

# Ageing and selective inhibition of irrelevant information in an attention-demanding rapid serial visual presentation task

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## Abstract

Attention involves both an ability to selectively focus on relevant information and simultaneously ignore irrelevant information (i.e. inhibitory control). Many factors impact inhibitory control such as individual differences, relative timing of stimuli presentation, distractor characteristics, and participant age. Previous research with young adults responding to an attention-demanding rapid serial visual presentations of pictures superimposed with task-irrelevant words evaluated the extent to which unattended information may be subject to inhibitory control. Surprise recognition tests following the rapid serial visual presentation task showed that recognition for unattended words presented with non-targets (i.e. non-aligned or 'NA' words) during the rapid serial visual presentation task were recognised at chance levels. However, when the unattended words were infrequently paired with the attended picture targets (i.e. target-aligned or 'TA' words), recognition rates were significantly below chance and significantly lower compared to NA words, suggesting selective inhibitory control for the previously unattended TA words. The current study adapted this paradigm to compare healthy younger and older adults' ability to engage in inhibitory control. In line with previous research, younger adults demonstrated selective inhibition with recognition rates for TA words significantly lower than NA words and chance, while NA words were recognised at chance levels. However, older adults showed no difference in recognition rates between word types (TA versus NA). Rather all items were recognised at rates significantly below chance suggesting inhibited recognition for all unattended words, regardless of when they were presented during the primary task. Finally, older adults recognised significantly fewer NA words compared to young adults. These findings suggest that older adults may experience a decline in their ability to selectively inhibit the processing of irrelevant information, while maintaining the capacity to exercise global inhibition over unattended lexical information.

## Keywords

Ageing, attention, inhibitory control, cognition, rapid serial visual presentation task

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## Introduction

To adequately perform a complex task such as driving a car, one must focus on driving (e.g. minding roads and traffic signals) while simultaneously ignoring task-irrelevant information, such as billboards or incoming text messages. Accordingly, selective attention involves two processes, the ability to selectively focus on task-relevant information and the ability to inhibit task-irrelevant information, also known as inhibitory control (Geng, 2014; Hasher et al., 2007; Tipper, 1992). Both processes are influenced by many factors, but inhibitory control has been studied to a lesser extent compared to attentional focus. Some of the factors that influence inhibitory control include the relative timing of stimuli, spatial separation, target-distractor similarity, and age-related decline in the ability to ignore irrelevant information (Campbell et al., 2012; Kane et al., 1994; Mayr, 2001; Rabbitt, 1965; Störmer et al., 2013).

Age-related cognitive decline in attention has largely been attributed to deficiencies in inhibitory control, with older adults

declining in their capacity to inhibit the processing of irrelevant information (Amer and Hasher, 2014; Bloemendaal et al., 2016; Eich et al., 2016; Hasher and Zacks, 1988; Kramer et al., 1999; Lustig et al., 2006; McDowd, 1997; Madden et al., 1996; Mayr, 2001; Plude and Hoyer, 1986). Illustrating this form of cognitive decline, older individuals exhibit difficulties performing several types of selective attention tasks (i.e. selecting and focusing on a stimulus of interest while inhibiting irrelevant information). For instance, Farkas and Hoyer (1980) used a card-sorting version of a visual search task to show that older adults were differentially slower to respond when presented with a distractor card that was

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very similar to the target card. This finding suggests that older adults are more likely to be distracted by these items, indicating a reduced ability to inhibit irrelevant items from re-orienting attention. Additional research has demonstrated that, as adults age, attentional allocation may become impaired when viewing displays containing moving items (Folk and Lincourt, 1996; Watson and Maylor, 2002). In this case, older individuals appear to have more difficulty visually marking (see Watson and Humphreys, 1997, 1998) the target stimulus. Thus, it appears that older adults have a reduced ability to inhibit processing of previously viewed distractor objects such that they continue to capture attention during the visual search task.

The neurological underpinnings of older people's inability to exercise inhibitory control has been investigated by Amer et al. (2016), who used functional magnetic resonance imaging (fMRI) to look at the neural correlates of inhibitory control in older and younger adults. They focused on two networks proposed to control externally oriented attention (dorsal attention network; DAN) and internally focused attention (default mode network; DMN). Their findings suggest that, for older adults, less distractibility is linked to greater DAN-DMN anticorrelation, while for younger adults, *greater* distractibility is linked to decreased DAN-DMN anticorrelation. The differing patterns of neural responses provide additional reasons to explore how this might be expressed at a behavioural level.

Many of the experiments investigating inhibitory control among older adults (Banich et al., 2000a; Bugg et al., 2007; Laguë-Beauvais et al., 2013; Mayas et al., 2012; Milham et al., 2002; Spieler et al., 1996) required participants to facilitate the relevant feature of the visual stimulus while simultaneously inhibiting the irrelevant feature, which has proven difficult for elderly individuals. However, these behavioural methods have two important limitations: First, it is difficult to isolate facilitatory from inhibitory mechanisms given that these paradigms do not offer an effective method for dissociating these two processes. Thus, it is difficult to assess whether the attentional system fails to facilitate processing of targets; fails to inhibit processing of distractors; or if instead the decline in performance for elderly participants is related to a deficit in both processes. Second, previously utilised behavioural methods evaluate the function of inhibitory control by looking at rates of online distraction induced by the irrelevant stimuli during task performance (e.g. Stroop, 1935). That is, the ability to inhibit processing of the irrelevant item is assessed by examining accuracy or reaction time (RT) to a target that is presented at the same time as the distracting item, with lower accuracy and/or slower RTs indicating higher rates of distraction and reduced inhibitory control. While this is useful information, the extent to the level of which these to-be ignored items are processed and subsequently stored in long-term memory is difficult to determine.

Directly comparing selective attention and inhibitory control, Dewald and colleagues modified a dual-task paradigm (see Dewald et al., 2011, 2013; Walker et al., 2014, 2017) in which participants were presented with a rapid serial visual presentation (RSVP) of attended and ignored items. During the primary task, participants monitored the RSVP stream for immediate picture repetitions (i.e. n-back task, see Kirchner, 1958) while ignoring superimposed words. Immediately after the primary task was completed, a surprise recognition test determined the extent to which participants are able to identify the previously ignored

words. This paradigm overcomes the ambiguities of previous studies by systematically varying the frequency with which irrelevant distractor items (i.e. ignored words) are presented simultaneously (i.e. paired) with attended target items (i.e. immediate picture repetitions) and has been shown to measure both inhibitory (i.e. inhibitory control) and facilitatory mechanisms (attentional control) (Dewald et al., 2011, 2013).

Research using this paradigm with young adults showed that infrequently pairing the ignored distractor items with targets in the attended task leads to inhibited processing of these distractor items when compared with ignored distractor items that are not paired with targets (see Dewald et al., 2011)<sup>1</sup>. The extent to which the irrelevant information may have been processed is then evaluated through the use of a surprise recognition test for the previously ignored distractor items. Items that are recognised at rates significantly below chance during the recognition test are interpreted as being inhibited both during encoding, which takes place during the primary task, and during retrieval, which takes place during the recognition test (see Dewald et al., 2011). This would suggest that, in young adults, inhibitory control can operate in a selective manner by exercising more stringent filtering on the processing of salient irrelevant information when it is presented simultaneously with task-relevant targets in an attention-demanding task (see also Tsuchida et al., 2008).

The current study employs the attention-demanding RSVP dual-task paradigm used by Dewald et al. (2011) to compare selective attention and inhibitory control in healthy older and younger adults. Due to ageing, we predict that older adults will exhibit deficits in both the primary task and the surprise recognition test (Andrés et al., 2008; Bugg et al., 2007; Hasher and Zacks, 1988; Kramer et al., 1999; Laguë-Beauvais et al., 2013; Lustig et al., 2006; Madden et al., 1996; Mayr, 2001; Plude and Hoyer, 1986). Specifically, and in line with a general slowdown in processing (Salthouse, 1996), we expect that older adults will exhibit significantly slower RTs and overall lower accuracy in the primary task. In the surprise recognition test, a decline in inhibitory control among older adults should lead to disproportionately higher recognition rates for words previously paired with target pictures (i.e. target-aligned words) from the primary task compared to younger adults. The predicted findings suggest two things: (1) younger adults inhibit the processing of irrelevant information that is simultaneously presented (i.e. paired) with an attended, relevant, task-target to a greater extent than irrelevant information paired with attended non-targets – again, demonstrating selective inhibitory control, and (2) that inhibitory control in older adults is compromised, compared to younger adults, demonstrated by the inability to inhibit the processing of target-aligned items. As a result, disproportionately more irrelevant information is processed and subsequently recognised at a higher rate during the surprise recognition test when compared with younger adults' performance.

## Methods

### Participants

Thirty-nine healthy young adults (mean age=20.84, *SD*=3.06 years, range=18–34) were recruited from undergraduate courses at the University of Hawai'i at Mānoa in exchange for course credit. The results from one participant were excluded

from the analyses due to a failure to complete the surprise recognition task. The final analyses were conducted with the remaining 38 young adults (Males:  $N=16$ , mean age=20.69,  $SD=2.24$ , range=18–25; Females:  $N=22$ , mean age=20.95,  $SD=3.59$ , range=18–34).

Twenty-six healthy older adult participants (mean age of 71.88,  $SD=8.22$  years, range=60–90; Males:  $N=7$ , mean age=72,  $SD=9.85$ , range=60–90; Females:  $N=19$ , mean age=71.84,  $SD=7.84$ , range=60–87) were recruited, on a voluntary basis, from local retirement communities around Honolulu, Hawai'i, as well as from continuing education programmes for seniors at the University of Hawai'i at Mānoa. All participants were naïve to the experiment and had normal, or corrected to normal, vision and hearing. As per self-report and confirmed by staff (where appropriate), none of the older participants suffered from any diagnosed neurological disorder.

Participants were presented with a written informed consent document prior to study enrolment, reminded of their voluntary participation and right to withdrawal at any time, and provided with ample opportunity to ask questions and receive clarifying information, where necessary. This study was approved by and carried out in compliance with the recommendations and guidelines of the University of Hawai'i Office of Research Compliance and Institutional Review Board (CHS number: 21455), in accordance with the Declaration of Helsinki.

### Stimuli

A total of 50 pictures (approximately 7° visual angle) were selected from the Snodgrass and Vanderwart (1980) picture database (i.e. attended stimuli). Each picture was superimposed with a single English word (i.e. ignored distractor items) selected from a pool of high-frequency words retrieved from the MRC psycholinguistic database (Wilson, 1988). The words had an average length of 5 letters (range=4–6) and average frequency of 120 per million (range=28–686) and were superimposed over the pictures in bold, capitalised letters in Arial font (24 points). Care was taken to ensure that picture-word combinations did not share any direct semantic relationship (see Dewald et al., 2011, 2013; Sinnett et al., 2009, for examples using similar stimulus parameters).

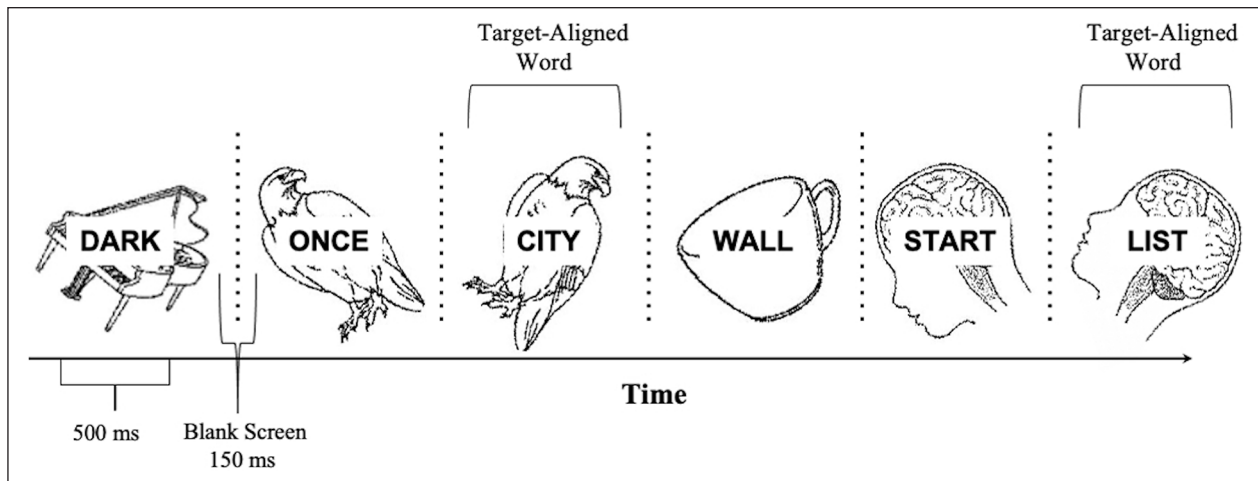
### Primary task

**Attended stimuli.** The 50 pictures were duplicated resulting in 2 copies of each picture (i.e. picture pairs) for a total of 100 picture stimuli. To ensure that the task was sufficiently demanding, all pictures were randomly rotated  $\pm 30$  degrees from their original orientation (see Rees et al., 1999). The primary task consisted of 2 blocks of 100 picture-word combinations. Each block contained half (25) of the picture-word pairs presented as immediate picture repetitions. These immediate picture repetitions served as the targets for the attended task. The remaining 25 pairs were randomly inserted into the visual stream to serve as non-targets. This process was replicated for the second experimental block using the same stimuli, but in a randomised order according to the following logic: The 25 picture pairs that were presented as immediate picture repetition targets in the first block appeared as separate randomly inserted non-targets in the second block, and those that appeared as non-targets in the first block were presented as immediate picture repetition targets in the second block

(i.e. picture pairs that were identification targets in the first block were non-repeating pictures in the second block and vice versa). Therefore, each of the original 50 pictures was presented four times, once as a target repetition pair in the first block, then again as non-repeating pictures in the second block. All groups of words were pseudo-randomised and care was taken to ensure similar average word frequencies.

**Ignored distractor items.** One hundred words were randomly selected and superimposed on top of the pictures. These 100 words were randomly split in 2 separate and equally sized groups (i.e. 50 words each with similar average word frequencies). One group of words was randomly selected and superimposed on the immediate picture repetitions (i.e. targets), serving as the target-aligned (TA) words, while the second group of words were superimposed on the non-repeating non-targets in the stream, serving as non-aligned (NA) words (both groups had similar average word frequencies). Each block contained 25 immediate target picture repetitions and accompanying superimposed TA words. The remaining 25 words from the TA group were superimposed over non-repeating pictures along with the 50 words from the NA group to create the remaining 75 non-repeating combined picture-word stimuli for that block. This process was repeated for the second block but the 25 words that were TA in the first block now served as NA words in the second block and vice versa. The NA words were always presented on top of non-repeating pictures in both blocks (i.e. they were never paired with picture repetition targets); all words were presented an equal number of times. None of the NA words that appeared in the surprise recognition test had been paired with a target at any point during the primary task. The items defined as TA were the only items to ever appear with targets. This experimental design is a more conservative approach to assess the effects of target alignment and was implemented in accordance with previous studies that have utilised this paradigm (Dewald et al., 2011, 2013; Dewald and Sinnett, 2011a, 2011b; Sinnett et al., 2009; Walker et al., 2017). Six versions of the experiment were created by counterbalancing picture and word pairs, stimuli presentation order, and ensuring that each word was presented as either TA or NA across the various versions (see Dewald et al., 2011).

**Surprise recognition test.** The surprise recognition test for the ignored words was administered immediately after participants had completed the primary task of detecting immediate picture repetition targets. The surprise test contained 50 words from the primary task along with 50 never before seen foil words, selected from the same database, and matched in length and word frequency (Wilson, 1988). Due to the high number of words presented during the primary task, and to avoid any concerns regarding fatigue, two types of surprise recognition tests were created for each version of the experiment, rather than a single, but much longer surprise test including all possible word types. One surprise test contained only the 50 TA words along with 50 foil words. The other recognition test contained only the 50 NA words, which never appeared with a target picture repetition during the primary task, along with 50 foil words. Each participant was randomly assigned and tested on one of the two word types (i.e. between-subjects, TA words only or NA words only). As such, there was no opportunity for participants to conflate TA and NA items during the recognition portion of the experiment. The



**Figure 1.** Schematic representation of the primary task. Immediately repeated pictures serve as the attended task targets while superimposed words are the ignored distractor items. Words appearing with attended task targets are TA words (i.e. 'City' and 'List'); all other words are NA words.

words in the recognition tasks were randomised and displayed one at a time, in bold, capitalised letters in Arial font at a size of 24 points (i.e. identical to their initial presentation in the primary task, but without the accompanying pictures).

**Procedure.** Participants were seated in front of a computer with the screen approximately 60 cm away. They were then presented with an RSVP of the picture-word stream, using DMDX software (Forster and Forster, 2003). Participants were instructed to ignore the superimposed words and focus their attention only on the pictures. They were required to respond by clicking the left mouse button with their preferred hand when they noticed a picture immediately repeat in the visual stream. Each item in the picture-word stream was presented for 500 ms followed by a 150 ms inter-stimulus interval (ISI; blank screen) for a stimulus onset asynchrony (SOA) of 650 ms (see Figure 1).

Participants were given two training blocks of eight trials, using separate stimuli from the experimental blocks in the primary task, and were allowed to repeat training until they were familiar and comfortable with the task. The primary task began immediately after participants completed their training session. Upon completion of the primary task, the surprise word recognition test was administered to all participants. Each word remained on the screen until a response (key press) was given. Participants were instructed to press the 'B' key if they recalled seeing the word during the primary task or, instead, the 'V' key if they did not recall seeing the word before (response keys counterbalanced). All participants were instructed to indicate their response as quickly and accurately as possible and all participants were monitored to ensure compliance with experimental protocol.

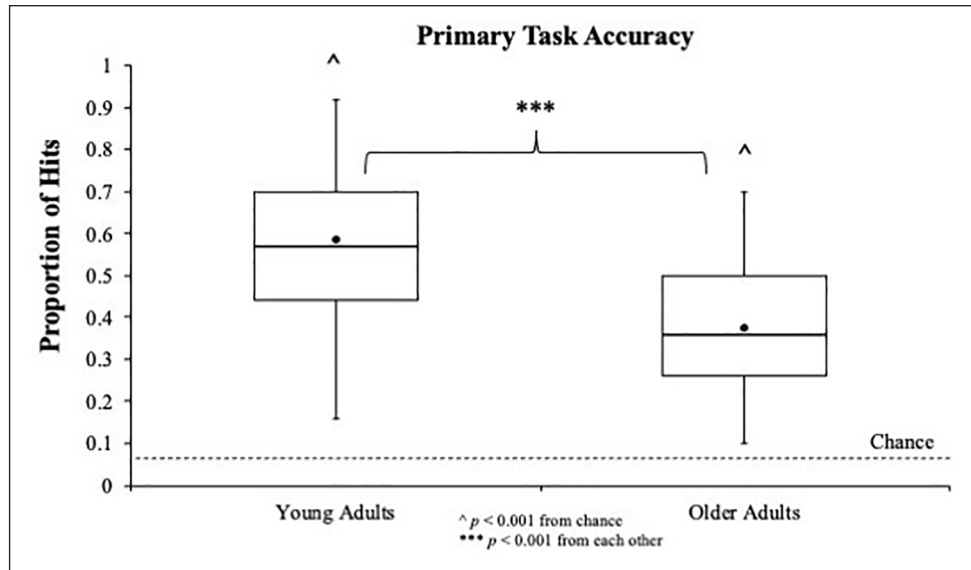
**Statistical analyses.** Performance on the primary task was assessed via a comparison between age groups and against chance. During the primary task, a target appeared, on average, in one of every 15 trials, therefore chance was defined as the probability of obtaining a hit in any given presentation of 15 trials (i.e. 7%). Independent-sample between-subjects *t*-tests were conducted to evaluate potential differences in the proportion of

correct target identifications (i.e. hits), false alarms (FAs), and RTs to targets between young and old participants (see also Walker et al., 2017) and single-sample within-subject *t*-tests were used to evaluate performance against chance for each age group. A hit in the primary task was defined as a response to an immediate repetition in the RSVP of pictures (i.e. mouse click) occurring within 1000 ms of initial stimulus presentation. This conservative criterion was applied in order to accommodate the possibility of late, yet accurate, responses to targets by participants. Bonferroni corrections were applied to account for multiple comparisons.

With regard to the surprise recognition test, independent *t*-tests were performed to evaluate potential differences in signal detection sensitivity (i.e. sensitivity), response bias, discrimination accuracy, foil word identification, and previously ignored word identification between young and old participants. Sensitivity and response bias were determined by calculating  $d'$  ( $d$ -prime) and  $\beta$  (beta), respectively, for each participant and compared between young and older adults. Discrimination accuracy between old and new items was determined by calculating the proportion of combined hits and correct rejections (CR) for each age group and comparing performance between the young and older adults. The ability of young and older adults to identify foil items was evaluated by comparing the proportion of CRs between age groups, and the identification of previously ignored items was assessed by comparing the proportion of hits between age groups.

Furthermore, because our interest was focused on determining potential differences in RT and recognition accuracy for TA and NA words between young and old adults, statistical analyses included two separate  $2 \times 2$  analyses of variance (ANOVAs) comparing age (young and old) and word type (TA and NA) as between subjects factors with RT and recognition accuracy as dependent variables. Our analyses also include pre-planned pairwise comparisons between recognition accuracy and RT for all previously ignored words (TA versus NA) within and between each age group and against chance via *t*-tests. The surprise recognition tests contained half old (i.e. either TA or NA) and half new (i.e. foil) words, therefore, chance performance was 50%. These





**Figure 2.** Box plots depicting mean (centre dot), median, quartiles, and range of target detection rates (i.e. hits) on the primary task between young and old participants. On average, older adults responded to significantly fewer targets compared to young adults. Both age groups had hit rates significantly higher than chance (i.e. 7%, indicated by the dashed line).

analyses were designed to assess overall performance on word types both within and across age groups and align with analogous analyses conducted using similar designs (Dewald et al., 2011, 2013; Dewald and Sinnott, 2012, 2013; Walker et al., 2014, 2017). Bonferroni corrections were applied to individual analyses to account for multiple comparisons.

Finally, in order to determine how accuracy results may change as a function of age, four linear regression analyses were performed comparing age range (young or old) and recognition accuracy for previously ignored word types (TA or NA). As before, Bonferroni corrections were applied to individual analyses to account for multiple comparisons.

## Results

### Primary task performance

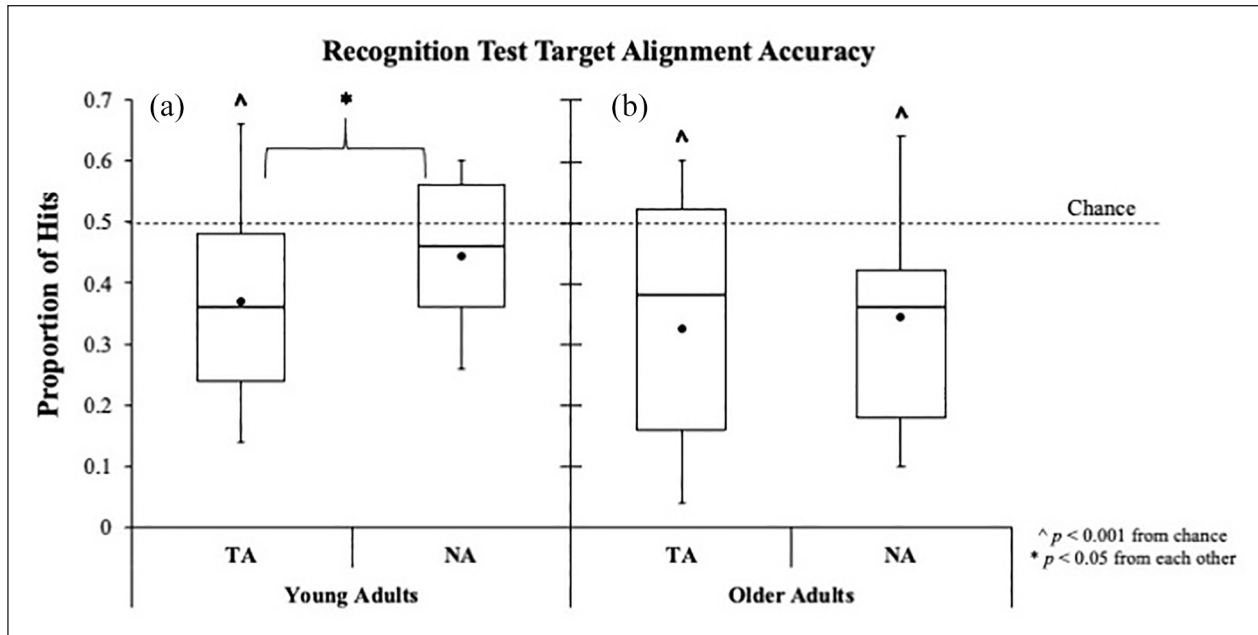
Young adults obtained significantly more hits than older adults (young adults:  $M=0.59$ ,  $SE=0.03$  versus older adults:  $M=0.37$ ,  $SE=0.03$ ) ( $t(62)=4.64$ ,  $p<0.001$ ,  $d=1.18$ ); however, both age groups detected targets at a rate significantly better than chance (i.e. 7%) (young adults: ( $t(37)=18.08$ ,  $p<0.001$ ,  $d=2.93$ ), older adults: ( $t(25)=9.29$ ,  $p<0.001$ ,  $d=1.82$ )). There was no significant difference in FA rates for young adults compared to older adults (young adults:  $M=0.01$ ,  $SE=0.002$  versus older adults:  $M=0.01$ ,  $SE=0.003$ ) ( $t(62)=0.783$ ,  $p=0.44$ ,  $d=0.20$ ) and both age groups had FA rates significantly lower than chance (young adults: ( $t(37)=39.49$ ,  $p<0.001$ ,  $d=6.41$ ), older adults: ( $t(25)=21.17$ ,  $p<0.001$ ,  $d=4.15$ )). This suggests that the lower accuracy score observed in the older adults can be attributed to an overall lower number of hits compared to the younger adults (see Figure 2), indicating that the primary task may have been more difficult for the older adults. With the exception of the between group FA analysis, all reported  $p$ -values met significance criteria for multiple comparison corrections (i.e.  $p<0.007$ ).

Next, response latencies during the primary task were evaluated by comparing RT to identified targets between young and old adults. Young adults were significantly faster to respond compared to older adults (young adults:  $M=412$  ms,  $SE=4.74$  versus older adults:  $M=435$  ms,  $SE=7.77$ ) ( $t(62)=2.68$ ,  $p<0.01$ ,  $d=0.69$ ).

### Surprise recognition test

**Overall surprise recognition test word discrimination accuracy.** There was no significant difference in  $d'$  between young and older adults (young adults:  $M=0.12$ ,  $SE=0.05$  versus older adults:  $M=0.03$ ,  $SE=0.08$ ) ( $t(62)=1.12$ ,  $p=0.27$ ,  $d=0.28$ ), suggesting that the task was quite challenging and that there were similar sensitivity levels between these two age groups. Likewise, there was no significant difference in  $\beta$  between young and older adults (young adults:  $M=0.07$ ,  $SE=0.04$  versus older adults:  $M=0.06$ ,  $SE=0.04$ ) ( $t(62)=0.08$ ,  $p=0.94$ ,  $d=0.02$ ), indicating that both age groups applied similar response criteria (see Macmillan, 2002; Macmillan and Creelman, 1990, 2004; Stanislaw and Todorov, 1999). Analysis of discrimination accuracy (Hits + CR) corroborated the  $d'$  results, showing no significant difference between age groups (young adults:  $M=0.52$ ,  $SE=0.01$  versus older adults:  $M=0.50$ ,  $SE=0.02$ ) ( $t(62)=1.10$ ,  $p=0.28$ ,  $d=0.28$ ).

Next, focusing on participants' ability to explicitly identify foil items (i.e. CRs) during the surprise recognition test, we found no significant differences between young and older adults (young adults:  $M=0.63$ ,  $SE=0.02$  versus older adults:  $M=0.68$ ,  $SE=0.04$ ) ( $t(62)=1.04$ ,  $p=0.30$ ,  $d=0.29$ ). Finally, recognition performance on correct identification of previously presented words only (i.e. hits only, excluding foil words) between young and older adults was evaluated. There was no significant difference in hit rates between the two age groups (young adults:  $M=0.41$ ,  $SE=0.03$  versus older adults:  $M=0.33$ ,  $SE=0.03$ ) ( $t(62)=1.82$ ,  $p=0.07$ ,  $d=0.46$ ).



**Figure 3.** (a) Box plots depicting mean (centre dot), median, quartiles, and range of recognition rates for TA words compared to NA words for young adults. On average, TA words were recognised significantly less often than NA words; NA words were recognised around chance levels (i.e. 50%) while TA words were recognised significantly below chance. (b) Box plots depicting mean (centre dot), median, quartiles, and range of recognition rates for TA words compared to NA words for older adults. There was no significant difference in recognition rates between word types; however, all words were recognised at rates significantly below chance (i.e. 50%).

Taken together, these findings suggest that both young and older adults had comparable levels of sensitivity ( $d'$ ) and discrimination accuracy, employed similar response strategies ( $\beta$ ), and they were equally able to identify previously seen targets and foil items during the surprise recognition task. The primary purpose of this study was to explore possible age-related differences in recognition rates between TA and NA items. Therefore, the following analyses focus on accuracy performance and RTs for these items specifically.

**Overall surprise recognition test accuracy.** In order to assess whether age modulated word recognition depending on how it was presented during the primary task (i.e. either TA or NA), a  $2 \times 2$  ANOVA was conducted on surprise recognition test performance for previously presented words only (i.e. excluding foil words) with age (young versus old) and target alignment (TA versus NA) as between subject factors, and accuracy as the dependent variable. There was a marginal main effect for age (young adults:  $M=0.41$ ,  $SE=0.02$  versus older adults:  $M=0.33$ ,  $SE=0.04$ ) ( $F(1, 30)=3.92$ ,  $p=0.06$ ,  $\eta^2=0.12$ ), suggesting that older adults may have recognised fewer previously ignored words overall compared to younger adults. There was no main effect for target alignment (TA:  $M=0.35$ ,  $SE=0.03$  versus NA:  $M=0.40$ ,  $SE=0.03$ ) ( $F(1, 30)=1.18$ ,  $p=0.29$ ,  $\eta^2=0.02$ ) indicating that overall TA word recognition was not significantly different from NA word recognition, and no interaction ( $F(1, 30)=0.43$ ,  $p=0.52$ ,  $\eta^2=0.01$ ). Although an interaction was not observed, in order to assess any possible influence of age on later surprise recognition rates between TA and NA words, pre-planned  $t$ -tests were conducted on accuracy performance for each age group.

#### Young adult TA versus NA surprise recognition test accuracy.

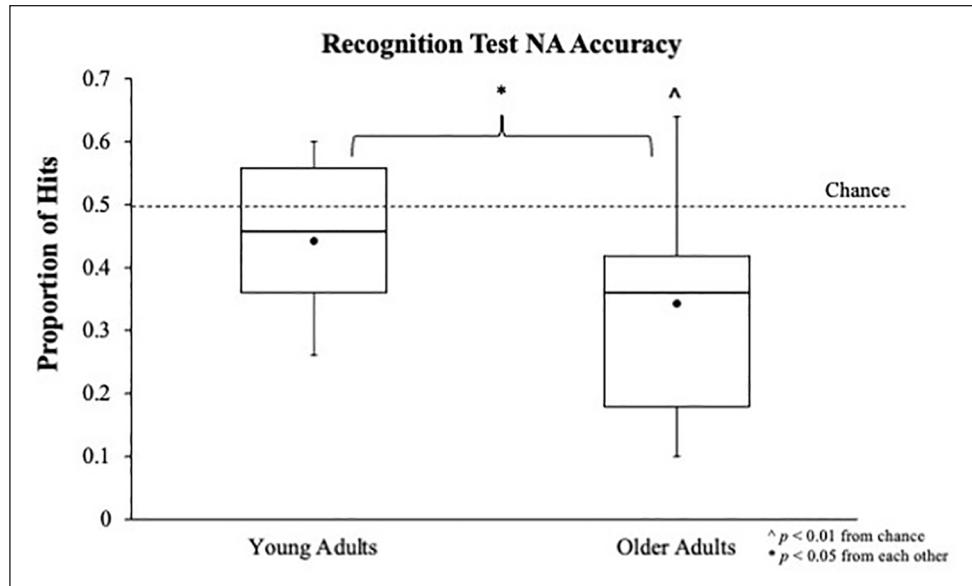
Performance scores were obtained by averaging the total number of hits (i.e. correct identification of TA and NA words). Consistent with findings from Dewald et al. (2011), younger adults recognised all words (TA and NA combined) at rates significantly lower than chance ( $M=0.41$ ,  $SE=0.02$ ,  $t(37)=4.15$ ,  $p<0.001$ ,  $d=0.67$ ). Recognition for TA words only ( $n=19$ ,  $M=0.37$ ,  $SE=0.03$ ) was significantly lower than chance ( $t(18)=3.85$ ,  $p<0.001$ ,  $d=0.88$ ). Recognition for NA words only ( $n=19$ ,  $M=0.44$ ,  $SE=0.03$ ) was marginally different from chance ( $t(18)=2.02$ ,  $p=0.06$ ,  $d=0.46$ ). Finally, recognition for TA words was significantly lower than NA words ( $t(36)=1.71$ ,  $p=0.04$ ,  $d=0.55$ ) (see Figure 3(a)).

#### Older adult TA versus NA surprise recognition test accuracy.

As with the younger adults, older adults recognised all words (TA and NA combined) at rates significantly lower than chance ( $M=0.33$ ,  $SE=0.03$ ,  $t(25)=9.33$ ,  $p<0.001$ ,  $d=1.83$ ). Importantly, recognition for TA words ( $n=13$ ,  $M=0.32$ ,  $SE=0.06$ ) and NA words ( $n=13$ ,  $M=0.34$ ,  $SE=0.05$ ) were both significantly lower than chance (TA words:  $t(12)=5.89$ ,  $p<0.001$ ,  $d=1.63$ ) and (NA words:  $t(12)=7.18$ ,  $p<0.001$ ,  $d=1.99$ ), respectively. Unlike the younger adults, recognition for TA words was not significantly different from NA words ( $t(24)=0.253$ ,  $p=0.40$ ,  $d=0.09$ ) (see Figure 3(b)).

#### TA and NA surprise recognition test accuracy between age groups.

Next, in order to determine if there was a significant difference in recognition performance for TA and NA items between age groups, we compared recognition rates for each item (TA and NA, separately) between young and older adults. There



**Figure 4.** Box plots depicting mean (centre dot), median, quartiles, and range of recognition rates for NA words for young and older adults. On average, young adults recognised NA words at chance levels while older adults recognised NA words at rates significantly below chance (i.e. 50%). Older adults recognised significantly fewer NA items ( $p < 0.05$ ) compared to young adults. There was no difference in recognition rates for TA words between age groups (not shown).

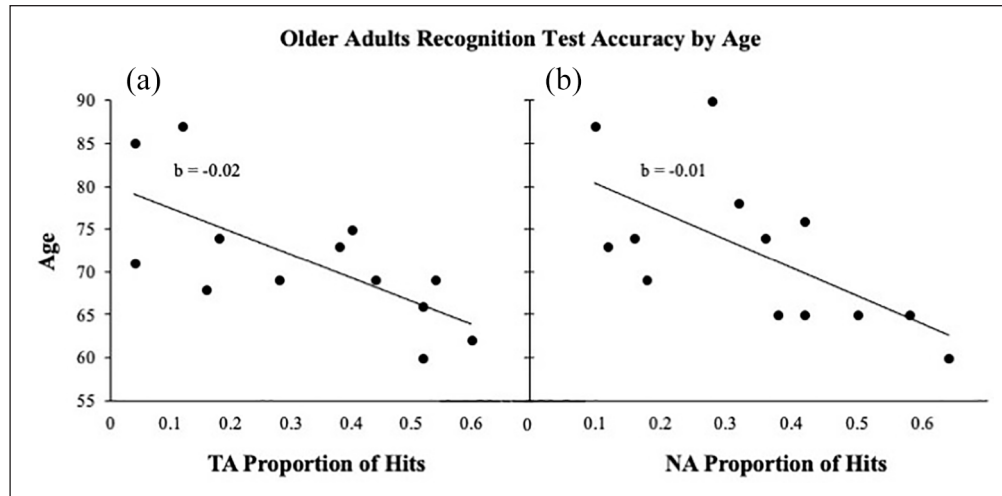
was no significant difference in recognition rates for TA items between young and older adults (young adults:  $M=0.37$ ,  $SE=0.03$  versus older adults:  $M=0.32$ ,  $SE=0.06$ ) ( $t(30)=0.73$ ,  $p=0.24$ ,  $d=0.26$ ) suggesting similar rates of inhibition for TA items between age groups. There was a significant difference in recognition rates for NA items between young and older adults (young adults:  $M=0.44$ ,  $SE=0.03$  versus older adults:  $M=0.34$ ,  $SE=0.05$ ) ( $t(30)=1.96$ ,  $p=0.03$ ,  $d=0.71$ ) (see Figure 4), suggesting that older adults recognised fewer NA items compared to young adults. In concert with the individual analyses and the marginal main effect of age in the ANOVA, these findings suggest that the differences noted in overall performance between age groups can be attributed to older adults recognising fewer NA items than young adults.

**Overall surprise recognition test speed.** To assess whether age modulated RT to TA and NA words during the surprise recognition test, a similar  $2 \times 2$  ANOVA was conducted on surprise recognition test RT for previously presented words only (i.e. excluding foil words) with age (young versus old) and target alignment (TA versus NA) as between subject factors, and RT speed as the dependent variable. There was a significant main effect for age (young adults:  $M=1101$  ms,  $SE=53.67$  versus older adults:  $M=1949$  ms,  $SE=159.71$ ) ( $F(1, 30)=24.41$ ,  $p < 0.001$ ,  $\eta^2=0.45$ ), suggesting that older adults were slower to respond during the surprise recognition test compared to young adults. Again, there was no main effect for target alignment indicating that overall RT to TA words ( $M=1517$  ms,  $SE=139$ ) was not significantly different than RT to NA words ( $M=1394$ ,  $SE=106$ ) ( $F(1, 30)=1.40$ ,  $p=0.247$ ,  $\eta^2=0.01$ ), and no interaction ( $F(1, 30)=0.613$ ,  $p=0.440$ ,  $\eta^2=0.01$ ).

**TA and NA surprise recognition test speed between age groups.** In order to assess whether age modulated response

latencies to previously presented words during the surprise recognition test, we compared overall speed performance (TA and NA) between age groups. There was a significant difference in RT to previously presented words between young and older adults (young adults:  $M=1117$  ms,  $SE=50$  versus older adults:  $M=1949$  ms,  $SE=159$ ) ( $t(62)=5.74$ ,  $p < 0.001$ ,  $d=1.46$ ). This trend continued when comparing RT to TA words (young adults:  $M=1141$  ms,  $SE=77$  versus older adults:  $M=2067$  ms,  $SE=261$ ) ( $t(30)=3.96$ ,  $p < 0.001$ ,  $d=1.43$ ) and NA words (young adults:  $M=1094$  ms,  $SE=66$  versus older adults:  $M=1832$  ms,  $SE=189$ ) ( $t(30)=4.22$ ,  $p < 0.001$ ,  $d=1.52$ ) specifically between the two age groups. There was no significant difference in RT between TA and NA words within each age group (all  $p > 0.47$ ). These findings suggest that older adults were slower to respond during the surprise recognition test compared to younger adults, but target alignment did not modulate RT within age groups.

**Young and older adult surprise recognition test age and accuracy linear regressions.** To determine whether surprise recognition test accuracy rates vary as a function of age, linear regression analyses were performed with predictor variable age (years) and outcome variable accuracy (proportion of hits) for each word type (TA or NA) for both young and older adults. For younger adults, age was not a significant predictor for TA accuracy scores ( $b=0.008$ , 95% CI  $(-0.01, 0.03)$ ,  $t(17)=0.81$ ,  $p=0.43$ ), and it failed to explain a significant proportion of variance in TA accuracy ( $R^2=0.04$ ,  $F(1, 17)=0.65$ ,  $p=0.43$ ). Likewise, age failed to predict NA accuracy scores ( $b=0.008$ , 95% CI  $(-0.01, 0.03)$ ,  $t(17)=0.78$ ,  $p=0.45$ ) or a significant proportion of variance in NA accuracy ( $R^2=0.04$ ,  $F(1, 17)=0.61$ ,  $p=0.45$ ). These findings suggest that surprise recognition test accuracy does not vary as a function of age among young adults aged 18–34 years.



**Figure 5.** (a) Proportion of hits for TA words plotted as a function of age among older adult sample. Age significantly predicted accuracy scores. The linear trend line depicts slope ( $b = -0.02$ ). As age increases by 1 year, proportion of hits declines by 0.02 (i.e. 2%). (b) Proportion of hits for NA words plotted as a function of age among older adult sample. Again, age significantly predicted accuracy scores. Linear trend line depicts slope ( $b = -0.01$ ). As age increases by 1 year, proportion of hits declines by 0.01 (i.e. 1%). Age was not a significant predictor of accuracy scores among the young adult sample (not shown).

Interestingly, for older adults, a significant relationship was observed for both word conditions. Age significantly predicted TA accuracy scores ( $b = -0.02$ , 95% CI  $(-0.03, -0.006)$ ,  $t(11) = 4.03$ ,  $p < 0.01$ ) and explained a significant proportion of variance in TA accuracy ( $R^2 = 0.49$ ,  $F(1, 11) = 10.45$ ,  $p < 0.01$ ). Age also significantly predicted NA accuracy scores ( $b = -0.01$ , 95% CI  $(-0.02, -0.002)$ ,  $t(11) = 3.76$ ,  $p < 0.01$ ) and explained a significant proportion of variance in NA accuracy ( $R^2 = 0.36$ ,  $F(1, 11) = 7.60$ ,  $p < 0.01$ ). Collectively, these findings suggest that as age increases by one unit, TA accuracy decreases by 0.02 units and NA accuracy decreases 0.01 unit among older adults aged 60–90 years (see Figure 5).

## Discussion

This experiment directly assessed the capacity of older adults to selectively inhibit the processing of irrelevant information. Previous researchers have evaluated inhibitory processes in younger and older adults by measuring rates of distraction from irrelevant items during an attention-demanding task (see Amer and Hasher, 2014; Bloemendaal et al., 2016; Brink and McDowd, 1999; Eich et al., 2016; Farkas and Hoyer, 1980; Folk and Lincourt, 1996; Geerligs et al., 2014; Hartley, 1993; Laguë-Beauvais et al., 2013; Milham et al., 2002; Spieler et al., 1996; Watson and Maylor, 2002). While informative, this approach does not allow one to evaluate the extent to which specific types of ignored information are processed and subsequently recalled or recognised. The paradigm used in the present study allows for such analyses to occur by testing recognition memory of the irrelevant information via a surprise test (Dewald et al., 2011).

Previous research has demonstrated that older adults may have difficulty inhibiting the processing of irrelevant information (Amer and Hasher, 2014; Campbell et al., 2010; Hasher and Zacks, 1988; Kramer et al., 1999; Laguë-Beauvais et al., 2013; Lustig et al., 2006; Madden et al., 1996; Mayr, 2001; Mertes et al., 2017; Plude and Hoyer, 1986). Therefore, this study

evaluated if this age group would show a decline in the ability to inhibit irrelevant information on the current task as well, leading to overall higher recognition rates for older adults during the surprise recognition test compared to the younger adults. However, we found the opposite, with older adults actually recognising significantly fewer words overall, compared to their younger counterparts. This is perhaps not all that surprising, given that older adults had slower RTs and lower hit rates during the primary task, suggesting increased task difficulty for this age group, which is discussed in more detail below.

Despite this unexpected result, what is important to note is the differential pattern of recognition rates between older and younger participants. Using this paradigm with young adults, Dewald et al. (2011) revealed inhibited processing for TA words, as they were recognised at rates significantly below chance and significantly less often than NA words during the surprise recognition test (NA words were recognised at chance levels). It was hypothesised that task-irrelevant items that are presented with task-relevant targets are more likely to be filtered during the encoding stage of processing in order to allow for successful target identification and the initiation of appropriate motor responses. This idea fits well with compelling evidence from the field of perceptual learning, which has demonstrated inhibited learning for irrelevant stimuli that was simultaneously presented with attended targets, while learning was evident for non-aligned irrelevant stimuli (see Tsushima et al., 2008). In this framework, and as demonstrated here with the young adult group, NA items were subjected to less stringent filtering processes presumably because responses were not required for non-target items. As such, the higher rate of inhibited processing for TA items, compared to NA items, leads to lower recognition rates during the surprise recognition test. This finding was replicated in the current study with our young adult sample and suggests that, for this age group, inhibitory control can be deployed in a selective manner by increasing the rate of filtering dependent on the difficulty of the task or if additional action, such as decision making and response selection, must be made.



In contrast, the selective nature of inhibitory processes was not present for the older adults in our experiment, as no difference in recognition rates between TA and NA words was observed and both word types were recognised at rates significantly below chance. Thus, it appears that older adults generally inhibited irrelevant information in order to complete the task, rather than just those specific items appearing with targets, as the young adults seem to do. This finding suggests that older adults processed all irrelevant words to a similar extent, regardless of target alignment. Furthermore, linear regression analyses suggest that the observed inhibitory control may become more robustly applied to task-irrelevant items as this group progress into advanced old age.

The findings from this study are particularly relevant when considering the lack of significant differences between age groups when comparing overall performance on the surprise recognition test. Recall that both younger and older adults had statistically indistinguishable  $d'$ ,  $\beta$ , and discrimination accuracy scores on average. These findings suggest that while both age groups had difficulty identifying previously seen items (i.e. TA and NA; as evidenced in overall low  $d'$  scores) they were similarly able to distinguish between previously seen items and foil items (evidenced in similar  $d'$  and discrimination accuracy scores) and there was no difference in response criteria between age groups (as evidenced by the lack of differences in response bias). Taken together, these data suggest that differences in NA word identification between younger and older adults may not be attributed to differences in response biases or discriminative capabilities between old and new items, and instead can be interpreted as a disturbance in the ability of older adults to selectively inhibit the processing of irrelevant information.

Thus, inhibitory attentional mechanisms may operate differently between younger and older adults. It is possible that older adults experience a reduced ability to selectively inhibit word processing while attending to the pictures in the RSVP stream, resulting in a broader inhibition of processing for all presented irrelevant words during the primary task, regardless of target alignment. This may be due to the primary task being more difficult for the older adults. Indeed, older adults exhibited overall lower accuracy and had significantly slower RTs when detecting picture repetitions during the primary task, as predicted. Perceptual load theory (Lavie, 2005) suggests that distracting information has less influence on task performance when task difficulty is increased. Therefore, larger amounts of attentional resources may have been required in order for older adults to identify, and respond to, targets during this portion of the experimental session. Rather than selectively filter the most intrusive irrelevant information (i.e. TA words), as young adults appear to do, older adults seem to employ a broader inhibitory control leading to more extensive filtering of all irrelevant information. Future research may explore this concept in more detail by varying task difficulty with a young adult population in order to determine the extent that attentional load influences inhibitory patterns.

Research investigating neural networks associated with proactive control in ageing adults sheds additional light on the current findings. Proactive control is a form of inhibition, localised within the lateral prefrontal cortex (LPFC), allowing for the rapid and efficient response to upcoming stimuli through the maintenance of task-relevant items guided by top-down information such as task instructions or the identity of a previous target

(Braver, 2012). Manard et al. (2017) found that older adults engaged in a task involving proactive inhibitory control showed a decrease in sustained activity in the bilateral anterior cingulate cortex (ACC), which is involved in conflict detection and monitoring (Botvinick et al., 2001). This decreased activity in the ACC corresponded with *increased* activity of the middle frontal gyrus (MFG), which is associated with active maintenance of contextual information and general task goals (Braver, 2012). The authors suggest that older adults may experience greater difficulty maintaining conflict-monitoring processes during situations involving proactive control (such as those incurring high-cognitive demands). As a result, elderly participants may need to keep general task goals and relevant contextual information more highly activated in the MFG in order to react appropriately to presented stimuli. Interestingly, these authors also observed high rates of activity in ACC relating to low interference conditions. Thus, higher levels of cortical recruitment are involved in less demanding tasks suggesting compensatory activation, which could lead to 'cerebral-overload' in resource demanding tasks (Manard et al., 2017).

These studies may offer a neurological explanation behind the presently observed behavioural results. If older adults indeed find the primary task to be more difficult, perhaps due to having less experience with the technology, being distracted by the irrelevant stimuli thereby making it more difficult to maintain task goals and relevant contextual information, or because visually tracking the rapidly presented attended stimuli requires more effortful deployment of selective attention, then it is possible that more extensive proactive inhibitory control may be employed in a compensatory manner. Among older adults, broader recruitment of sub-systems within the fronto-parietal control network (FPCN), which includes portions of the LPFC and posterior parietal cortex and is thought to be involved in a variety of attention-related tasks by initiating and modulating cognitive control abilities (Zanto and Gazzaley, 2013), may be utilised to maintain task goals and contextual information while also engaging proactive control during the primary task. On one hand, these neural processes may serve to increase primary task performance. However, a high level of proactive control among older adults may also lead to increased inhibitory processes being applied to the task-irrelevant non-target items, resulting in the observed lower recognition rates among NA words during the surprise recognition test.

We also found that older adults were significantly slower to respond in the surprise recognition test. While these results should be interpreted with caution, as the recognition test was not speeded, it may be further indication of inhibited processing for words during the primary task. If older adults employed a broader inhibitory control over unattended items during the primary task, this lack of processing of the irrelevant items may be reflected by higher rates of indecision when later presented in the recognition task. Meaning that if older adults failed to process the unattended words during the primary task, they may take longer to decide if they were indeed present when seen again during the recognition test. However, this may also simply be reflective of speed-accuracy trade-offs wherein older adults favour accuracy over speed, which would also result in slower RTs, as has been observed in many studies comparing older and younger adults (Rabbitt, 1965; Salthouse, 1979; Smith and Brewer, 1995; Starns and Ratcliff, 2010). However, it should also be noted that such behavioural shifts may have a neurological underpinning that is not directly tied to strategy alone (Forstmann et al., 2011).

Taken together, the findings suggest that as age progresses, inhibitory control may diminish, resulting in a decreased capacity to execute selective inhibition over irrelevant information presented in attention-demanding tasks. Additional research is necessary in order to fully understand how these mechanisms may operate in old age and to what extent qualitative differences might exist between younger and older adults in this regard. Future studies should systematically increase task difficulty, through faster presentation rates, in a young adult population. We predict that increased presentation speed of the RSVP stream will result in reduced performance on the primary task (as seen in older adults here). If young adults continue to show preferential inhibition for TA words under these circumstances, this may provide additional support for a decline in selective inhibitory control in an older adult population. In addition, neuroimaging could shed light upon the differences in control networks and modulated areas linked to both selective focus and inhibitory control.

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### Note

1. This same body of literature has also demonstrated facilitated processing of ignored information using a variation of this paradigm wherein distractors frequently appear with targets (Dewald and Sinnott, 2012, 2013; Seitz and Watanabe, 2003; Walker et al., 2014, 2017; Watanabe et al., 2001). However, the current study is only concerned with inhibitory processes.

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