. Young participants were recruited from the undergraduate population in the school of psychology at the University of Birmingham, UK. They were compensated for their participation with course credits. The older participants were recruited from a volunteer pool maintained by the School of Psychology at the University of Birmingham. They were compensated for 1.5 hours of their time with a one-time payment of £7. All participants had to sign an informed consent form prior to the study. Participants' were healthy with no history of head injury, mental health issues or neurological disorders. The old participants were screened for decline in cognitive functions using the Montreal Cognitive Assessment (MoCA). All of the older participants scored within the normal range (Mean Score: 27.5, SEM of Score: .23).

Power Analysis

An a priori statistical power analysis was performed for sample size estimation, based on data from DiQuattro and Geng (2011; N = 21). They found that the presence of a salient distractor significant improved both response time and accuracy for healthy young participants, with an effect size of cohen's d = 2.9 and d = 1.7, respectively. These are considered to be extremely large using Cohen's (1988) criteria. With an alpha = .05 and power = 0.95, the projected sample size needed to detect an effect size of 1.7 (GPower 3.1.9.2; Faul et al, 2007; 2009) is approximately N = 6 for a repeated measures ANOVA with a within-between subjects interaction. However, one possibility is that the effect size will be much smaller for the older participants. Therefore, as an additional check the projected sample size needed to detect an effect size of .3 (with all the same other parameters) is approximately N = 40 (20 per group). Thus, our sample size of 51 should be adequate to assess the main objectives of this study, unless the effect size for older participants is lower than .3. This power analysis also applies to experiment 2 which has a sample size of 39.

Stimuli and Procedure

Participants were presented with five blocks of 46 trials each. Color was defined using RGB color coordinates. The background color of the display was grey [100 100 100]. On all trials, target and non-target stimuli were displayed. Each stimulus was a square whose center was 6.5 degrees of visual angle (horizontally 6.3 degrees; vertically 1 degree; all measures of visual angle were calculated assuming a viewing distance of 50 cm) diagonally left or right and below the center of the screen. Each square subtended 1.8 degrees of visual angle. The target square was dark grey [120 120 120]. In the target square, a vertical line with a width of .224 degrees of visual angle bisected the square. A second horizontal line also appeared to create a 'T'-like shape (Figure 1). These lines were a dark grey [80 80 80]. On half of trials, the horizontal line was .281 degrees of visual angle above the center of the square, creating an 'Upright' T (Figure 1) and on the other half, the horizontal line was .281 degrees of visual angle below the center of the square creating an 'Inverted' T. The color of the non-target square depended on the trial type. On 'Similar' trials, the color was the same as the target square. On 'Salient' trials, the non-target square was white [255 255 255]. In the non-target square, an horizontal line with a height of .224 degrees of visual angle bisected the square. A second vertical line also appeared to create a sideways 'T'-like shape (Figure 1). On 'Similar' trials, the line color was the same as inside the target square. On 'Salient' trials, the line color was black [0 0 0]. On 50% of trials, the vertical line was .281 degrees of visual angle right of the center of the square, creating a clockwise rotated "T". On 50% of the trials, the vertical line was .281 degrees of visual angle left of the center of the square creating a counter-clockwise rotated "T".

In each block there were 50% "Salient" trials and 50% "Similar" trials, randomly intermixed. On any given trial there was a 50% chance that the target would appear in the left position and 50% chance that it would appear in the right position. Participants had to identify if there was an upright or inverted "T" stimulus on each trial by pressing the "H" or "B" keys, respectively. These buttons were chosen because the "H" key is positioned above the "B" key on the keyboard, mimicking the spatial orientation of the target stimuli, where the upright "T" stimulus has a horizontal line above the center of the stimulus square and the inverted “T” stimulus has a horizontal line below the center of the stimulus square.

Every trial began with a white [255 255 255] fixation cross presented at the center of the screen, which persisted throughout the trial (including during ‘blank’ screens). Each trial began with blank screen. The “fixation” time was randomly selected based on a uniform distribution of times between 1500 – 2000 msec (Figure 1). Next, the appropriate stimulus (depending on the trial) was displayed for 200 msec. Participants could respond starting when the stimulus was presented. After the stimulus was removed, the participant was presented with blank screen until they made a response. Once a response was made, the next trial would begin. Participants were given the chance to take short breaks in between blocks (< 5 min). Each session began with 20 practice trials. During the practice, participants received visual feedback such that if they made an identification error, the fixation cross changed to red for 250 msec before turning back to white for the rest of the fixation time.

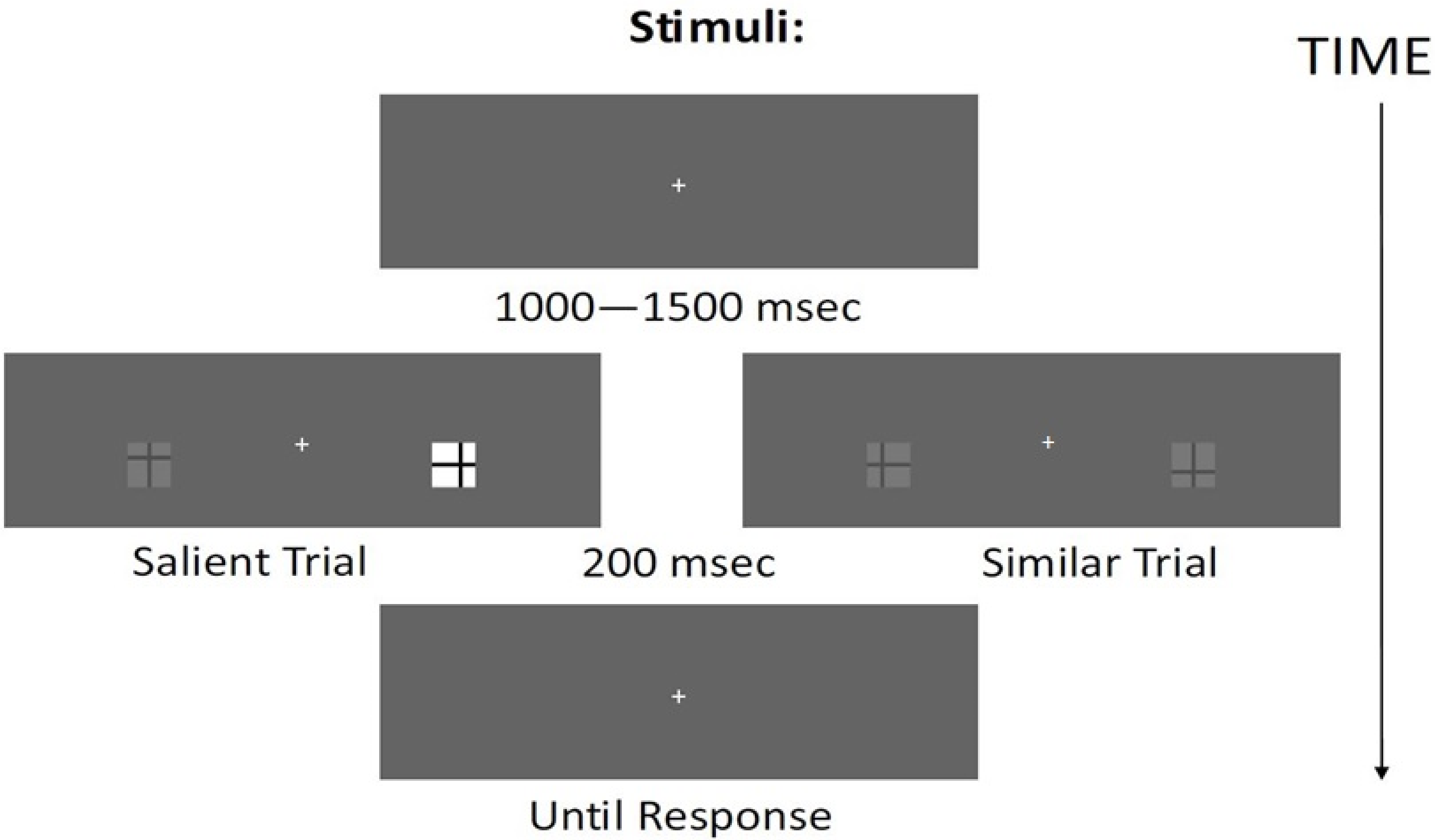

Figure 1. Diagram of the reactive distractor inhibtion t-task. Participants were presented with either a salient or similar stimulus on any give trial. In the salient example the correct response would be to press the H-key to indicate an upright target. In the similar example the correct response would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

Results & Discussion

Response time in msec (RT) and accuracy rate (i.e. proportion of correct responses) were measured as dependent variables. All values are presented as mean +/- standard error of the mean. The data was cleaned to account for outliers. For each participant, response time data that was greater than and less than 2 standard deviations from the participants' individual mean was excluded from all analyses. The individual mean response time was calculated separately for each salience condition (salient trials and similar trials). This resulted in the loss of an average of 4.37% (SEM = .22%) of the response time data per older participant and 3.71% (SEM = .23%) per young participant. An independent samples t-test revealed that these values were significantly different ($t(46) = -2.039$, $p = .047$, $d = .58$). This is attributable to the notion that older participants tend to exhibit greater variability in cognitive performance (Hultsch and MacDonald, Chapter 4 in Dixon et al, 2004; Morse, 1993) than younger participants. As such, their response time distributions would be wider and they would have more trials that would fall outside of 2 standard deviations from the mean.

For the accuracy data, a rationalized arcsine transformation (Equation 1) was applied to each participants' overall accuracy in each salience condition. This was done to account for possible violations of normality that can arise in binomially distributed data. The rationalized arcsine transformation was designed to normalize the data in accordance with the arcsine transformation while maintaining a more intuitive scale for interpretation of results (Studebaker, 1985). Since the transformation don't reflect true probabilities, they will not be reported with a % symbol, but for interpretation purposes the values do approximate the raw data, albeit skewed towards larger values than the raw data.

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

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

Transformed accuracy values (Figure 2a) were analysed using a repeated measures ANOVA with Saliency (salient distractor vs similar distractor) as within subject factor and participants age group (Young vs Older) as a between subject factor. The main effects of salience (F(1,46) = 2.368, p = .131, η_p^2 = .049) and age group (F(1,46) = .446, p = .508, η_p^2 = .010), were not significant, but there was a significant interaction between salience and age group (F(1,46) = 5.132, p = .028, η_p^2 = .100). Planned comparisons with paired samples t-tests comparing performance in the salient and similar conditions within each age group revealed that for older participants there was no significant difference in accuracy for salient (90.99 +/- 2.88) and similar trials (92.00 +/- 1.78, t(23) = -.505, p = .618, d = .10). In contrast, young participants were more accurate on salient trials (96.28 +/- 2.52) than on similar trials (90.98 +/- 2.56; t(23) = 2.739, p = .012; *d* = .56).

Moreover, an independent samples t-test revealed there was no significant difference in RArcSine transformed accuracy during the similar condition between the young (90.98+/- 2.56) and older (92.00 +/- 1.78), participants (t(46) = -.329, p = .744, d = .09), which highlights that the group differences we observed were not due to greater difficulty in identifying the stimuli by the older group. It also confirms that the benefit effect for the young participants was specifically due to enhanced performance in the presence of a salient distractor.

For the Response Time data, the raw response times were transformed into z-scores to account for generalized speed of processing deficits reported in aging populations that can be confounded with inhibition deficits (Craik and Salthouse, 2011; Salthouse, 1994; 1996; 2000; Salthouse and Meinz, 1995). We applied a z-score transformation to each individual subject's response time data by subtracting their overall mean response time from their condition mean (Salient or Similar), then dividing by the standard deviation of their condition means. To be clear, this was done separately for their salient and similar condition data. This procedure has been used previously to account for speed of processing deficits (Tsvetanov et al, 2013) in aging populations and is described in more detail in Faust et al (1999).

The z-RT data were analysed using a repeated measures ANOVA with Saliency (salient distractor vs similar distractor) as within subject factor and participants age group (Young vs Older) as a between subject factor (Figure 2b). The analysis revealed a main effect of saliency ($F(1,46) = 15.173$, $p < .001$, $\eta_p^2 = .248$), where participants were quicker to respond to salient trials (z-RT = -.103 +/- .025) than to similar trials (z-RT = .071 +/- .020; Smaller values reflect faster response times). This effect is a typical result for this paradigm and supports the notion that participants are engaged in reactive cognitive control and utilise the salient distractor as an anti-cue (DiQuattro and Geng, 2011; Geng and DiQuattro, 2010). There was not a main effect of age group ($F(1,46) = 2.629$, $p = .112$, $\eta_p^2 = .054$, but there was an interaction between salience and age group ($F(1,46) = 7.881$, $p = .007$, $\eta_p^2 = .146$).

We conducted planned comparisons using a paired samples t-test to compare z-RTs for the two salience conditions in each group. For the older participants, there was no significant difference in z-RT across salience conditions ($t(23) = -.782$, $p = .442$, $d = .16$; Salient: z-RT = -.033 +/- .034; Similar: z-RT = .015 +/- .029). However, younger participants responded significantly quicker ($t(23) = -4.665$, $p < .001$, $d = .95$) in the salient condition (z-RT = -.17 +/- .038) compared with the similar condition (z-RT = .127 +/- .027). These results suggest that the main effect of saliency was primarily driven by the younger participants and that the older participants showed no benefit in performance when the salient distractor appeared.

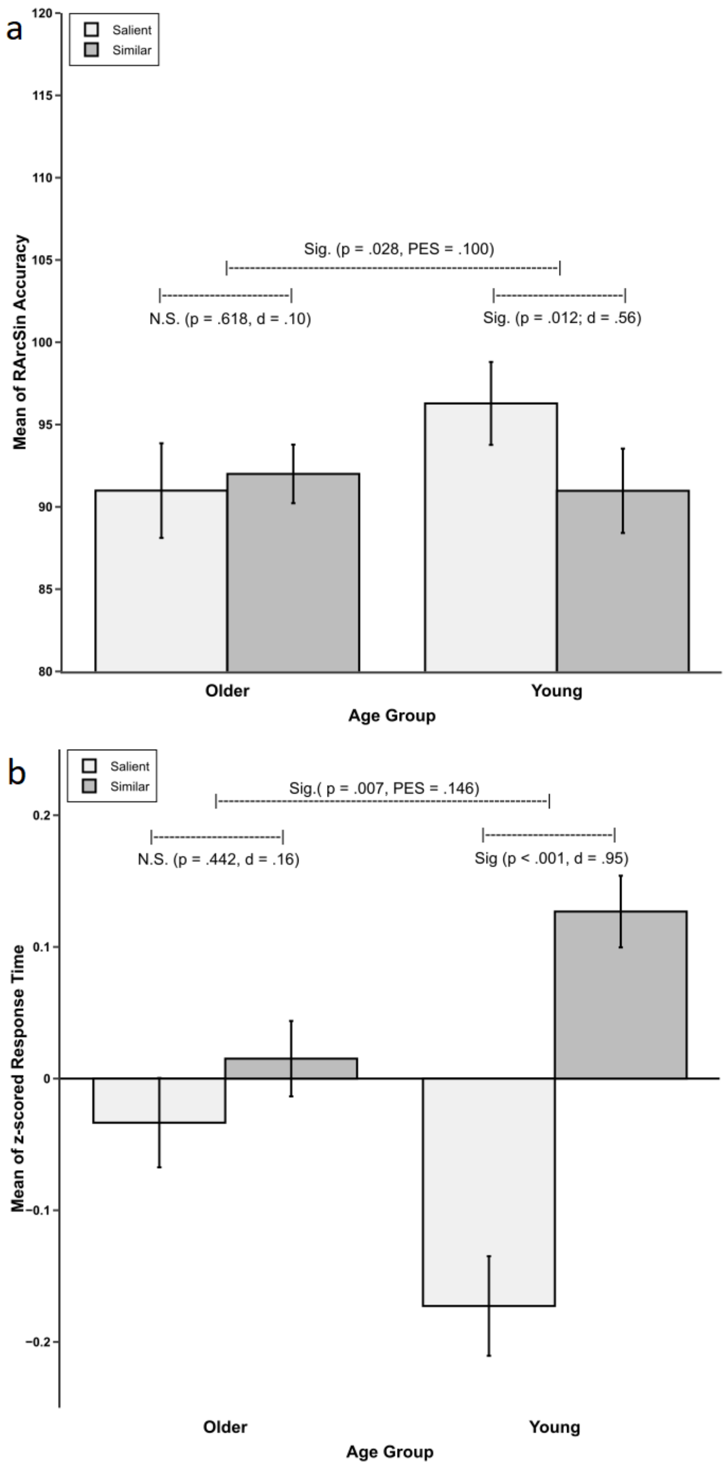

Figure 2. (a) Graph reflecting mean of RArcSine transformed accuracy for salient and similar conditions across age groups. (b) Graph reflecting z-scored response time data (msec) for salient and similar conditions across age groups. PES stands for partial eta squared and d stands for cohen's d.

Experiment 1b

The identical performance we documented for older participants in the similar and salient trials could potentially stem from reduced visual contrast sensitivity in this age group (Roberts and Allen, 2016; Pardhan, 2004; Owsley et al, 1983; Sekuler et al, 1980). One possible complication in any aging study of higher order cognitive abilities – such as reactive cognitive control – is that low quality information due to age-related impairments to lower level perceptual abilities may cascade through the information processing stream affecting performance (the information degradation hypothesis; Monge and Madden, 2016; but see Houston et al, 2016 for a counter-perspective). Notably, Porto et al (2016) found that controlling for visual acuity scaled and/or eliminated an age-related reduction in posterior P3b amplitude during a visual oddball task. The posterior P3b amplitude is generally presumed to be indicative of higher-level decision making and executive functions, although it should be noted that the specific role of the posterior P3b amplitude is still under a great deal of debate (See Polich, 2007 for a more in-depth discussion).

Indeed, if our older participants were not sensitive to the contrast differences between salient and similar non-targets then their performance in the two conditions would be equivalent. To exclude this possibility, we invited a subset of the older participants who took part in experiment 1a back and assessed whether or not they are able to distinguish between the two contrast conditions (Salient vs Similar). In experiment 1b we presented the exact same stimuli to a set of older participants, but instead of responding to the t-shapes, they had to indicate if the box colors of the two elements of the display (target and non-target) were the same or different. If the participants can successfully distinguish between the salient and non-salient stimuli, then we can be confident that age-related impairments to visual contrast sensitivity are not influencing our results.

Methods

Participants

5 older participants (Mean Age: 70.8, SEM of Age: 2.35, Age Range: 65 - 78; 1 Female) participated in the experiment. The older participants were recruited from the initial cohort who

participated in Experiment 1a. They were compensated for 1.5 hours of their time with a one-time payment of £7. All participants had to sign an informed consent form prior to the study. Participants' were healthy with no history of head injury, mental health issues or neurological disorders. The older participants were screened for decline in cognitive functions using the Montreal Cognitive Assessment (MoCA). All of the older participants scored within the normal range (>= 26 out of 30).

Stimuli and Procedure

The stimuli and procedure were exactly the same as in experiment 1a except that instead of indicating if the target were upright or inverted, participants pressed the "h" key to indicate if the two stimulus boxes were the same color (similar trials) and the "b" key if they were different (salient trials).

Results and Discussion

Overall raw accuracy across the 5 participants was very high (Mean = 98% +/- .68%). The data was transformed to a rationalized arcsine measure, consistent with experiment 1a. To assess the RArcSine transformed accuracy results, a one-way one-sample t-test was conducted to determine if a statistically significant difference existed between the average RArcSine and an RArcSine of 50 (equivalent to a proportion correct of .5). The t-test was significant, $t(4) = 19.8$, $p < .001$, $d = 8.85$, suggesting that older participants were able to successfully distinguish between the salient and non-salient stimulus boxes.

The response time was not z-transformed like in experiment 1a since there is only an older participants group and we do not need to account for group differences. However, the response time data was cleaned to account for outliers using the same procedure described in experiment 1a. This resulted in the loss of an average of 4.69% (SEM = .59%) of the response time data for salient trials and 3.82% (SEM = .89%) of the response time data for similar trials. A paired samples t-test revealed that these were not significantly different ($t(4) = 1.12$, $p = .326$, $d = .5$). The ability to distinguish successfully between these scenarios was evidenced by virtually identical response times for same (Mean = 592 +/- 37.4 msec) and different (593 +/-37.5 msec) trials ($t(4) = -.029$, $p = .977$, $d = .013$), confirming that older participants were not simply increasing accuracy during different trials by taking more time.

Overall, these results exclude the possibility that the lack of benefit for older participants, observed in Experiment 1a was attributed to impairments to visual contrast sensitivity yielding the salient and similar trials identical for our older participants. It should be noted that although there is a small sample size in this study, the consistently high accuracy (≥ 96%) across all participants and their age range allows us to be relatively confident that these results are a reasonable estimation of our participants' visual contrast sensitivity.

Experiment 2

Although we show that general age-related processing speed deficits can't fully account for our data (as overall RTs were not associated with the benefit measure for older participants), it is still possible that certain aspects of processing speed affect older participants ability to utilise reactive distractor suppression this task. For instance, if older adults take longer to accumulate evidence that will yield a disengagement decision from a non-target element, it might be the case that even though they are sensitive to the contrast differences it takes them similar amount of time to reach a decision to disengage. In experiment 1b, it took the older participants 592 msec to simply discriminate between the salient and similar conditions, whereas in experiment 1a they were only given 200 msec to use the salient distractor. Thus, it is possible that in old age effective reactive distractor suppression is possible given enough time.

This idea would fit with the argument that older participants favor reactive control in the first place because it takes longer to accumulate neural resources in old age and reactive control typically requires fewer resources over a shorter period of time compared to proactive control (Grady, 2012). Consequently, slow resource accumulation could theoretically impact reactive control as well. In particular, it would result in a delayed initiation of reactive inhibition. If the initiation of reactive distractor suppression is delayed in older cohorts, then we would expect them to be able to effectively utilise reactive distractor suppression as long as they are given enough time to engage reactive suppression mechanisms.

To address the possibility that there is an age-related delay in the initiation of reactive inhibition processes, Experiment 2 was conducted in which the stimulus presentation time was extended from 200 msec to 600 msec. If the initiation of reactive inhibition takes longer in old age, then a longer presentation time should allow older participants to take advantage of the salient distractor, and we would expect to see a performance benefit. Alternatively, if reactive inhibition is simply less effective in old age we expect to replicate the results from experiment 1a and find no performance benefit for the old participants.

Methods

Participants

20 young participants (Mean Age: 19.2, SEM of Age: .20, Age Range: 18 -21; 18 Females) and 19 older participants (Mean Age: 69.47, SEM of Age: 1.12, Age Range: 62 - 78; 11 Females) participated in the experiment. Like experiment 1a, we planned to exclude any participants with less than 60% overall accuracy, but no participants met this criterion and none were excluded from analysis. Young participants were recruited from the undergraduate population in the school of psychology at the University of Birmingham, UK. They were compensated for their participation with course credits. The older participants were recruited from a volunteer pool maintained by the School of Psychology at the University of Birmingham. They were compensated for 1.5 hours of their time with a one-time payment of £7. All participants had to sign an informed consent form prior to the study. Participants' were healthy with no history of head injury, mental health issues or neurological disorders. The older participants were screened for decline in cognitive functions using the Montreal Cognitive Assessment (MoCA). All of the older participants scored within the normal range (>= 26 out of 30).

Stimuli and Procedure

The stimuli and procedure were exactly the same as in experiment 1a, except that the stimulus was presented for 600 msec instead of 200 msec.

Results and Discussion

Response time in msec (RT) and accuracy rate (i.e. proportion of correct responses) were measured as dependent variables. The response time data was cleaned to account for outliers. For each participant, response time data that was greater than and less than 2 standard deviations from the mean was excluded from all analyses. The mean response time was calculated separately for each salience condition (salient trials and similar trials). This resulted in the loss of an average of 3.64% (SEM = .22%) of the response time data, per older participant and 3.61% (SEM = .24%) per young participant. An independent samples t-test revealed that these values were not significantly different (t(37) = -.093, p = .927). All values are presented as mean +/- standard error of the mean.

Accuracy data was rationalized arcsine (RArcSine) transformed and response time data was z-transformed using the same procedures as in experiment 1a. RArcSine transformed accuracy and z-transformed response time were analysed using a repeated measures ANOVA with Saliency (salient distractor vs similar distractor) as within subject factor and participants age group (Young vs Older) as a between subject factor. Data is reported as mean +/- standard error of the mean.

For RArcSine transformed accuracy (Figure 3a), the main effect of salience was significant (F(1,37) = 39.75, p < .001, η_p^2 = 0.518), driven by more accurate responses during salient trials (109.99 +/- 1.68) relative to similar trials (102.07 +/- 1.56). However, the main effect of age group (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 significant. This data suggests that, in terms of RArcSine transformed accuracy, the young and older participants were equally effective at using the salient distractor as an anti-cue when the stimulus presentation time was extended.

For response time (Figure 3b), the main effect of salience was significant ($F(1,37) = 84.654$, $p < .001$, $\eta_p^2 = 0.696$) driven by relatively faster responses during salient trials (zRT: -.451 +/- .053) compared to similar trials (zRT: .271 +/- .026), suggesting that the salient distractor provided a benefit to performance. However, the main effect of age group ($F(1,37) = 1.211$, $p = .278$, $\eta_p^2 = 0.032$), and the interaction were not significant ($F(1,37) = 3.696$, $p = .062$, $\eta_p^2 = 0.091$). Given the marginal p-value for the interaction, we conducted an exploratory analysis to assess whether there is potential evidence the interaction is driven by a lack of performance benefit (i.e. the difference between salient and similar performance) for the older adults. Crucially, simple effects revealed that the difference in performance between the salient and similar conditions was significant for both the young ($p < .001$, $\eta_p^2 = 0.632$; Salient: -.542; Similar: .330) and older ($p < .001$, $\eta_p^2 = 0.411$; Salient: -.359; Similar: .212) cohorts. Further simple effects revealed that there was no difference in performance between older and younger participants for the salient trials ($p = .093$, $\eta_p^2 = 0.075$; Older: -.359; Younger: -.542), but there was a difference in performance for the similar trials ($p = .031$, $\eta_p^2 = 0.120$; Older: .212; Younger: .330; Older participants were less slowed during similar trials). This verifies that despite the trending interaction, both age groups showed a clear performance benefit in the presence of a salient distractor, even if it is attenuated in the older cohort.

These data suggest that given enough time older participants are able to use the salient distractor as an anti-cue as effectively as the younger participants. This suggests that older participants may take longer to initiate reactive inhibition, possibly due to the slower accumulation of neural resources, but that given enough time reactive inhibition can be effectively implemented.

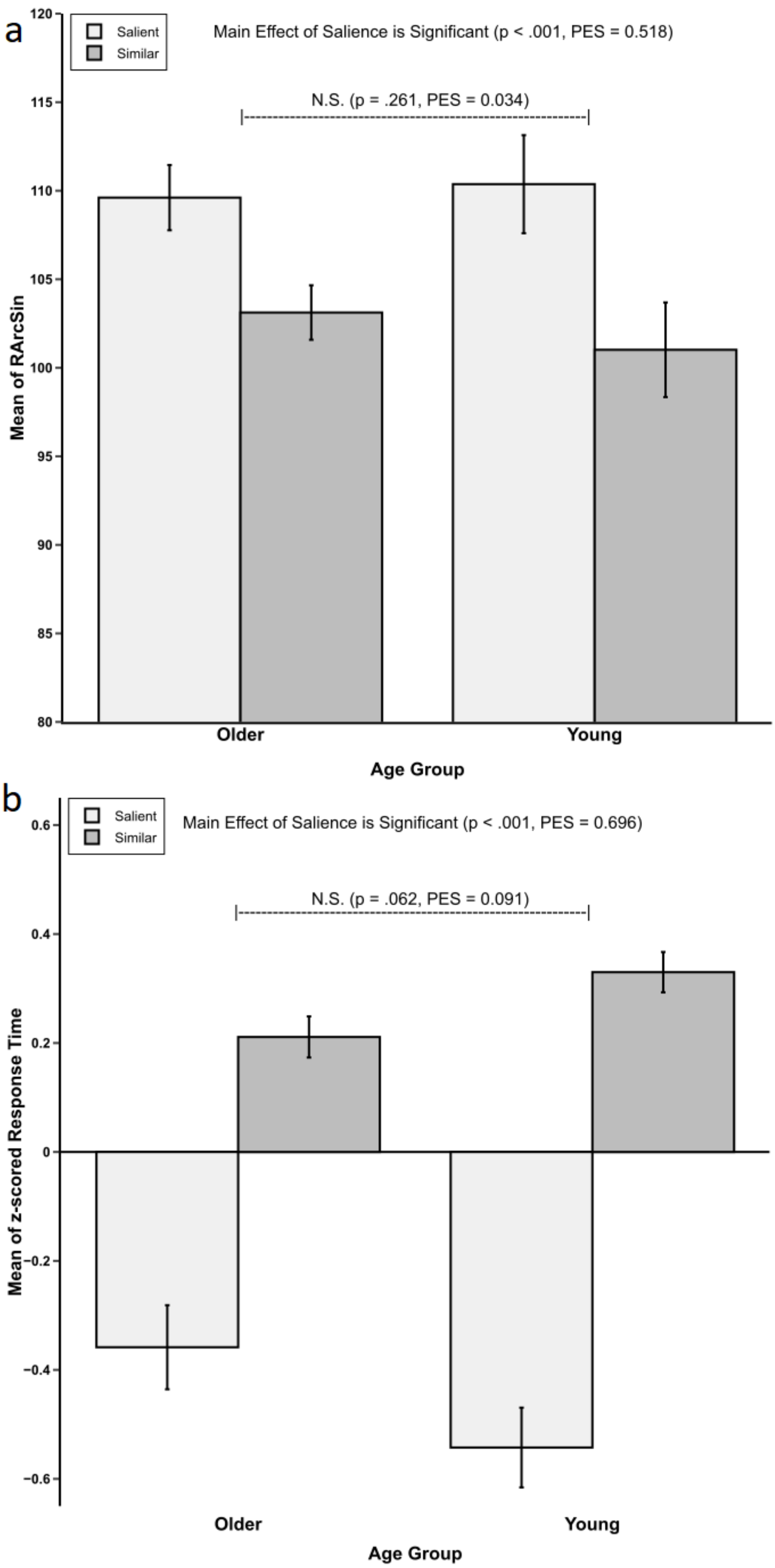

Figure 3. (a) Graph reflecting mean RArcSine transformed accuracy for salient and similar conditions across age groups. (b) Graph reflecting z-scored response time data (msec) for salient and similar conditions across age groups.

General Discussion

The purpose of this study was to assess the effect of aging on reactive suppression in older populations by comparing performance in a task that relies on reactive suppression in young participants too. In experiment 1a, with a 200 msec display, we found that young participants were able to effectively use a salient distractor as an anti-cue to benefit performance in terms of both accuracy and response time, demonstrating effective reactive distractor suppression. Older participants on the other hand showed no change in performance when the salient distractor was present in the display. Importantly, the lack of performance benefit for old participants could not be attributed to reduced contrast sensitivity as a subset of the older participants were shown to be able to distinguish between low and high contrast items in experiment 1b. However, experiment 2 showed that older participants could engage reactive inhibition if given enough time. When the stimulus presentation time was extended to 600 msec, older participants showed better performance during salient trials than similar trials (in both accuracy and response time) at an equivalent magnitude to the young participants. These data suggest that older participants have a delayed initiation of reactive inhibition processes that scales with age, but that given enough time effective reactive inhibition is possible. Prior literature typically shows a) impairments to proactive control in aging and b) a shift from proactive to reactive mechanisms in aging. Despite the dearth of studies directly investigating reactive control deficits, this has led to an implicit (and sometimes explicit) assumption throughout prior literature that older participants shift to reactive control because proactive control is impaired and reactive control is intact. Our study challenges this notion as we did find an age-related deficit in a measure reflecting reactive distractor inhibition. That being said, it is possible that reactive control is less impaired than proactive control, which induces a shift, but that is a different issue than shifting due to no deficit.

One concern for this type of research in general is that inhibition deficits may in fact be attributed to a generalized deficit in processing speed (Salthouse and Meintz, 1995; Salthouse, 2000; Verhaeghen and De Meersman; 1998). Since most studies that identify inhibition deficits measure response time, it could appear as if there were impaired response times in a specific inhibition task for older participants, when in fact they are simply overall slower. However, even after accounting for this possibility, inhibition deficits still persist in many inhibition tasks (Verhaeghen and Cerella, 2002). In our study, we z-transformed the response time data to account for this possibility and still found no performance benefit in the 200 msec condition (Experiment 1a). As such, we would argue that the age-related lack of a benefit we report cannot be attributed to general speed of processing deficits and is more likely associated with a delay in reactive distractor suppression specifically.

A second concern with respect to this specific study is that the deficit observed may in fact be completely or partially due to age-related impairments in attentional orienting rather than reactive inhibition. The nature of orienting attention is complex and there are many variables to consider, particularly with respect to aging (see Erel and Levy, 2016 for a comprehensive review), but the most relevant aspects in the context of our study are covert and overt orienting, and exogenous and endogenous orienting. Participants in the current study were instructed to keep their eyes focused on the fixation point throughout the trials ostensibly to encourage covert attention (no eye movements) which is also likely given the short presentation times in experiment 1a, however eye tracking was not employed so the use of overt attention cannot be ruled out. Regardless, research shows that older participants typically do not have impairments in covert attentional orienting (Jennings et al, 2007), and that while deficits in overt attention tasks have been reported (Kingstone et al, 2002), it has been argued that they can be attributed to deficits in motor control over eye movements (Chen and Machado, 2016; Dowiasch et al, 2015; Warren et al, 2013; Crawford et al, 2013; Klein et al, 2000, Ross et al, 1999) rather than attentional control (Erel and Levy, 2016).

With regard to exogenous and endogenous orienting during trials with a salient distractor, it is arguable that this study engages both. Geng and DiQuattro (2010) showed that salient distractors could facilitate performance (using a similar t-task paradigm to our study) using a combination of two attentional strategies: inhibition, where saccades toward the salient distractor are actively inhibited, and rapid rejection, where a saccade toward the salient distractor is quickly disengaged and redirected towards the target. Inhibition took place on target-first trials, when the first saccade went towards the target, and rapid rejection followed by inhibition took place on distractor-first trials, when the first saccade went towards the salient distractor. Within the t-task, the process of rapid rejection essentially consists of three phases: Orienting attention towards the salient distractor, disengaging attention from the salient distractor, and reorienting attention towards the target/inhibiting the salient distractor. The initial orienting of eye movements towards the salient distractor is a classic example of overt exogenous orienting. However, disengaging, reorienting, and inhibiting only begins because the participants recognize the distractor as such, making the target no longer in an unpredictable location. This suggests that endogenous orienting is an integral part of reactive distractor suppression processes which are likely important for performance in our task.

Previous studies have typically reported intact (Waszak et al, 2010; Iarocci et al, 2009; Jennings et al, 2007; Folk and Hoyer, 1992; Craik and Byrd, 1982) or even enhanced (Langley et al, 2011a; 2011b; Mahoney et al, 2010) exogenous orienting in aging. In contrast, endogenous attention is sometimes reported to be impaired (Olk and Kingstone, 2009; Bojko et al, 2004; Brodeur and Enns, 1997; Greenwood et al, 1993; see also Erel and Levy, 2016). Furthermore, impaired (i.e. slow) attentional disengagement (Owsley, 2016; Greenwood and Parasuraman, 1994) has also been documented in older populations. Consequently, if spatial endogenous disengagement and orienting is impaired in old age it may well be the case that these impairments also manifest in impaired reactive distractor suppression.

Nevertheless, disengagement and endogenous orienting are likely engaged in both salient and similar trials in our task as both trials may involve the initial selection of the non-target item (Geng & DiQuattro, 2010). Thus, an impairment in these processes should have affected performance in both trial types. However, the older participants in Experiment 1a did not show such a general impaired performance. In fact, accuracy was the same for both young (86%) and older

(86.2%) participants during the similar condition in experiment 1a. As such, the performance patterns we report point to a difference in the efficiency of processes that are specifically utilised when a salient distractor is present. One reason behind this could simply be a slower processing capacity for salient items in old age (that is overcome when the input is presented for longer). This seems unlikely as Experiment 1b demonstrated that the older participants showed virtually no difference in response time when discriminating between similar (two low contrast stimuli) and salient (one low and one high contrast stimuli) conditions. If salient stimuli required more processing time in old age, we would have expected to see longer response times on trials where a salient item was present in the display. A second, and seemingly more likely explanation, is that old participants are exhibiting impairments in the reactive suppression of salient information (rather than having difficultly processing salient information in the first place). In fact, impaired suppression of salient information in old age has previously been reported by Tsvetanov et al (2013) in the context of a proactive inhibition task. It is therefore possible that older adults exhibit impairments in salience suppression in general, regardless of whether reactive or proactive inhibition is called upon.

A final possibility is that 600 msec is too long to still be considered "reactive." According to Irlbacher et al (2014), reactive control can be parsed into an early and late mechanism and that each mechanism provides a unique method of identifying and resolving conflict. In the context of working memory inhibition, both mechanisms resolve interference that occurs when a familiar stimulus is identified but must be ignored. Familiarity-inhibition models favor speed over accuracy and are considered to be a quick and early acting reactive control mechanism, engaging around 300-450 ms after stimulus presentation (Du et al, 2008). In these models, the interference is resolved through the inhibition of the familiar stimulus (Mecklinger et al, 2003). On the other hand, context retrieval models favor accuracy over speed and are considered to be a slower and late acting reactive control mechanism, engaging around 550 ms after stimulus presentation (Zhang et al, 2010). In these models, the interference is resolved by selecting for the relevant target features more strongly (by retrieving the appropriate contextual information; Badre and Wagner, 2005; 2007). Based on this, it is reasonable to believe that reactive processes were used by participants with a presentation time of 600 msec.

However, despite indications that our data reflect an impairment in reactive distractor suppression, a major limitation was that we did not use eye-tracking and therefore cannot tease apart the relative contribution of proactive and reactive distractor suppression during this task. In other words, there is no direct evidence that young and old participants are completing the task in a similar manner (i.e. specifically via reactive control mechanisms). That being said, Geng and DiQuattro (2010) showed that young participants had a failure of proactive control mechanisms (i.e. a saccade was made to the salient distractor) on ~68% of trials, leading necessarily to the engagement of reactive control mechanisms (i.e. rapid rejection). Importantly, performance on these "reactive" trials was still better than on control trials on which the first saccade went to a non-salient distractor, suggesting that the reactive rejection of the salient distractor was facilitated even when it initially captured attention. Based on this we can infer that a similar proportion of "proactive failure" trials likely occurred in our study for the young participants. Further, in conjunction with well-characterized prior literature that has shown age-related deficit across proactive control mechanisms, we also infer that "proactive failures" are probably more common in our older cohort. This would suggest that our older cohort likely relied more on reactive control mechanisms to complete the task than the younger cohort. However, this is ultimately speculative and must be confirmed in future research with other methods.

Overall, this study suggests that older participants exhibit an age-related delay in the initiation of reactive inhibition. The nature of this impairment is hypothesized to be specific to reactive salience suppression, since the underlying rapid rejection and inhibition processes appear intact when there is no salient distractor present (as evidenced by equivalent performance across age groups in experiment 1a during similar trials). Future research will have to investigate the underlying impairment that leads to this delay in the initiation of reactive distractor suppression. For example, reactive distractor suppression may be engaged late because of the slower accumulation of neural resources (Grady, 2012), or because the attentional capture process is intact but the delay is in the transition to inhibition/rapid rejection, or because both attentional capture and inhibition/rapid rejection are independently delayed. Of course, these possibilities are not necessarily mutually exclusive. An alternative explanation that could account for this data is that there is a “fast” and a “slow” reactive control mechanism and that only the faster reactive mechanism is impaired. Future research will have to distinguish between these possibilities.

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