Effect of Aging on Inhibitory Attentional Mechanisms

Maegen Walker (maegenw@hawaii.edu)
Margeaux Ciraolo (ciraolo@hawaii.edu)
Andrew Dewald (adewald@hawaii.edu)
Scott Sinnett (ssinnett@hawaii.edu)
Department of Psychology, University of Hawai‘i at Mānoa
2530 Dole Street, Honolulu, HI 96822 USA

Abstract

The ability to inhibit the processing of irrelevant information declines as adults age (Hasher & Zacks, 1988; Lustig, Hasher and Tonev, 2006; Mayr, 2001). However, previous research investigating inhibitory control in older adults has not evaluated the *extent* to which irrelevant information is processed and later recognized. Using a dual task paradigm with young adults, Dewald, Sinnett, and Doumas (2011) demonstrated inhibited recognition for previously ignored words, provided they had appeared infrequently with targets in the primary task, compared to words that did not appear with targets. The current study adapted this paradigm to examine inhibitory mechanisms in a sample of older adults. Here, older adults exhibited inhibited recognition for all words while young adults continued to show greater inhibition for words that had appeared with targets compared to words that had not. This finding suggests that older adults may experience a decline in the *selective* inhibition of irrelevant information.

Keywords: Aging; Attention; Dual Task Paradigms; Inhibition; Inattentional Blindness

Introduction

One critical mechanism for information processing is the ability to *inhibit* irrelevant information from being processed (Tipper, 1992). This is accomplished by directing attention toward the desired target or task while ignoring potential distractors. For example, in order to drive a car one must be able to focus on driving (e.g., minding roads and traffic signals) while ignoring potential distractors, such as billboards or an incoming text message. However, attentional capabilities change over the course of the human lifespan and it is well established that performance decreases as adults progress in to old age (Campbell, Grady, Ng, & Hasher, 2012; Mayr, 2001; Rabbitt, 1965; Störmer, Heekeren, & Lindenberger, 2013). This age related cognitive decline in attention has been largely attributed to deficiencies in inhibitory control, with older adults unsuccessfully inhibiting the processing of irrelevant information (Hasher & Zacks, 1988; Kramer, Hahn, & Gopher, 1999; Lustig, Hasher and Tonev, 2006; Madden, Pierce, & Allen, 1996; Mayr, 2001; Plude & Hoyer, 1986).

Illustrative of this cognitive decline, older individuals exhibit difficulties in tasks involving selective attention (i.e., selecting a stimulus of interest and focusing attentional resources toward it while inhibiting irrelevant information). A study conducted by Farkas and Hoyer (1980) used a card-sorting version of a visual search task and found that, compared to younger individuals, older adults were slower to respond when presented with a distractor card that was very similar, compared to cards that were dissimilar, 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 studies of selective attention demonstrate that, as adults progress in to old age, top-down control over attentional allocation may become impaired when viewing displays containing moving items (Folk & Lincourt, 1996; Watson & Maylor, 2002). In this case, older individuals appear to have more trouble visually identifying the target stimulus (Watson & Humphreys, 1997; 1998). This suggests that they may be less able to inhibit processing of previously viewed distractor objects such that they continue to capture attention during the visual search task. Therefore, being unable to inhibit processing for the irrelevant items appears to negatively impact perception of the target stimulus in moving displays.

The most compelling evidence supporting the perspective that the ability to inhibit the processing of irrelevant information declines as adults age has come from work with the classic Stroop task. During this task, participants are presented with a series of written color words appearing in a variety of different colors (i.e., the word “yellow” written in the color red). Participants must inhibit reading the word (e.g., yellow) and report only the color (e.g., red). When comparing performance on this task between younger and older adults, the tendency to incorrectly report the word rather than the color (i.e., Stroop interference) is significantly more pronounced for older participants (Brink & McDowd, 1999; Hartley, 1993; Spieler, Balota & Faust, 1996). That is, the ability to inhibit the incorrect responses appears to be compromised in older adults.

Milham et al. (2002) conducted further work exploring inhibitory processes with the Stroop task in aging adults using fMRI. Along with higher instances of Stroop interference in older participants, results from this study suggest decreased responsiveness in brain regions believed to be associated with attentional control and working memory, in particular the dorsolateral prefrontal cortex (DLPFC) and the parietal cortex (Banich et al., 2000a, 2000b; MacDonald, Cohen, Stenger, & Carter, 2000; Sinnett, Snyder, & Kingstone, 2009). These particular brain regions are associated with the modulation of neural activity by facilitating processing systems that contain task-relevant information while inhibiting systems that contain task-irrelevant information. Through this early inhibition of processing irrelevant information, the DLPFC suppresses activation of semantic and phonological associations as well as potential actions related to the irrelevant information (Banich et al., 2000b).

The Stroop task is favored among those investigating the modulation of inhibitory attentional mechanisms with an aging population because participants must simultaneously facilitate the processing of the written word *color* (i.e., say "red" if the word "yellow" is written in the color red) and inhibit the processing of the semantically written word (i.e., "yellow"). However, this, and previously used behavioral methods, have two important limitations. First, when using the Stroop task it is difficult to isolate facilitatory from inhibitory mechanisms because this paradigm does not offer an effective method for dissociating these two processes. Thus, when Stroop interference occurs it is difficult to determine if the attentional system is failing to facilitate processing of the presented color (i.e., the relevant information) or if it is failing to inhibit processing of the written word (i.e., the irrelevant information). Second, other previously utilized behavioral methods evaluate the function of inhibitory mechanisms by looking at rates of distraction induced by the irrelevant stimuli. That is, the ability to inhibit processing of the irrelevant item is assessed by examining accuracy or reaction time to a target that is presented at the same time as the distracting item, with higher rates of distraction and slower reaction times indicating reduced inhibitory control. While this is useful information, the *extent* to which these ignored items are actually processed and subsequently stored in long-term memory is presently undetermined.

To address these gaps in the literature, we adapted a dual-task paradigm (see Dewald, Sinnett, & Doumas, 2011; 2012) for use with older adults. This paradigm overcomes the ambiguity presented in the Stroop task by varying the frequency with which irrelevant distractor (i.e., ignored) items are presented simultaneously (i.e., paired) with attended target items. This method allows for the isolation and examination of both inhibitory and facilitatory mechanisms separately. Previous research using this paradigm with young adults has shown that infrequently pairing the ignored distractor items with targets in the attended task leads to *inhibited* processing of these distractor items over ignored distractor items that are *not* paired with targets (see Dewald et al., 2011)[1]. The extent to which the irrelevant information may have been processed is evaluated through the use of a surprise recognition test for the previously ignored distractor items.

The current study focuses on evaluating the proposed inhibitory effect in an older adult population and compares performance on this task to a sample of younger adults. Based on findings from previous research suggesting that older adults experience an overall decline in their ability to inhibit processing of irrelevant information (Hasher & Zacks, 1988; Kramer et al., 1999; Lustig et al., 2006; Madden, et al., 1996; Mayr, 2001; Plude & Hoyer, 1986), we predict that older adults will be less able to inhibit processing the distractor items during the primary task compared to the young adults. This decline in inhibitory control should lead to the ignored items being processed to a greater extent. As a result, older adults should have overall higher recognition scores than the younger adults on the surprise recognition test as younger adults tend to inhibit these items (Dewald et al., 2011). Specifically, older adults should recognize all distractor items at or around chance levels while younger adults should exhibit greater inhibition for distractor items that were paired with task targets when compared to distractor items that were not paired with task targets. This finding would suggest that older adults are less able to inhibit processing of the irrelevant information resulting in greater amounts of the ignored information capturing attention, being stored in long-term memory, and subsequently recognized more often later.

Methods

Participants

Thirty-nine young adults (23 female, mean age of 20.7) 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 (22 female, mean age of 20.8).

Twenty-six healthy older adult participants (18 female, mean age of 72.2) were recruited, on a voluntary basis, from local retirement communities around Honolulu, Hawai`i, as well as from continuing education programs for seniors at the University of Hawaiʻi at Mānoa. This target age group (>60 years old) was chosen based on criteria set by the World Health Organization (2014) designating 60 as the generally accepted age at which an individual is considered to be 'elderly'. All participants were naïve to the experiment, provided informed consent, and had normal, or corrected to normal, vision and hearing.

Stimuli

A total of 50 pictures (on average 5 to 10 cms) 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

[1] This same body of literature has also demonstrated facilitated processing of ignored information using a variation of this paradigm, (Dewald & Sinnett, 2012, 2013; Walker, Dewald, & Sinnett, 2014; Seitz & Watanabe, 2003; Watanabe, Nàñez & Sasaki, 2001). However, the current study is only concerned with conditions of inhibited processing.

(Wilson, 1988). All words had an average length of 5 letters (range 4-6) and average frequency of 120 per million (range 28-686). The words were superimposed over the pictures in bold, capitalized letters and presented in Arial font (24 points). Care was taken to ensure that picture-word combinations did not have any semantic relationship.

Attended Stimuli The 50 pictures were duplicated resulting in two copies of each picture (i.e., picture pairs). All pictures were randomly rotated +/-30 degrees from their original orientation to ensure that the task is sufficiently demanding in each version of the experiment (see Rees et al., 1999). To create an experimental block, half (25) of the picture pairs were presented as immediate picture repetitions. These immediate picture repetitions served as the identification targets for the attended task. The remaining 25 pairs did not occur as immediate repetitions in the same block. Instead, they were separated from their duplicate and randomly inserted in between occurrences of repeating picture pairs creating the non-repeating pictures in the visual stream. This process was repeated to create the second experimental block using the same stimuli. Critically, the 25 picture pairs that served as immediate repetitions in the first block did not repeat in the second block and those that did not repeated in the first block did repeat 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 a non-repeating picture pair in the second block.

Ignored Distractor Items 100 words were randomly selected and superimposed on the pictures. Half (50) of the words appeared superimposed on immediate picture repetitions (i.e., targets), serving as the *target-aligned* (TA) words, and the other half were superimposed on the non-repeating pictures in the stream, serving as *non-aligned* (NA) words. This created a block size of 100 picture-word combinations with 25 immediate target picture repetitions and accompanying superimposed TA words for each of the two blocks. The same 100 words and 50 picture pairs used in the first block were used in the second block and the same procedure was applied. Like the pictures, the 25 words that were TA in the first block were NA in the second block and vice versa. Therefore, all of the words were presented twice in the experiment. Twenty-five of the 50 TA words were presented as TA in the first block and were then presented as a 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., always NA). This method was used to create six different versions of the experiment (see Dewald et al., 2011).

Surprise Recognition Test The later surprise recognition test for the ignored words was administered after participants had completed the primary attended task. This test consisted of 50 words from the experiment along with 50 never before seen foil words, selected from the same database (Wilson, 1988). Because of the high number of words presented, two types of surprise recognition tests were created for each version of the experiment. One tested only the 50 TA words along with 50 foil words and the other tested only the 50 NA words along with 50 foil words for a total of 100 words in each recognition test. Each participant was randomly assigned to get one type of test only (TA words or NA words). The recognition tasks were randomized and presented one word at a time. The words were written in bold, capitalized letters in Arial font at a size of 24 points (i.e., identical to their initial presentation in the repetition detection task).

Procedure

Participants were seated in front of a computer with the screen a comfortable distance away. They were then shown a rapid serial visual presentation (RSVP) of the picture-word stream, using DMDX software (Forster & Forster, 2003). In the primary repetition detection task participants were instructed to ignore the superimposed words and attend only to the pictures. Participants were required to respond when they noticed a picture immediately repeat by clicking the left mouse button with their preferred hand. Each item in the picture-word presentation was presented for 500ms with a 150ms inter-stimulus interval (ISI; blank screen) between each item for a stimulus onset asynchrony (SOA) of 650ms (see Figure 1). Before the first experimental block, a training block of eight trials was given and repeated until participants were familiar and comfortable with the task. Immediately after the primary picture repetition detection task, the surprise word recognition test was administered to all participants. Words were presented, one at a time, on the computer screen, again using DMDX software (Forster & Forster, 2003). Each word remained on the screen until a response (key press) was given. Participants were instructed to press the "B" key if they felt that they had seen the word during the repetition detection task or, instead, the "V" key if they felt that they had not seen the word before. Response buttons were counterbalanced across participants.

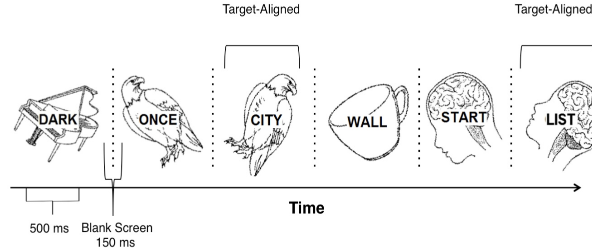

Figure 1: Schematic representation of the task. Immediately repeated pictures serve as the attended task targets while superimposed words are the ignored distractor items. Words appearing with attended task targets are the TA words (i.e., "City" and "List"); all other words are NA words.

Results

Because our interest was focused on determining if recognition rates for TA and NA words differ between young and old adults, statistical analyses include a two-way ANOVA as well as pre-planned t-tests within each age group. These analyses were designed to assess performance both within and across age groups.

Immediate Repetition Accuracy Overall performance accuracy for both younger and older adults on the repetition detection task revealed that participants had an equal number of hits and misses on the primary task, [hit rate: $M = 0.50$, $SE = 0.025$, miss rate: $M = 0.50$, $SE = 0.025$, $t(63) = 0.030$, $p = 0.488$]. Performance on this task was significantly above chance [$t(63) = 16.67$, $p < 0.01$], which was taken to be an indication of the successful detection of picture repetitions on the primary task. A target appears, on average, in one of every 15 trials. Therefore chance is calculated as the probability of obtaining a hit in any given presentation of 15 trials (i.e., 7%).

Older adults accuracy (hit rate: $M = 0.37$, $SE = 0.032$) was significantly lower than young adults (hit rate: $M = 0.58$, $SE = 0.031$) when detecting picture repetitions on the primary task [$t(62) = 4.64$, $p < 0.001$], indicating that the repetition detection task may have been more difficult for them. There was no significant difference in false alarm (FA) rates for older adults ($M = 0.01$, $SE = 0.003$) compared to young adults ($M = 0.007$, $SE = 0.001$) [$t(62) = 0.783$, $p = 0.218$].

Overall Recognition Performance In order to assess whether age modulated overall word recognition, a two-way ANOVA was conducted on surprise recognition test performance with age (young vs. old) and target-alignment (TA vs. NA) as between subject factors, and accuracy as the dependent variable. There was a marginal main effect for age [$F(1, 64) = 3.35$, $p = 0.07$], suggesting that older adults recognized fewer words on the surprise recognition test compared to young adults. There was no main effect for target alignment indicating that overall TA word recognition ($M = 0.35$, $SE = 0.030$) was not significantly lower than NA ($M = 0.40$, $SE = 0.026$) [$F(1, 64) = 1.75$, $p = 0.190$], and no interaction [$F(1, 64) = 0.495$, $p = 0.485$] (see Figure 2).

Although an interaction was not observed, in order to assess any possible influence of age on later surprise recognition rates pre-planned t-tests were conducted on accuracy performance for each age group.

Young Adult Accuracy Performance Overall word recognition on the surprise recognition test was $M = 0.40$ ($SE = 0.022$), which was significantly different from chance [$t(37) = 4.15$, $p < 0.001$]. Recognition for TA words ($n = 19$, $M = 0.37$, $SE = 0.033$) was significantly different from chance [$t(18) = 3.85$, $p < 0.001$], while recognition for NA words ($n = 19$, $M = 0.44$, $SE = 0.027$) was only marginally significantly different from chance [$t(18) = 2.02$, $p = 0.06$]. Recognition for TA words was significantly lower than NA words [$t(36) = 1.71$, $p = 0.04$] (see Figure 3).

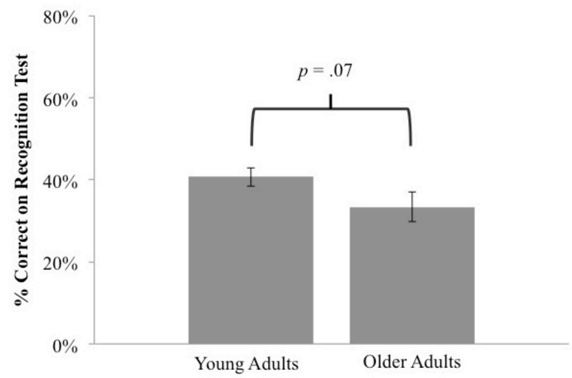

Figure 2: Recognition rates and SE for all word types (TA and NA combined) between young and older adults. The ANOVA revealed a marginal main effect for age (p = 0.07) suggesting older adults recognized fewer words, overall, compared to young adults.

Older Adult Accuracy Performance Overall word recognition on the surprise recognition test was $M = 0.33$ ($SE = 0.036$), which was significantly different from chance [$t(25) = 4.64$, $p < 0.001$]. Recognition for TA words ($n = 13$, $M = 0.32$, $SE = 0.055$) was significantly different from chance [$t(12) = 3.18$, $p < 0.008$], and recognition for NA words ($n = 13$, $M = 0.34$, $SE = 0.047$) was also significantly different from chance [$t(12) = 3.29$, $p < 0.007$]. Recognition for TA words was not significantly different from NA words [$t(24) = 0.253$, $p = 0.401$] (see Figure 3).

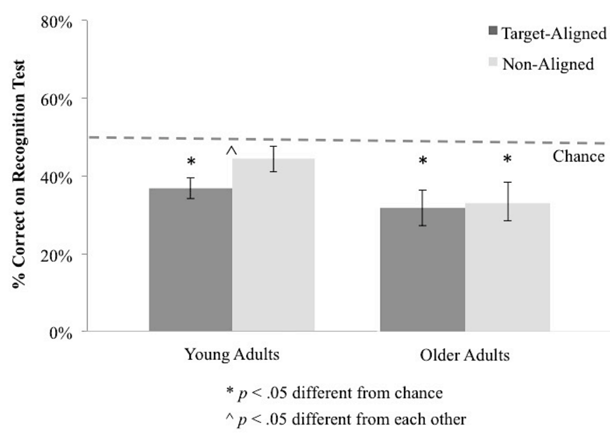

Figure 3: Recognition rates and SE for TA words (dark grey bar) compared to NA words (light grey bar) for young and older adults. Young adults recognized TA words significantly less often than NA words; NA words were recognized around chance levels. Older adults showed no significant difference in recognition rates between word types, however all words were recognized at rates below chance.

Discussion

This experiment directly assessed the ability to inhibit the processing of irrelevant information within an elderly population. In the past, researchers have evaluated inhibitory processes in younger and older adults by measuring rates of distraction from irrelevant items during an attention-demanding task (see Brink & McDowd, 1999; Farkas & Hoyer, 1980; Folk & Lincourt, 1996; Hartley, 1993; Milham et al., 2002; Spieler et al., 1996; Watson & Maylor, 2002). While informative, this approach does not allow one to evaluate the *extent* to which ignored information is processed and subsequently recalled or recognized later. The paradigm employed here allows for such analyses to be made by testing memory of the irrelevant information via a surprise recognition test.

Using this paradigm with young adults, Dewald and colleagues (2011) revealed inhibited processing for TA words, as they were recognized less often than NA words during the surprise recognition test. This finding was replicated in the current study with our young adult sample. Previous research has demonstrated that older adults may have difficulty inhibiting the processing of irrelevant information (Hasher & Zacks, 1988; Kramer, Hahn, & Gopher, 1999; Lustig, Hasher and Tonev, 2006; Madden, Pierce, & Allen, 1996; Mayr, 2001; Plude & Hoyer, 1986). Therefore, it was reasonable to predict that this age group would show a decline in the ability to inhibit irrelevant information on this task as well, resulting in similar recognition rates for TA and NA words. Consistent with our prediction, we found that older adults showed no difference in recognition rates between TA and NA words. This finding suggests that older adults processed all irrelevant words to a similar extent regardless of target-alignment.

Due to a reduction in the ability to execute inhibitory control, we expected that older adults would have overall higher recognition rates during the surprise recognition test compared to the younger adults. Specifically, we expected that older adults would recognize all word types at or around chance levels, while younger adults would demonstrate below chance recognition rates for TA words and at chance recognition for NA words (as seen in Dewald et al., 2011). However, we found that older adults actually recognized significantly fewer words overall, compared to younger adults. Therefore, it appears that older adults inhibited all types of irrelevant information in order to complete the task, rather than just those items appearing with targets, as the young adults seem to do.

It is possible that older adults experienced a reduced ability to *selectively* inhibit word processing while attending to the pictures in the RSVP stream. This reduction in selective inhibitory control may have resulted in a more global inhibition of processing for all presented irrelevant words during the exposure stage, regardless of target alignment. This may be due to the fact that the primary task may have been more difficult for the older adults. Indeed, older adults exhibited overall lower accuracy scores when detecting picture repetitions during the primary attended task. Lavie (2005) has demonstrated that distracting information has less influence on task performance when task difficulty is increased. This is likely due to the fact that increased task difficulty requires additional attentional resources (i.e., increased cognitive load). As a result, processing of irrelevant information is more likely to be inhibited. Therefore, if the primary task was more difficult for the older adults, larger amounts of attentional resources may have been required in order to identify and respond to targets during this portion of the experimental session. Therefore, 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 more global inhibitory control leading to more extensive filtering of all irrelevant information.

Alternatively, the observed lower recognition rates for the older adults may be due to a reduced ability to attend to the words during the primary task. This may also be reflected by older adults' lower performance in the repetition task when compared younger adults. Thus, it could be argued that lower recognition rates in the surprise task may be due to a lack of attentional allocation rather than a decline in selective inhibitory control. However, we would expect older adults to exhibit chance performance on the surprise recognition test if this were the case, which would suggest that the information failed to be processed rather than undergoing active inhibition.

Taken together, the findings tentatively demonstrate that as we progress in old age, inhibitory control may diminish, resulting in an inability 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. Future studies will investigate this further by systematically increasing task difficulty, through faster presentation rates, in a young adult population. We predict that increased presentation speed of the RVSP 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.

References

Banich, M., Milham, M., Cohen, N. J., Wszalek, T., Kramer, A., Liang, Z.-P., Gullet, D., Shah, C., & Brown, C. (2000a). Prefrontal regions play a predominant role in imposing an attentional ''set'': Evidence from fMRI. *Cognitive Brain Research*, 10, 1–9.

Banich, M., Milham, M., Atchley, R., Cohen, N.J., Wszalek, T., Kramer, A., Liang, Z. P., Gullet, D., Shah, C., & Brown, C. (2000b). FMRI studies of Stroop tasks reveal unique roles of anterior and posterior brain system in attentional selection. *Journal of Cognitive Neuroscience*, 12, 988–1000.

Brink, J. M., & McDowd, J. M. (1999). Aging and selective attention: an issue of complexity or multiple mechanisms?. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *54*(1), P30-P33.

Campbell, K. L., Grady, C. L., Ng, C., & Hasher, L. (2012). Age differences in the frontoparietal cognitive control network: implications for distractibility. *Neuropsychologia*, *50*(9), 2212-2223.

Dewald, A. D., & Sinnett, S. (2012). Enhanced Performance for Recognition of Irrelevant Target-Aligned Auditory Stimuli: Unimodal and Cross-modal Considerations. In *Proceedings of the Thirty-Fourth Annual Conference of the Cognitive Science Society* (pp. 294-299).

Dewald, A. D., & Sinnett, S. (2013). Speed Facilitation In The Absence Of Enhanced Recognition For Target-Aligned But Irrelevant Stimuli Under Cross-modal Presentations. In *Proceedings of the Thirty-Fifth Annual Conference of the Cognitive Science Society* (pp. 2183-2188).

Dewald, A. D., Sinnett, S., & Doumas, L. A. (2011). Conditions of directed attention inhibit recognition performance for explicitly presented target-aligned irrelevant stimuli. *Acta psychologica*, *138*(1), 60-67.

Farkas, M. S., & Hoyer, W. J. (1980). Processing consequences of perceptual grouping in selective attention. *Journal of Gerontology*, *35*(2), 207-216.

Folk, C. L., & Lincourt, A. E. (1996). The effects of age on guided conjunction search. *Experimental Aging Research*, *22*(1), 99-118.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers*, *35*(1), 116-124.

Hartley, A. A. (1993). Evidence for the selective preservation of spatial selective attention in old age. *Psychology and Aging*, *8*(3), 371.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), The psychology of learning and motivation (Vol. 22, pp. 193-225). New York: Academic Press.

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: Explorations of executive control processes in the task switching paradigm. *Acta Psychologica*, *101*(2), 339-378.

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences*, 9(2), 75-82.

Lustig, C., Hasher, L., & Tonev, S. T. (2006). Distraction as a determinant of processing speed. *Psychonomic bulletin & review*, *13*(4), 619-625.

MacDonald, A. W., III, Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science, 288*(5472); 1835–1838.

Madden, D. J., Pierce, T. W., & Allen, P. A. (1996). Adult age differences in the use of distractor homogeneity during visual search. *Psychology and aging*, *11*(3), 454.

Mayr, U. (2001). Age differences in the selection of mental sets: the role of inhibition, stimulus ambiguity, and response-set overlap. *Psychology and aging*, *16*(1), 96.

Milham, M. P., Erickson, K. I., Banich, M. T., Kramer, A. F., Webb, A., Wszalek, T., & Cohen, N. J. (2002). Attentional control in the aging brain: insights from an fMRI study of the stroop task. *Brain and cognition*, *49*(3), 277-296.

Pashler, H. E. (1998). *The psychology of attention* (Vol. 15). Cambridge, MA: MIT press.

Plude, D. J., & Hoyer, W. J. (1986). Age and the selectivity of visual information processing. *Psychology and Aging*, *1*(1), 4.

Rabbitt, P. (1965). An age-decrement in the ability to ignore irrelevant information. *Journal of Gerontology*, *20*(2), 233-238.

Rees, G., Russell, C., Frith, C. D., & Driver, J. (1999). Inattentional blindness versus inattentional amnesia for fixated but ignored words. *Science*, *286*(5449), 2504-2507.

Seitz, A. R. & Watanabe, T. (2003). Psychophysics: Is subliminal learning really passive? *Nature*, 422, 36.

Sinnett, S., Snyder, J. J., & Kingstone, A. (2009). Role of the lateral prefrontal cortex in visual object-based selective attention. *Experimental brain research*, 194(2), 191-196.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of experimental psychology: Human learning and memory*, *6*(2), 174.

Spieler, D. H., Balota, D. A., & Faust, M. E. (1996). Stroop performance in healthy younger and older adults and in individuals with dementia of the Alzheimer's type. *Journal of Experimental Psychology: Human Perception and Performance*, *22*(2), 461.

Störmer, V. S., Li, S. C., Heekeren, H. R., & Lindenberger, U. (2013). Normal aging delays and compromises early multifocal visual attention during object tracking. *Journal of cognitive neuroscience*, *25*(2), 188-202.

Tipper, S. P. (1992). Selection for action: The role of inhibitory mechanisms. *Current Directions in Psychological Science*, *1*(3), 105-109.

Walker, M., Dewald, A. D., & Sinnett, S. (2014). The role of modality congruence in the presentation and recognition of task-irrelevant stimuli in dual task paradigms. In Bello P., Guarini M., McShane M. & Scassellati B. (Eds.) *Proceedings of the 36th Annual Conference of the Cognitive Science Society* (pp. 1736-1741). Austin TX: Cognitive Science Society.

Watanabe, T., Náñez, J. E., & Sasaki, Y. (2001). Perceptual learning without perception. *Nature*, *413*(6858), 844-848.

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological review*, *104*(1), 90.

Watson, D. G., & Humphreys, G. W. (1998). Visual marking of moving objects: A role for top-down feature-based inhibition in selection. *Journal of Experimental Psychology: Human Perception and Performance*, *24*(3), 946.

Watson, D. G., & Maylor, E. A. (2002). Aging and visual marking: Selective deficits for moving stimuli. *Psychology and Aging*, *17*(2), 321.

Wilson, M. (1988). MRC Psycholinguistic Database: Machine-usable dictionary, version 2.00. *Behavior Research Methods, Instruments, & Computers*, *20*(1), 6-10.

World Health Organization (2014). *Definition of an older or elderly person.* United Kingdom: WHO press.

Wright, R. E. (1981). Aging, divided attention, and processing capacity. *Journal of Gerontology*, *36*(5), 605-614.