

INVESTIGATION OF INHIBITORY AND FACILITATORY ATTENTIONAL
MECHANISMS IN COGNITIVE AGING

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Maegen E. Walker

Thesis Committee:

Scott Sinnett, Chairperson
Particia Couvillion
Lorey Takahashi

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Abstract

It is well understood that human cognition declines with age. While much research has explored cognitive decline in the elderly, it is still unknown as to what specific mechanisms underpin this decline. Processing speed theory (Salthouse, 1996) would suggest that any observed differences between elderly and young adult samples are due to a generalized slowing of information processing. On the other hand, inhibitory deficit theory (Hasher & Zacks, 1988) posits that any age related decline in cognition is not related to a general slowdown, but rather to deficits in inhibitory control. The research in this thesis used a dual-task paradigm that has the ability to examine both inhibitory and facilitatory attentional mechanisms in both younger and older adult populations. Overall, the findings from two experiments provide support for both of the theoretical standpoints used to explain cognitive decline. That is, there was evidence for a general slowdown in information processing (Experiments 1 and 2) as well as a disturbance in inhibitory processes (Experiment 1). Thus, it appears that both theories may account for the cognitive decline, at least as measured with these experimental paradigms. The findings also provide evidence for a separate facilitatory attentional mechanism that appears to be less susceptible to age related decline.

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1. Introduction

A large proportion of the aging population is projected to live to age 85 or older (Arias, 2002); consequently, dementia rates are expected to triple by the year 2050 (World Health Organization, 2012). As a result, investigations into the aging process have received a large amount of attention, leading to significant contributions regarding the nature of age related cognitive decline. It is imperative that research endeavors also focus on investigating the bases of age related deficits in cognitive processing. For example, there have been a number of investigations focusing on potential changes to attentional mechanisms in older adults (i.e. >60 years old), with evidence suggesting that inhibitory processes decline during the course of natural aging (Hasher & Zacks, 1988; Kramer, Hahn, & Gopher, 1999; Madden, Pierce, & Allen, 1996; Mayr, 2001; Plude & Hoyer, 1986).

This thesis research focuses mainly on two attentional mechanisms: the inhibition and facilitation of information processing. This is not without reason as humans' ability to process information and use it for goal directed behavior relies on the attention system. For instance, like many daily activities, the simple act of driving a car presents more perceptual information than is needed or even possible to process. Thus, in order to successively operate an automobile, it is necessary to filter irrelevant information while simultaneously highlighting important elements of our environment. It is commonly understood that these facilitatory and inhibitory processes are mediated by attentional mechanisms (Pashler, 1998). Indeed, several studies have indicated that selectively focusing attention on a specific object enhances the perceptual signal of that object (Bashinski & Bacharach, 1980; Downing, 1988; Posner, 1980), as well as enhances the

perceived resolution of items appearing in an attended location (Carrasco & Yeshurun, 1998; Jonides & Irwin, 1981; Posner, 1980; Posner & Cohen, 1984; Spence & Driver, 1997; Spence, Ranson & Driver, 2000; Yeshurun & Carrasco, 1999) thereby facilitating information processing and subsequent perception. In addition to the facilitation of processing information at attended locations, attentional mechanisms also function as a filter to diminish the influence of irrelevant stimuli. This is accomplished by inhibiting the processing of irrelevant information presented in the environment in parallel with the facilitation of information that is attended (Dewald & Sinnott, 2011; Dewald, Sinnott, & Doumas, 2011; Houghton & Tipper, 1994; Neill, 1977; Tipper & Cranston, 1985; Tsushima, Sasaki, & Watanabe, 2006; Tsushima, Seitz, & Watanabe, 2008).

The research presented in this Master's thesis explores how the aging process might adversely affect the attentional mechanisms of inhibition and facilitation. However, prior to an in depth discussion regarding aging and attentional mechanisms, it is necessary to address some of the ways in which the aging process may affect sensory and neurological systems that are intricately linked to the attention system. This is important as degradation in one sense (e.g., vision) may adversely affect the attentional system as a whole. In order to understand the process of cognitive aging and the effect it may have on the attention system, the following discussion will focus first on age related changes in global neurological processes followed by changes to the visual and auditory sensory systems specifically.

2. Background

I. Global neurological changes associated with aging

It is commonly accepted that our sensory, perceptual, and attentional systems work in concert to select, process, and integrate information arriving at our senses. It is also widely accepted that many biological systems are subject to a myriad of alterations, due to varying reasons, as years increase in number (Campbell, McComas, & Petito, 1973; Finch, 1976; Griffith, 2013; Weinstein & Anderson, 2010). For example, Azari et al. (1992) found age related reductions in the resting regional cerebral metabolic rate for glucose (rCMRglc) in both frontal and parietal regions when comparing healthy younger (< 40) and older (> 64) adults. The results were taken to suggest that older adults exhibit a reduction in frontal and parietal interactions; two areas believed to be involved in voluntary attentional control (Hopfinger, Buonocore, & Mangun, 2000). When compared directly, structural decline was observed in the frontal lobes of aging individuals compared to younger participants (de Leon et al., 1987; Kuhl, Metter, Riege, & Phelps, 1982). Additionally, age-related declines have been found in both the volume and integrity of gray and white matter of the prefrontal regions (Head et al., 2004; Raz et al., 2005; Salat et al., 2005). This may contribute to reduced attentional control in older adults resulting in slower perceptual processing.

More recent studies have also found evidence to suggest that glucose regulation may have significant impacts on older adult individuals (Kaplan, Greenwood, Winocur, & Wolever, 2000; Messier, & Gagnon, 2000). Kaplan et al. (2000) found that glucose regulation may be associated with verbal declarative memory and visuomotor performance in healthy older adults such that a dysregulation of glucose metabolism and

glucose intolerance may be correlated with deficits in these cognitive processes. Finally, D'Esposito, Zarahn, Aguirre, and Rypma (1999) used fMRI to demonstrate a reduction in metabolic activity of the primary motor cortex in response to the presentation of various stimuli in an older adult sample (for additional examples see also Brodtmann, Puce, Syngeniotis, Darby, & Donnan, 2003; Buckner, Snyder, Sanders, Raichle, & Morris, 2000; Huettel & McCarthy, 2000; Huettel, Singerman, & McCarthy, 2001). It is worth noting, however, that investigations using fMRI have returned mixed results. For example, Brodtmann et al. (2003) found age related differences in hemodynamic responses only in participants over the age of 90, and Buckner et al. (2000) found age related reductions in the primary visual cortex, but failed to see significant reductions in other brain regions.

Determining an absolute measurement of metabolic activity requires invasive procedures (e.g., arterial blood sampling) therefore, in addition to fMRI, investigations have also used positron emission tomography (PET) scans to evaluate potential age related changes in baseline neural activity. Here, estimates of overall neurological activity are obtained by injecting a radiotracer into the bloodstream and regional cerebral blood flow (rCBF) can be monitored through the radiotracer half-life. Using this method, neural activity can be monitored by comparing rCBF between a prestimulus baseline control condition and a perceptual or cognitive task. Therefore, if older adults maintain a higher level of baseline activity than younger adults, but reach the same overall level of activation during a task-relevant activity, the rate of relative change between the control and test conditions should be smaller for the older adults compared to younger adults.

Such a difference may be interpreted as age-related decline in task-related activation (Madden, Whiting, & Huettel, 2005).

Investigations using this methodology suggest that age related differences in cognitive function might result from higher levels of baseline neural activity in older adults. For example, evidence that implies age related decline in occipitotemporal activation was found using PET scans during conjunction visual search tasks compared to singleton search tasks¹. Higher magnitude increases in neural activation of the striate cortex and extrastriate region was observed in younger compared to older adults (Madden et al., 2005). It is likely that this reduction in activity is a result of the older adult group having higher baseline activity during easier singleton search tasks. This could perhaps suggest that more effort was needed for even simple(r) tasks for the older adult group, although it is important to note that an increase in neural activity does not necessarily imply an increase in conscious cognitive effort. Other studies found evidence to suggest that older adults maintain higher baseline neural activity in other brain regions as well, specifically the anterior cingulate (Milham et al., 2002) and dorsolateral prefrontal cortex (DLPFC) (DiGirolamo et al., 2001). This increase in baseline activity may be a result of signal enhancement due to increased top-down attentional control as a means to compensate for a reduction in information-processing efficiency.

Highlighting this notion of a compensatory mechanism, DiGirolamo et al. (2001) had both young and old participants engage in either a numerosity or value judgment task

¹In a singleton search task target objects pop out of the visual field as they differ from distractor objects by a single feature such as color (e.g., a green square among red squares) making them easy to identify regardless of how many distractor objects are present. Conversely, conjunction search tasks are more difficult as the target shares multiple features, such as color and shape, with the distractor objects (e.g., a green square among a field containing red squares, red circles, and green circles; see Treisman, 1980).

using strings of repeating numbers (i.e., how many number are present vs. what is the value of the numbers present). In the non-switch condition, participants engaged in one task only (numerosity or value judgment); in the switch condition participants were to randomly switch between the two tasks on various trials. Prior to the start of each trial in the switch condition, a colored box appeared for 150ms that indicated the type of trial to be performed. Results suggest that, during switch tasks, older adults activated a larger percentage of the DLPFC and medial frontal cortex (MFC) than younger adults.

Following a task switch condition, older participants showed evidence of lingering switch costs while younger participants did not. Older individuals also showed significantly more DLPFC activation for both switch and non-switch conditions than younger individuals. Finally, during non-switch conditions, older adult individuals activated similar areas of the DLPFC and MFC that had been activated during switch tasks, while younger adults showed less extensive activation during non-switch conditions.

Collectively, these results were taken to suggest that older adults engage in more extensive neural activation, additional computation, and stronger reliance on executive function to ensure efficient and successful performance of cognitive processing compared to younger adults.

II. Sensory Decline

While alterations to global neurological processes may account for some of the age related differences observed between young and old individuals, consideration must also be given to age related changes associated with our dominant sensory systems. A large amount of the sensory information that is processed throughout our daily activities arrives through our visual and auditory sensory systems. Indeed it is widely accepted that

vision is the dominant sensory modality in humans (Chandra, Robinson, & Sinnett, 2011; Colavita, & Weisberg, 1979; Posner, Nissen, & Klein, 1976; Sinnett, Spence, & Soto-Faraco, 2007). Additionally, there is a wide range of studies indicating the importance of the auditory modality in humans, in some cases taking precedence over vision and often modulating visual perception (Burr, Banks, & Morrone, 2009; Giard, & Peronnet, 1999; Repp, & Penel, 2002; Robinson & Sloutsky, 2007, 2008, 2010; Shimojo, & Shams, 2001). However, individual sensory input is rarely, if ever, experienced in isolation. As a result our sensory systems are constantly integrating information from our visual and auditory (among other) sensory modalities to provide a coherent perceptual experience through multisensory integration (Calvert, Spence & Stein, 2004; Jones & Callan, 2003; Soto-Faraco, Navarra, & Alsius, 2004; Spence & Squire, 2003; Stein, Meredith, Huneycutt, & McDade, 1989). Given the importance of both auditory and visual stimuli it is necessary to focus on the age related changes that may affect information processing both within and across sensory modalities. The following sections will address such issues, focusing first on age related physiological changes to the visual system followed by an assessment of age related alterations to the auditory system with a final brief discussion on the effects of multisensory stimulus presentations on information processing for both young and older adults.

- i. Visual System

As mentioned earlier, the deterioration of the visual and auditory sensory systems across the lifespan might adversely influence information processing. For instance, anatomical changes in the visual system and corresponding oculomotor musculature may be correlated with decreases in cognitive processes involving visual perception and

response times (Scialfa, 2002). As aging occurs, changes in the structure of the eye can include: diminished pupil size and yellowing, reduced flexibility and increased opacity of the lens resulting in reduced amounts of light reaching the retina (Kashima, Trus, Unser, Edwards, & Datiles, 1993; Weale, 1961; Winn, Whitaker, Elliot, & Phillips, 1994). With regard to motor control of the eye, aging can result in attenuated control of the extra-ocular musculature (Doig & Boylan, 1989). Atrophy of these motor muscles may cause negative changes in both saccadic eye movements and smooth pursuit tracking.

Specifically, diminishment of pursuit gain may result in retinal slippage, which is then compensated for by increased saccades when a moving target reaches high velocities. Finally, fixation onset latencies are generally higher with reduced fixation accuracy when distractors are present between the current fixation point and saccade location target, suggesting that older adults may have diminished sensitivity in their visual periphery making target and distractor discriminations difficult (Huaman & Sharpe, 1993; Morrow & Sharpe, 1993; Scialfa, Hamaluk, Skaloud, & Pratt, 1999).

Neurological changes to the visual system associated with aging may also influence information processing of visual stimuli. Studies on humans, and other mammalian species, indicate that as age increases there is a reduction in the density of rod concentrations and retinal ganglion cell axons (Curcio, Millican, Allen, & Kalina, 1993; Gao & Hollyfield, 1992). Furthermore, event related potentials (ERP) suggest a decline in visually evoked P100 amplitude in an older adult sample, corresponding to the primary visual cortex, which becomes more pronounced for higher spatial frequencies (Bobak, Bodis-Wollner, Guillory, & Anderson, 1989) as well as a reduction in the amplitude of response to visual input and reduced segregation in the striate and

extrastriate cortices (Buckner et al., 2000; Grady et al., 1992). Taken together, it is apparent that these reductions in the visual sensory system will have adverse effects on the ability to effectively process visual information. Of note, reduction in pupil size and changes to the lens may result in reduced visuospatial information available and the information that can be processed may be less detailed as the visual stimuli become more complex (Crassini, Brown, & Bowman, 1988; Gittings & Fozard, 1986; Scialfa, Adams, & Giovanetto, 1991). Finally, due to the reduction in concentrations of rods and retinal ganglion cells, this decrease in visual input may be exacerbated under conditions of low luminescence (Sturr, Kline, & Taub, 1990), which may also adversely affect visual perception.

ii. Auditory System

Another essential sense for processing information is the auditory system. Unlike that of vision, *presbycusis*, or age related auditory decline, is nearly impossible to parse out from degradation resulting from noise damage, hereditary deficits, ototoxicity, or disease (Willott, 1991). Though the outer and middle ear are susceptible to age related change; the structural alterations incurred by these parts of the ear have minimal impact on sound perception (Willott & Lister, 2003). Of primary concern is the loss of sensory and support cells evidenced in a reduction of the inner and outer hair cells in the basal end of the cochlea. Age related hearing loss is also associated with complete atrophy of spiral ganglion cells throughout all three turns of the cochlea. This process can begin at any age; however hearing loss will not actually begin until the number of neural units lost results in a total population below the required amount for processing acoustic input (Schuknecht, 1989). Furthermore, atrophy of the stria vascularis, an ion transport and

control structure located in the cochlea, may reduce the generation of endocochlear electrical potentials (Marcus, 1986; Schuknecht et al., 1974). Finally, physical changes to the cochlea, as a result of atrophy, may also account for age related hearing loss. In this case, hearing loss may result from reduced elasticity to the basilar membrane or reduced attachment of the spiral ligament (Schuknecht & Gacek, 1993). Though there are many speculative causes for presbycusis, atrophy of the spiral ligament is the only structural alteration consistently seen in individuals with gradually sloping hearing loss as opposed to acute loss of auditory perception (Wright & Schuknecht, 1972).

III. Perceptual and attentional considerations associated with aging

i. Changes in unisensory attentional processes

So far, the focus of this thesis has been on age related alterations that may occur to global neurological processes and various physiological changes associated with decline, specifically in the visual and auditory sensory systems. However, as adults' progress into old age, attentional tasks become particularly difficult (Rabbitt, 1965). This decrement in attentional control may be related to a variety of structural and functional changes, which might adversely affect processing of perceptual stimuli. For example, neuroimaging studies conducted by Kastner et al. (1999) suggest that covert attention directed toward peripheral spatial locations is associated with increased BOLD signals in both the parietal and prefrontal regions. This study also found evidence indicating that the onset of a direct visual display may lead to increased activity in the extrastriate cortex, a brain region associated with visual processing, but not in the parietal and prefrontal regions, suggesting that these regions are associated with attentional operations rather than higher level visual perception. Of critical importance, investigations suggest that the

parietal and prefrontal brain regions show evidence of age related decline (Azari et al., 1992; de Leon et al., 1987; Kuhl et al., 1982).

With regard to selective attention (i.e., selecting a stimulus of interest and focusing attentional resources toward it while inhibiting irrelevant information) Farkas and Hoyer (1980) used a card-sorting version of a visual search task and found that older adults showed differential slowing in task performance when presented with a distractor card that was similar to the target, compared to distractors that were dissimilar to the target card. Along this same vein, studies of selective attention in older adults suggest that top-down control over attentional allocation is impaired compared to younger adults when viewing displays containing moving items (Folk & Lincourt, 1996; Watson & Maylor, 2002) making it more difficult for older individuals to visually mark the target stimulus (Watson & Humphreys, 1997; 1998) when the objects are moving. As a result, older adults are less able to inhibit the processing of previously viewed distractor objects such that they continue to capture attention during the visual search task, thereby negatively impacting perception of the target stimulus.

Investigations into task-switching have aimed at assessing age related changes associated with attentional control specifically related to allocation of attention toward multiple concatenated tasks or skills. Older adults tend to exhibit longer reaction times (RT) when engaging in activities that require switching attention between two different types of tasks compared to performing the same simple task multiple times in a row (Kray & Lindenberger, 2000; Mayr, 2001). Studies conducted by Mayr (2001; see also, Hahn, Andersen, & Kramer, 2004) suggest that this age related degradation might be associated with a decline in frontal lobe function, which may be more affected by aging.

Related to task-switching, dual-task performance requires the rapid switching of attentional resources between two or more events that co-occur, or occur in very close temporal succession. Studies into how this form of attentional control might change as we age are of particular importance because dual-task paradigms are representative of complex coordinative behavior typical of real-world activities, which often require simultaneous computation. When assessing dual-task performance in both young and old adults, psychological refractory period (PRP; see Telford, 1931) paradigms are typically used. Here, participants are instructed to perform two tasks, or quickly respond to two different types of stimuli, on the same trial using a very short delay between stimulus presentations (a matter of milliseconds). Participants respond to one type of stimulus first (Target 1) and then respond to a second stimulus (Target 2) after a very short delay (~100ms). The time between the targets is referred to as the stimulus onset asynchrony (SOA), though the time it takes to *respond* to the first target often overlaps with presentation of the second target (see Figure 1a). The PRP is the time point in which response to the second target is significantly delayed, which is likely due to the processing of the response being made to the first target. Evaluating the RT lag associated with the second target provides an estimate of the central processing time necessary to respond to the first target (see Figure 1b). Typically, in both young and old individuals, RT to the second target is increased when the SOA is very brief, however older individuals show longer lags to the second target relative to younger participants (Allen, Smith, Vires-Collins, & Sperry, 1998; Glass et al., 2000; Hartley, 2001; Hartley & Little, 1999). Glass et al. (2000) concluded that such age related differences might be a result of three potential factors. First, RT differences may be attributed to a general

slowing of information processing. Second, a reduction in perceptual identification of presented stimuli, and third, a more cautious task coordination strategy employed by older adults.

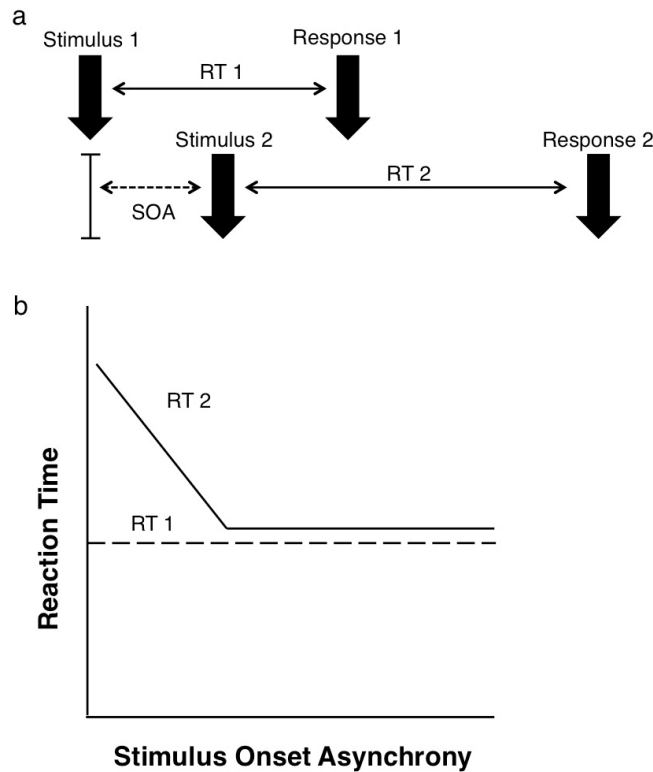


Figure 1 – Psychological Refractory Period: (a) Schematic representation of the psychological refractory period (PRP). Note that RT2 is longer than RT1. (b) Graphical depiction of delayed response to Stimulus 2 as a function of decreased SOA between Stimulus 1 and Stimulus 2. See text for details.

Along a similar vein to PRP paradigms, the attentional blink (AB) paradigm has also been used to study attentional capacity (Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1997). In this paradigm, participants are presented with a rapid serial visual presentation (RSVP) stream containing two target items (T1 and T2) separated by a varying number of distractor items. Participants are required to monitor

the target stream for both targets. Immediately following the presentation of each trial, participants report the identity of T1 and the presence of T2. When the presentation time between T1 and T2 is very short (200-600ms), the identification of T2 is markedly impaired in younger adults (provided that participants correctly identified T1).

Maciokas and Crognale (2003) conducted a version of the AB paradigm with older and younger adults in order to assess potential age related differences. Participants were shown an RSVP stream of distractor digits with two target letters inserted into the stream, T1 appeared as a red uppercase letter and T2 appeared as a green uppercase letter. T2 could appear at an interval ranging from lag 1 (immediately after T1 in the RSVP stream) to lag 10 (i.e., with nine distractor numbers between presentation of T1 and T2) with the shortest SOA (lag 1) lasting just 118-ms and the longest SOA (lag 10) lasting 1180-ms. In the single task condition participants were instructed to ignore T1 and verbally report only when they saw T2. In the dual-task condition, participants were instructed to verbally identify both targets.

Results from the single task condition suggest that older individuals are less able to inhibit the processing of T1 despite being told to ignore it. This finding suggests that older individuals might have more difficulty inhibiting the first target when necessary. For the dual-task condition, older individuals showed marked attentional blink, compared to younger participants, with increased deficits found at all lag times. The most pronounced attentional blink interference for older adults occurred between lags 2 – 5, compared to young participants. Combined, these results clearly suggest an impaired ability to ignore irrelevant items and focus attention on target items for the older adult group.

ii. Changes in multisensory attentional processes

Multisensory presentations have been shown to enhance performance in cognitive tasks such as visual perception (McDonald, Teder-Sälejärvi, & Hillyard, 2000; Van der Burg, Olivers, Bronkhorst, & Theeuwes, 2008), haptic space perception (Zuidhoek, Visser, Bredero, & Postma, 2004), and reduce physiological RTs to stimuli when compared to unisensory presentations alone (Rowland, Quessy, Stanford, & Stein, 2007). These improved responses are likely due to the possible existence of individual attentional resources for each sensory modality (Duncan, Martens, & Ward, 1997; Sinnott et al., 2006; Soto-Faraco & Spence, 2002; Wickens, 1984).

Research investigating potential age related changes associated with multisensory integration provide mixed results. There is evidence to suggest that older adults may experience reduced multisensory integration. For instance, Helfer (1998) found that older adults were less able to identify conversational sentences presented audiovisually compared to young adults, while there was no difference in sentence identification for audio only presentations. This suggests that older adults may have a reduced ability to integrate auditory and visual signals in speech perception. However, other research would suggest that young and older adults integrate multisensory information in a similar manner. Work conducted by Cienkowski and Carney (2002) using the McGurk effect with young and older individuals suggest that there are no significant differences in multisensory integration for auditory and visual speech perception between these two age groups. Still other studies found that multisensory integration appears to in fact enhance cognitive performance in older adults and that this enhancement occurs to an even greater

extent than has been observed in younger populations (Laurienti, Burdette, Maldjian, & Wallace, 2006; Mahoney, Li, Oh-Park, Verghese, & Holtzer, 2011; Peiffer, Mozolic, Hugenschmidt, & Laurienti, 2007). In line with this, multisensory integration may even be utilized to improve balance for older individuals (see Hu & Woollacott, 1994a, 1994b).

Laurienti et al. (2006) examined the benefits of multisensory integration by presenting both young and old individuals with a two-alternative forced choice speeded discrimination task. During each trial, participants were presented with either a visual only, auditory only, or multisensory (audiovisual) stimulus. Visual stimuli were either a red or a blue circle presented at fixation on a black background; auditory stimuli were recordings of the words “red” or “blue” presented for 350ms; multisensory stimuli were bimodal presentations of the auditory word paired with the corresponding color circle. Participants were to make one response if the presented stimulus (regardless of modality) was red and another response if the presented color was blue. Accuracy was similar for both young and old individuals. Interestingly, while all participants were significantly faster to respond during multisensory presentations for both red and blue stimuli, older individuals showed significantly greater reductions in response time (13.5%) compared to younger adults (8.3%). Furthermore, when presented with multisensory stimuli, older participants response times were decreased (537ms) such that they were equal to that of fastest unisensory (visual) response times for young participants (538ms).

These results were taken to suggest that older adults exhibit greater benefits from multisensory facilitation and a broader window of enhancement than younger individuals. The dramatic increase in multisensory RTs for older adults was also taken to suggest that

the benefits of multisensory presentation could potentially be so robust for older individuals that it may restore information processing speeds comparable to those observed in unisensory (i.e., visual) processing in young adults. According to Laurienti et al. (2006), it is possible that such enhancements may be due to older individuals being more adept at exploiting the redundant nature of multimodal cues. This may be due to the fact that older individuals tend to exhibit unimodal decrements, which may result in greater reliance on available multimodal cues as a coping mechanism.

3. Theories of attentional decline in older adult populations

Understanding how changes in cognitive processing may affect the perception of sensory information is crucial for disentangling the effects of aging on attention mechanisms. There are a number of theories regarding the underlying cause of attentional decline in older individuals; the following sections will address two proposed theories, specifically, the processing speed theory (Salthouse, 1996) and the inhibitory deficit theory (Hasher & Zacks, 1988).

II. Processing speed theory

Salthouse (1996) suggested that age related attentional decline is a result of generalized slowing of information processing. Wang, Fu, Greenwood, Luo, and Parasuraman (2012) supported this notion using both behavior and neurological measurements. Their experiment used a combination of endogenous cueing² and visual search tasks to assess attentional control under conditions of high or low working memory load. Participants were presented with two visual search displays, one on either

² Endogenous, or central, cues are presented in the center of the screen, usually at or just above fixation in the form of an arrow or other directionally relevant symbol. This type of cueing relies on top-down attentional control in that the individual is in control of the direction of their attention (Posner, 1980).

side of a fixation cross. Next, a predictive (75% validity) endogenous cue was presented for 500ms just above fixation in the form of an arrow pointing to either the left or right visual field. After a short delay, either the left or right visual field would briefly (150ms) present an array of four angled lines, two horizontal (“-”), one vertical (“|”), and one diagonal either facing forward (“/”) or backward (“\”). For each trial, the probability that the diagonal line would face forward or backward was equal. Participants were instructed to locate and respond to the diagonal line in the array. For each trial, the endogenous cue could be congruent (i.e., point toward the box in which the array appeared) or incongruent (i.e., point toward the box opposite of the array). In low-load conditions, all lines except the target diagonal line were segmented into 10 fragments in their respective quadrants, making the diagonal line “pop-out” of the array; in high-load conditions, all lines were intact (see Figure 2). Event related potentials (ERP) were also measured.

Behavioral results indicated that RT decreased and accuracy increased for congruent trials with the highest performance increases occurring for congruent, low-load trials. For both high and low-load trials, young participants were significantly faster and more accurate than older participants, with age related effects on accuracy being the most pronounced in the high-load conditions. The results were taken as reflections of generalized slowing of information processing in the older adults (Wang et al., 2012).

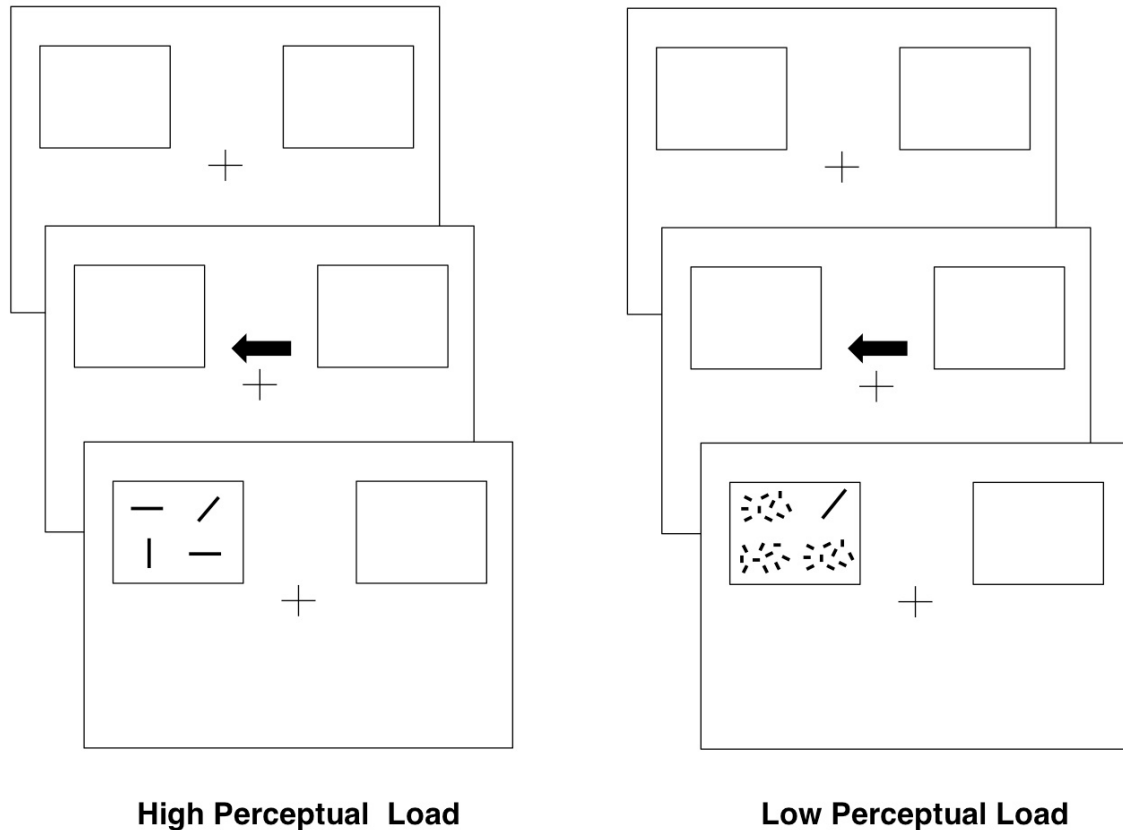


Figure 2 – Example of Stimuli in Wang et al. (2012): Schematic representation of congruently cued high perceptual load and low perceptual load conditions. See text for details.

Behavioral results comparing the two age groups were supported by the ERP findings, as they suggested a later N1 latency for older adults. This suggests that older participants required more time to localize the target line in the visual arrays for both high and low load conditions compared to the young participants. In addition to the processing delay suggested in older adults, Wang et al. (2012) found that older individuals exhibited larger N1 amplitude compared to young adults under conditions of higher perceptual load. An increase in N1 amplitude has been suggested to reflect a difficulty of target discrimination (Vogel & Luck, 2000). Therefore, the increase in N1

amplitude was taken here to suggest that older adults experienced increased difficulty compared to younger participants in discriminating the target from distractors during high load conditions. This may be due to a possible reduction in processing capacity, leading to poorer performance on target discrimination seen in the behavioral results. Overall, results were interpreted to suggest that, as we age, the speed at which early perceptual information is processed declines and that this decline affects stimulus discrimination. Furthermore, they assert that increased perceptual load modulates attention, which varies with age, as evidenced in differing neural patterns between young and old participants under conditions of high-load (Wang et al., 2012).

Another type of methodology employed when looking for behavioral evidence suggestive of a slowing of information processing is the use of Brinley plots³. This is a statistical method for demonstrating that, over a wide variety of cognitive tasks, changes in RT associated with task performance varies at an increasing interval as a function of age, to an extent greater than would be predicted by chance (Brinley, 1965). For any given task in which RT is recorded, the mean RT performance for older adults is plotted as a function of the complimentary mean RT performance for younger counterparts on that same task. RT is then plotted as the dependent variable with age and task type as independent variables, allowing for regression analyses to be conducted. When this is done, differences in RT performance between younger and older adults yields a highly linear, and in some cases a monotonic, relation between condition and age group (see

³ It should be noted that when interpreting age differences in performance, the use of Brinley plots is widely debated. One major consideration lies in the fact that a wide variety of tasks are used and the plotted values come from two groups (young and old) with unequal variance, which may be more or less severe depending on the task. Furthermore, the RTs plotted are averaged means, which do not take into account the shape of the RT distribution for each age group, potential speed-accuracy trade offs, or speed on correct and error responses. As such, the extent that Brinley plots can contribute to theoretical considerations regarding age-related differences in processing speed is questioned because they arguably represent an incomplete analysis of the underlying elements associated with RT differences (Ratcliff, Spieler, & Mckoon, 2004).

Figure 3). That is, over a wide range of cognitive tasks, older adults reliably show longer RTs than their younger counterparts. This difference is taken as evidence of generalized age-related slowing of perceptual information processing (Cerella, 1985, 1990).

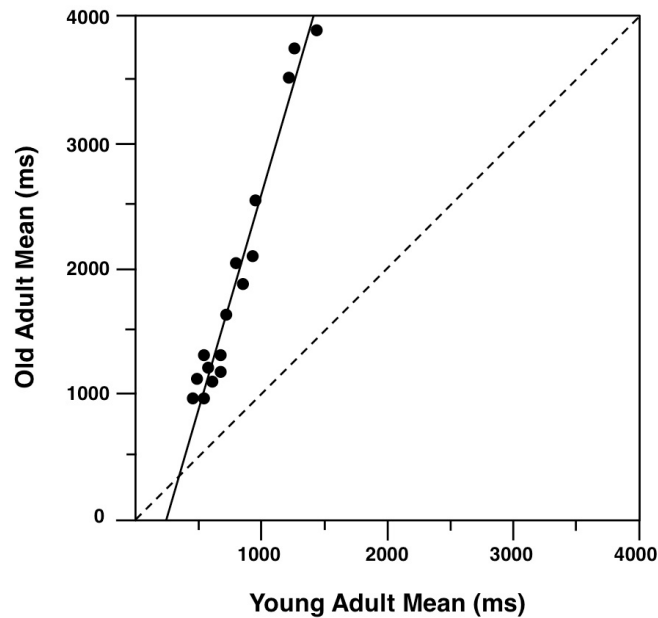


Figure 3 – Brinley Plot: Schematic representation of a linear relationship between young and old participant RTs graphed in a Brinley plot. The dashed line represents a one-to-one ratio between young and old participant RTs (i.e., the line of best fit the Brinley plot would take if there were no difference in RTs between the two age groups). The solid line is the line of best fit for the observed Brinley plot, illustrating the overall slower RT exhibited by older adults. Note the increased RT on any given task (expressed as a data point) for older adults compared to younger adults.

II. *Inhibitory deficit theory*

An alternative theory, initially presented by Hasher and Zacks (1988), suggests

that, in addition to a generalized slow down in information processing, age related attentional deficits could be explained from the perspective of reduced inhibitory function. Hasher and Zacks posit deficiencies occur in inhibitory function, which operates at encoding, to mediate the range of contents that has access to working memory. This diminishment in inhibitory control results in an “enriched” memory due to the fact that fewer stimuli are excluded at the onset of perceptual processing.

Furthermore, irrelevant stimuli that are selected receive richer processing because they will not be as effectively inhibited once they have entered into working memory (Hasher & Zacks, 1988). At first glance this might sound like a benefit, however it leads to difficulties in information processing as irrelevant stimuli that should otherwise be inhibited compete for a limited supply of attentional resources. In line with this theory, Carlson, Hasher, Connelly, and Zacks (1995) found that older adults were slowed to greater extents than their younger counterparts while reading aloud when distractions are randomly inserted into the text. Further investigating inhibitory control, Lustig, Hasher and Tonev (2006) assessed information processing speed in the presence of distractors. Young and old participants were presented with pairs of strings of letters, which varied in length ranging from strings of three, six, and nine letters long (e.g., RXL___RXL) and asked participants to determine if the letter strings were the same. In conditions of low distraction, each letter string was presented one at a time; in conditions of high distraction participants viewed the letter strings as pairs in two columns on the screen (see Figure 4). Lustig et al. (2006) found that the high distraction condition slowed older participants’ RTs by over 15% compared to low distraction conditions, while younger adults showed no difference between the two conditions. Results from both studies were taken to

suggest that older adults might be less able to ignore distractors and inhibit irrelevant information from accessing attentional focus, thereby slowing RTs.

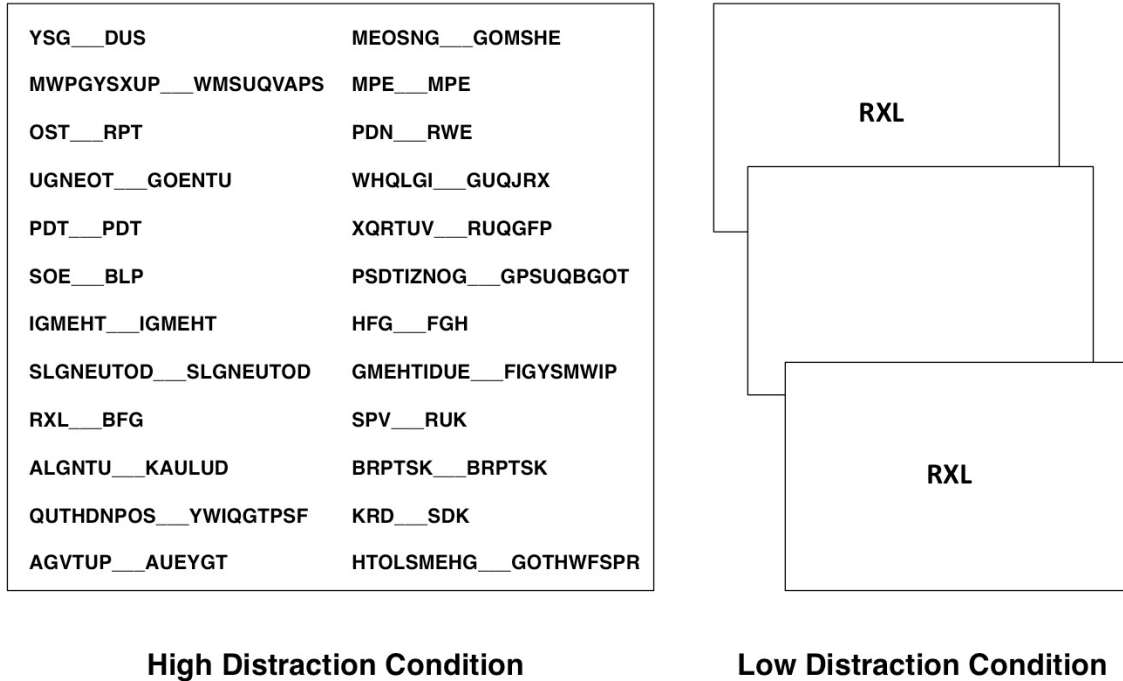


Figure 4 – Example of Stimuli in Lustig et al. (2006): Pictorial representation of high and low distraction conditions of letter string identification task.

In a further examination of inhibitory control in aging populations, McDowd and Filion (1992) measured habituation tendencies exhibited through skin conductance. Young adults (average age of 19 years) and old participants (average 73 years old) were presented with a 25-minute recording of a radio play. During the auditory play, experimenters inserted a series of 20 tones playing at an irregular interval. In the ignore condition, participants were instructed to ignore the tone series and focus on the story; in the attend condition, participants were instructed to ignore the story and focus on counting the tones. Skin conductance and heart rate were monitored for signs of

inhibitory control over processing of the tone series. Evidence for successful inhibition was measured as a reduction in skin conductance orienting response (SCOR), a gradual decrease in skin conductance and heart rate, in reaction to the irregular tone series.

McDowd and Filion (1992) found that younger participants habituated significantly faster to the unattended tone stream than older adults (3 tone presentation vs. 17 respectively).

Furthermore, younger participants exhibited significantly lower SCOR magnitudes in the ignore condition compared to the attend condition, while older adult participants showed no difference between the two conditions. Collectively, this data was interpreted to suggest that older adults exhibited a compromised ability to inhibit responses to irrelevant stimuli, which could then lead to age related deficits in selective attention (McDowd & Filion, 1992).

Proponents of the inhibitory deficit theory of cognitive aging (see for example, Hasher & Zacks, 1988) assert that age related differences seen in behavioral performance are due to a reduced ability to inhibit irrelevant information in many cognitive tasks, specifically those associated with working memory (May, Kane & Hasher, 1995; Zacks, 1989). The most compelling evidence to support this perspective has come from work with the classic Stroop task, in which participants are presented with written color words (“red,” “blue,” “yellow” etc.). In the incongruent condition the written color words are presented in an incongruent color (e.g., the word “yellow” presented in the color red) and in the congruent condition the written color words and presented color are matched (e.g., the word “yellow” presented in the color yellow). Critically, participants must inhibit the compulsion to read the word (yellow) and report only the color (red, i.e., incongruent) for both conditions. When doing so it has been demonstrated that response latencies increase

and more errors are made in the incongruent condition when compared with the congruent condition. Critically, when comparing performance on this task between younger and older adults the tendency to incorrectly report the word rather than the color 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.

Some have argued that a limitation of this theory is that such reported differences between younger and older populations could be explained by the generalized slowing of information processing (see section 3.1; Verhaeghen & De Meersman, 1998). However, a closer look at the aforementioned study shows that age-related slowing was a factor taken into consideration, but was unable to account for all observed differences in performance (Brink & McDowd, 1999). Though it is true that older adults tend to exhibit slower RTs on incongruent trials, the higher tendency for older adults to incorrectly report the semantic word, rather than the color the word is written in, provides compelling evidence in favor of reduced inhibitory control over irrelevant information, which may occur concurrently with a general slowing of information processing (Brink & McDowd, 1999; Spieler, Balota & Faust, 1996).

Milham et al. (2002) conducted further work with the Stroop task toward investigating attentional control in aging adults using fMRI. Along with typical behavioral results of moderately longer RTs and 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). These brain regions are believed to modulate 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 or attenuates activation of semantic and phonological associations and actions with the irrelevant information (Banich et al., 2000b). Furthermore, Milham et al. (2002) found evidence to suggest that older adult patients have decreased DLPFC activity and increased posterior activity such as the ventral visual processing stream. As the need for attentional control increases with task difficulty, activation of the parietal cortex was less pronounced for older compared to younger participants. However, parietal activity increased as older participants became more practiced with the task, suggesting that recruitment for this region may become more difficult or slower to come online with age (Milham et al., 2002). Although there is evidence to suggest that information processing may incur a global reduction with age, it is possible that a reduction in inhibitory *and* facilitatory attentional control may be a complimentary form of cognitive decline as we age. Next, current research on these attentional mechanisms and what is known about the nature of facilitation and inhibition of information processing in healthy young adults will be considered.

4. Current research on inhibitory and facilitatory attentional mechanisms

To date, a rapidly growing body of literature has collected a wealth of information, using healthy young adults, regarding some of the properties surrounding inhibitory or facilitatory mechanisms by examining the processing rates of irrelevant information. Initial research suggested that facilitation or inhibition was dependent on

whether an irrelevant target item was presented either below or above (respectively) the threshold for explicit awareness. For instance, seminal research by Watanabe, Náñez, and Sasaki (2001) presented participants with an attention demanding target identification task in which they were required to identify a grey letter amongst a string of black letters presented in a rapid serial visual presentation (RSVP) in the center of the screen. While engaged in this task, participants were simultaneously exposed to a dynamic random dot (DRD) display, presented in a black circle around the target letter identification task. In the DRD display a small subset (5%) of the dots moved coherently in one of eight possible directions while the rest of the dots moved randomly around the display. One coherent motion direction was randomly assigned to each participant and the direction was held constant throughout the experiment. Importantly, this small subset of motion coherence was below threshold for visual perception, meaning that participants could not tell that a subset of dots moved in one coherent direction while the others moved at random. Participants were instructed to ignore the moving dots and focus on the letter identification task.

After this exposure stage, participants were presented with a motion identification task in which they were required to identify the direction of moving dots in a similar DRD display. Here, the subset of coherently moving dots was slightly higher (10%) to ensure that detection of motion coherence was perceptually possible. Participants were significantly better at later detecting coherent motion directions in the DRD displays that moved in the same direction as the motion presented during the exposure stage of the experiment compared to the motion directions to which they were not exposed.

These findings were extended in a later study conducted by Seitz and Watanabe (2003) in which participants were presented with the same DRD display and RSVP letter identification task. The crucial difference here is that during the exposure stage of this experiment, participants were presented with four different coherent motions an equal number of times. Each time the target letters appeared in the RSVP stream the dots moved in the same 5% coherent motion direction and while the black distractor letters were presented the dots moved in one of the other three predetermined coherent directions. Performance on the later motion detection task revealed that recognition was significantly higher only for the motion direction that appeared in temporal alignment (i.e., target-aligned) with the target grey letters in the RSVP stream compared to the motions that were not target-aligned; that is, those motions paired with black non-target letters (i.e., non-aligned). Together, these results were taken as evidence that processing of ignored, task-irrelevant, stimuli is facilitated provided that exposure is frequent and the ignored stimuli appear in temporal alignment with an item that is being attended. This leads to learning effects for the ignored, irrelevant, information, provided that it is originally presented below awareness while in synchronous temporal pairing with an attention demanding target task.

Given that Watanabe et al. (2001) and Seitz and Watanabe (2003) found facilitation for motion presented at subthreshold levels, a naturally ensuing question would be what happens with suprathreshold presentations using the same paradigm. This question was addressed by Tsushima et al. (2008), who systematically varied the salience of the target-aligned, but irrelevant, motion coherence in an attempt to determine the effects of stimulus saliency on information processing of ignored items. Here, on half of

the trials, participants were exposed to dots moving with 5% coherence in one direction when a target grey letter was presented, and on the other half of the trials the dots moved with 50% coherence in a different direction when there was a target grey letter.

Remarkably, when participants were later presented with the motion detection tasks, facilitation was still seen for the subthreshold motion direction but later recognition for the motion directions initially presented at 50% coherence was inhibited. This finding was taken to suggest that when task-irrelevant stimuli are presented in synchronous temporal pairing at a salience level that is *above* the threshold for explicit awareness, initial processing of the irrelevant information might be inhibited resulting in drastic reductions in later recognition of the irrelevant stimuli.

One criticism of this work was that stimuli such as motion and individual letters are perceptually simple, leading others to consider if the same rates of inhibition would be seen for semantically rich items. Recently, Dewald et al. (2011) extended this work with a more complex and salient stimuli, by utilizing a procedure employed by Rees et al. (1999; see also Sinnott et al., 2006). In this experiment, participants viewed a RSVP stream of line drawn pictures with words superimposed on top of them. Participants were required to attend to the picture stream and identify an immediate picture repetition while ignoring the superimposed words. After this repetition detection task, participants were given a surprise recognition test in which they were asked to identify a series of words from the experiment intermixed with novel foil words. Similar to the results obtained by Tsushima et al. (2008), words that were temporally aligned with picture repetitions were recognized at levels significantly *below* chance when compared with non-aligned words, which were recognized at chance levels. This finding suggests that the processing of the

target-aligned words was actually inhibited and that this inhibition of information processing was significantly higher for words that appeared with task relevant targets compared to other words that were equally salient, and presented an equal number of times. These findings have also been extended to the auditory modality. For instance, while performing an isomorphic version of this experiment presented aurally, Dewald and Sinnett (2011) found inhibited processing of target-aligned spoken words paired with target sound repetitions in a sound stream.

In order to more closely parallel previous investigations which only presented a single, frequently occurring, unchanging motion with the target tasks (see Tsushima et al., 2008; Watanabe et al., 2001, 2003), Dewald et al. (2012) reduced the total number of presented words such that there were eight words total and only one unchanging word (i.e., analogous to the single unchanging motion used in Watanabe et al., 2001) was paired with picture repetitions in the RSVP stream. This was done to mimic the eight motion directions that were used (see Watanabe et al., 2001), resulting in frequent and equal exposure to the irrelevant stimuli. After completing the identification task, participants later recognized both target-aligned and non-aligned words at levels significantly *above* chance. Moreover, recognition for target-aligned words was significantly higher than non-aligned words. Therefore, rather than inhibiting information processing of irrelevant items as would have been expected based on findings by Tsushima et al. (2008), frequent exposure to complex stimuli during an attention demanding task resulted in facilitation for those items, with the highest rates of facilitation observed for items that had appeared with task relevant targets (i.e., target-aligned words). These findings suggest that, in addition to explicit or implicit

presentations and synchronization with an attended target, the rate of exposure is also a critical element in understanding how irrelevant but target-aligned items are processed.

Collectively, this body of research has demonstrated several important elements leading to either the facilitation or inhibition of unattended information. First, regardless of whether information is presented above or below the threshold for explicit perception, inhibitory mechanisms work to filter out irrelevant information under conditions of infrequent temporal pairing with an attention demanding target task. Second, this inhibition occurs for target-aligned items over equally salient information that is presented in temporal alignment with items to which attention is directed, but not acted upon. Third, under conditions of frequent temporal pairing with attended items that are responded to, unattended subthreshold (Seitz & Watanabe, 2003; Tsushima et al., 2008; Watanabe et al., 2001) or suprathreshold (Dewald et al., 2012) information can still be processed and later recognition for these items can be facilitated.

In sum, the crucial element to the facilitation or inhibition of unattended items appears to be the rate of temporal alignment between the ignored information and a concurrently presented item to which attention is directed and requires a response. This is rather telling when considering the way in which inhibitory control is executed in daily activities. When processing perceptual input, infrequently presented information may carry less excitatory weight and therefore be easier to suppress when it is not pertinent to a current task. Conversely, frequently occurring stimuli that are presented with items to which attention *is* being directed may excite more processing pathways despite the execution of inhibitory control. It is possible that this frequent exposure causes a

perceptual window resulting in an attentional boost (Dewald et al., 2013; Swallow & Jiang, 2010) for the ignored items.

5. Inhibitory and facilitatory attentional mechanisms in cognitive aging

II. Purpose

The research outlined in this thesis extended the paradigm used by Dewald et al. (2011, 2012, see also Rees et al., 1999) to an older adult population. Previous work with healthy young adults (Dewald et al., 2011, 2012; Seitz & Watanabe, 2003; Tsushima et al., 2008; Watanabe et al., 2001) provides a framework regarding the conditions under which inhibitory and facilitatory control can be modulated. Given that much research has indicated that inhibitory processes could be adversely affected in the aging process (see Brink & McDowd, 1999; Carlson et al., 1995; Hartley, 1993; Hasher & Zacks, 1988; Lustig et al., 2006; McDowd & Filion, 1992; Milham et al., 2002; Spieler et al., 1996), it is likely that age related differences in inhibitory function might be observed using this paradigm as well. However, there remains a paucity of information on facilitatory control in older populations, therefore this paradigm also offers the opportunity to explore how this mechanism might differ between younger and older adults.

The Stroop task is obviously a favorite choice among those investigating the modulation of inhibitory attentional mechanisms with an aging population because participants must simultaneously facilitate processing of the written word color (i.e., say “red” if the word “yellow” is written in red) while at the same time inhibit the processing of the semantically written word (i.e., “yellow”). However the current paradigm offers several advantages over the Stroop task. First, when using the Stroop task, it is difficult to isolate facilitatory from inhibitory mechanisms. As such, it is difficult to tell which

mechanism is failing when Stroop interference occurs because this paradigm does not offer an effective method for dissociating facilitation from inhibition. Instead, the proposed paradigm overcomes this obstacle by varying the frequency of words and picture repetitions, which allows for the isolation of both inhibitory and facilitatory mechanisms.

The experimental design adopted here also makes it possible to test in both the visual and auditory modalities, meaning that the stimuli can be presented in the auditory modality by replacing the pictures with auditory sounds presented simultaneously with spoken words. In this case, future research could require participants to attend to the sound stream while ignoring the spoken words. Finally, this methodology allows for the possibility of exploring attentional mechanisms from a multimodal perspective by varying the modality presentation of the attended and unattended information streams. For example, participants can be presented with a visual stream of pictures in which they must identify picture repetitions while being presented with corresponding spoken words, which they are to ignore. Conversely, an auditory stream of sound can be presented while participants view a corresponding stream of written words on the computer screen.

To begin initial investigations into inhibitory and facilitatory mechanisms in cognitive aging, the following experiments were conducted. The first experiment was designed to extend the findings of Dewald et al. (2011) to an older adult sample, and thereby assess inhibitory processes in this age group. Experiment 1 utilized the *short exposure* paradigm, in which each picture repetition in the primary task is paired with a different target-aligned word. This pairing results in infrequent exposure to the task-irrelevant stimuli allowing for the examination of inhibitory processes in both young and

older individuals. This approach has direct implications in the debate as to whether observed age related differences in performance are more likely linked to a generalized slowing of global information processing (Salthouse, 1996), or a decline in inhibitory control (Hasher & Zacks, 1988).

If any observed performance differences are due to a generalized slowing of global information processing, then an increase in RTs during the primary task of identifying repetitions would be expected in older adults compared to the young adults. A generalized slowing may also lead to a reduction in primary task accuracy for older adults compared to younger adults because information processing and subsequent reactions may be too slow to respond to the target picture-repetition during the appropriate response window. Thus, the generalized slowing of global information processing would hypothesize that older adults will have significantly slower RTs and poorer performance on the primary task compared to younger adults. While it is expected that older adults will also have overall slower RTs on the surprise recognition test, the pattern in recognition rates (i.e., inhibition) should not differ between the two age groups. Therefore, it is hypothesized that both young and old participants should show significantly *lower* recognition rates for target-aligned words compared to non-aligned words, meaning that the amount of inhibition should be equal between age groups. It is also expected that this pattern of inhibition will be reflected in participant RTs during the surprise recognition test. Meaning that while older adults should have significantly slower RTs, overall, both older adults and young adults are expected to exhibit slower (i.e., inhibited) RTs to the target-aligned words compared to the non-aligned words during the surprise recognition test.

Conversely, if any observed differences in performance between the age groups are the result of a decline in inhibitory control then a different pattern in the results would be observed. Performance in later recognition rates between the target-aligned and non-aligned words (i.e., inhibition) should be different, with older adults experiencing less inhibition (i.e., more similar accuracy scores between word types) compared to the young adults. With regard to RTs, inhibitory control theory (Hasher & Zacks, 1988) does not deny a general slow down in information processing, but also attributes cognitive decline to a dysfunction in inhibitory control, therefore the same trend that was predicted by processing speed theory (Salthouse, 1996) should still be expected here (i.e., overall slower RTs and poorer performance during the primary task as well as overall slower RTs during the surprise recognition test). However older adults should not show a significant difference in RT between target-aligned and non-aligned words, which would indicate a decline in inhibitory control, while this pattern is still expected among the younger adults. Therefore, if older adults experience a decline in inhibitory control, it is hypothesized that when participants are exposed to a large number of target-aligned words (see again, Dewald et al., 2011), recognition rates between target-aligned and non-aligned words should be relatively similar, and possibly near chance, for older adults, while young adults should exhibit significantly lower recognition rates for target-aligned words compared to non-aligned words and chance (i.e., an increased inhibition for these words) (see Table 1).

<i>Experiment 1: Inhibition</i>	<i>Processing Speed Theory</i>	<i>Inhibitory Deficit Theory</i>
<i>Primary Task</i>	<ul style="list-style-type: none"> • Slower RTs among older adults • Poorer performance among older adults 	<ul style="list-style-type: none"> • Slower RTs among older adults • Poorer performance among older adults
<i>Recognition Test</i>	<ul style="list-style-type: none"> • Slower RTs among older adults • Inhibited recognition and RT for target-aligned words compared to non-aligned words in young adults • Inhibited recognition and RT for target-aligned words compared to non-aligned words in older adults 	<ul style="list-style-type: none"> • Slower RTs among older adults • Inhibited recognition and RT for target-aligned words compared to non-aligned words in young adults • Similar recognition rates and RT for target-aligned and non-aligned words in older adults (i.e., less inhibition)

Table 1 – Predictions for Experiment 1: Predicted outcomes for young and old adults in Experiment 1 according to processing speed theory (Salthouse, 1996) and inhibitory deficit theory (Hasher & Zacks, 1988). Note the major differences in predictions from these two theories occur in how older and younger adults will respond to target-aligned and non-aligned words during the surprise recognition test.

Experiment 2 was designed to assess the facilitatory mechanisms observed by Dewald et al. (2012) in an older adult sample. This experiment utilized the *long exposure* paradigm. Here, the experiment contained only eight words total with one word selected to be target-aligned with picture repetitions in the primary task. This pairing results in

very frequent exposure to the task-irrelevant stimuli, which will allow for the examination of facilitatory mechanisms in both young and old participants. The literature on how the aging process may affect facilitatory mechanisms is lacking, however, this approach will also allow for specific hypotheses to be made regarding whether observed age related differences in performance are more likely linked to a generalized slowing of global information processing (Salthouse, 1996) or, rather, a decline in facilitatory control, which is also possible.

As before, if any observed performance differences are due to a generalized slowing of global information processing, then older adults should exhibit similar performance during the primary task of identifying repetitions as predicted in Experiment 1 (i.e., a reduction in task speed and overall accuracy for older adults compared to younger adults). The main difference here is that facilitation (rather than inhibition) for the target-aligned words should be observed in both age groups in the surprise recognition test. Therefore, it is hypothesized that both young and old participants should show significantly *higher* recognition rates for target-aligned words compared to non-aligned words and chance, meaning that the amount of facilitation should be equal between age groups. Again, while overall slower RTs are expected for the older adults, both age groups are expected to exhibit faster (i.e., facilitated) RTs to the target-aligned words compared to the non-aligned words during the surprise recognition test.

While research regarding facilitatory attentional mechanisms in older adults is lacking, it is possible that they may experience age related decline in this area as well. Therefore, if older adults experience a decline in facilitatory control, it is hypothesized that when participants are exposed to a single, unchanging, target-aligned word (see

again, Dewald et al., 2012), recognition rates between target-aligned and non-aligned words should be relatively similar for older adults, while young adults should exhibit significantly higher recognition rates for target-aligned words compared to non-aligned words and chance (i.e., an increased facilitation for these words). Again, overall slower RTs and poorer performance during the primary task as well as overall slower RTs during the surprise recognition test are still expected. However, there should be no significant difference in RT between target-aligned and non-aligned words for the older adults, while this finding is expected among the younger adults (see Table 2).

<i>Experiment 2: Facilitation</i>	<i>Processing Speed Theory</i>	<i>Facilitatory Deficit</i>
<i>Primary Task</i>	<ul style="list-style-type: none"> • Slower RTs among older adults • Poorer performance among older adults 	<ul style="list-style-type: none"> • Slower RTs among older adults • Poorer performance among older adults
<i>Recognition Test</i>	<ul style="list-style-type: none"> • Slower RTs among older adults • Facilitated recognition and RT for target-aligned words compared to non-aligned words in young adults • Facilitated recognition and RT for target-aligned words compared to non-aligned words in older adults 	<ul style="list-style-type: none"> • Slower RTs among older adults • Facilitated recognition and RT for target-aligned words compared to non-aligned words in young adults • Similar recognition rates and RT for target-aligned and non-aligned words in older adults (i.e., less facilitation)

Table 2 – Predictions for Experiment 2: Predicted outcomes for young and old adults in Experiment 2 according to processing speed theory (Salthouse, 1996) and a possible deficit in facilitatory control. Note the major differences in predictions here occur in how older and younger adults will respond to target-aligned and non-aligned words during the surprise recognition test.

II. Experiment 1: Inhibition

i. Participants

Thirty-nine healthy control participants (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 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 through the University of Hawai'i at Mānoa such as the Osher Life Long Learning (OILL) and Student Equity Excellence Diversity (SEED) organization. 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'. For purposes of this thesis 'elderly' individuals will be referred to as 'older adults'. Screening procedures were utilized to avoid recruitment of any individuals suffering from age related cognitive decline resulting from pathological influences, such as seizure disorders, Alzheimer's disease or other forms of age related dementia. All participants were permitted to utilize visual and auditory aids such as glasses and hearing aids during experimentation. All participants (young adult or older adult) were presented with informed consent (See appendix A and B) prior to beginning the experiment and debriefed upon completion (See appendix C).

ii. Stimuli

A total of 100 pictures (on average 5 to 10 cms) were selected from the Snodgrass and Vanderwart (1980) picture database. These pictures were randomly rotated +/-30 degrees from their original orientation to ensure that the identification task is sufficiently demanding in each version of the experiment (see Rees et al., 1999). Each picture was superimposed with one of 150 high frequency English words selected from the MRC

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

For maximum randomization, the 100 pictures were separated into two equal groups and the 150 words were separated into three equal groups. In each of the groups of pictures, half (25) were pre-selected, duplicated, and then match paired. These matched pairs were presented as immediate picture repetitions during the first block in the RSVP stream, serving as identification targets. The remaining 25 were also duplicated but care was taken to ensure that these pairs did not occur as immediate repetitions in the same block, creating the non-repeating distractors in the visual stream.

To create the compound stimuli, 100 of the 150 words were selected and superimposed on the pictures. Half (50) of the words appeared on immediate picture repetitions, serving as the target-aligned words, and the other half were superimposed on the non-repeating pictures in the stream, serving as non-aligned words. This created a block size of 100 picture-word combinations with 25 immediate repetitions and accompanying target-aligned words. The same 100 words and 50 picture pairs used in the first block were used in the second block and the same procedure was used. Critically, the 25 picture pairs that did not repeat in the first block did repeat in the second block and those that repeated in the first block did not repeat in the second block (i.e., target picture repetitions served as non-repeating distractors and vice versa). Like the pictures, the 25 words that were target-aligned in the first block were non-aligned in the second block and

vice versa. Each picture was therefore 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. Likewise, all of the words were presented twice in the experiment. Twenty-five of the 50 target-aligned words were presented as target-aligned in the first block and were then presented as a non-aligned words in the second block. The other 25 of the target-aligned words were presented as target-aligned in the second block and non-aligned in the first block. The non-aligned words were presented on top of non-repeating pictures in both blocks. This method was used to create six different versions of the experiment (see Dewald et al., 2011).

The later surprise recognition test was administered after participants had completed the primary task. This test consisted of 50 words from the experiment along with 50 never before seen foil words. The foil words were obtained by randomly selecting from words used in other versions of the experiment. 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 target-aligned words along with 50 foil words and the other tested only the 50 non-aligned 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 (target-aligned words or non-aligned words). The recognition tasks were randomized and presented by DMDX software (Forster & Forster, 2003) 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), and remained on the screen until a response was made.

iii. Procedure

Participants were instructed to ignore the superimposed words (attend only to the pictures) and respond when they noticed a picture immediately repeat in the RSVP stream by clicking the left mouse button. 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 5). 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 repetition detection task, the surprise word recognition test was administered to all participants. 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.

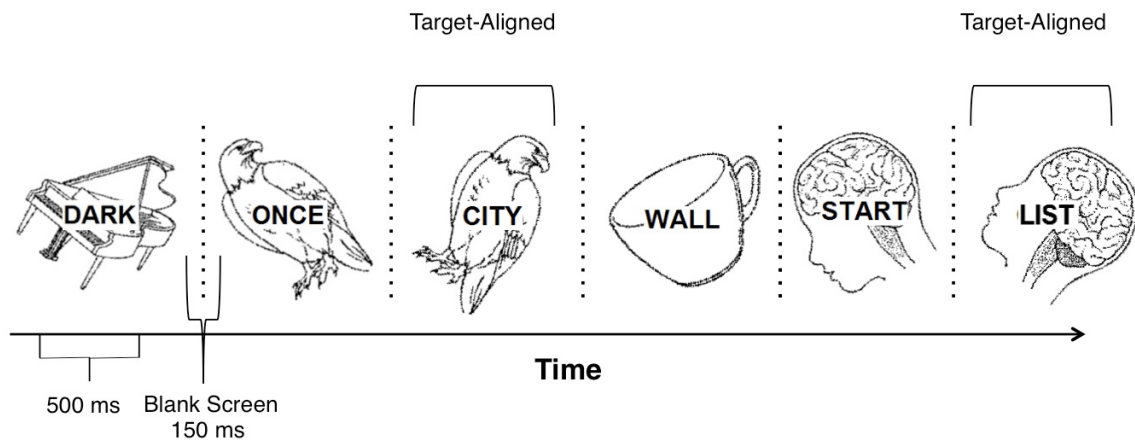


Figure 5 – Example of Stimuli in Experiment 1: Schematic representation of the primary task in Experiment 1. Note that the target-aligned words are different for each picture repetition.

iv. Results

Young Adult Performance Accuracy

Overall accuracy performance on the primary task of detecting immediate picture repetitions during the exposure stage was analyzed. Participants ($n = 38$) obtained an average hit rate of 59% ($SE = .031$). A hit is defined as a response to a presented target stimulus that occurs within 1150ms of initial onset of stimulus presentation. This criterion was adapted from protocol used in previous experiments utilizing similar stimuli, presentation, and SOAs (see Ngo, Cadieux, Sinnett, Soto-Faraco, & Spence, 2011). The miss rate was 41% ($SE = .036$). A miss is defined as a failure to respond to a target picture repetition within 1150ms. The false alarm (FA) rate was 0.7% ($SE = .001$). A FA is defined as responses to pictures that do not immediately repeat. The hit rate was significantly higher than the miss rate [$t(37) = 2.84, p < .01$]. Performance was also significantly above chance [$t(37) = 16.77, p < .01$], which was taken to be an indication of the successful detection of picture repetitions on the primary task. In this exposure stage 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%).

For the surprise recognition test, chance is defined at 50%, as the task required participants to indicate whether they recognized a word from the previous repetition detection task, or if that word was novel. Overall word recognition on the surprise recognition test was 40% ($SE = .022$), which was significantly different from chance [$t(37) = 4.15, p < .001$]. Recognition for target-aligned words ($n = 19, M = 37\%, SE = .033$) was significantly different from chance [$t(18) = 3.85, p < .001$], while recognition

for non-aligned words ($n = 19$, $M = 44\%$, $SE = .027$) was only marginally significantly different from chance [$t(18) = 2.02$, $p = .06$] (see Figure 6).

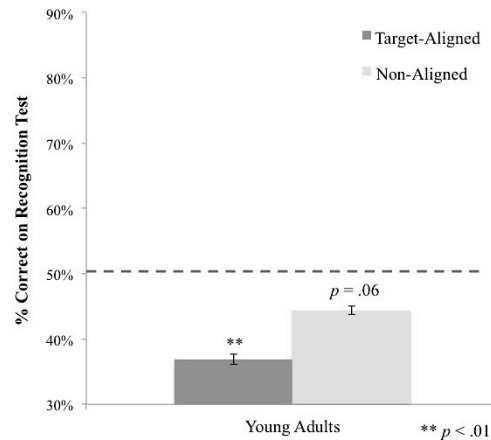


Figure 6 – Young Adult Performance Against Chance (Exp. 1): Graph depicting recognition rates for target-aligned words (dark grey bar) and non-aligned words (light grey bar) against chance for young adults in Experiment 1. Recognition for target-aligned words was significantly different from chance. Error bars represent standard error.

Recognition for target-aligned words was significantly lower than non-aligned words [$t(36) = 1.71$, $p = .04$]⁴ (see Figure 7). There was no correlation between performance on the primary task and performance on the recognition test [$r(38) = .243$, $p = .141$], suggesting that performance on the primary task had no significant influence on later recognition rates.

⁴ Interestingly, a pilot version of this experiment failed to replicate these results. The main difference observed was the direction of inhibition. Non-aligned words were inhibited to a greater extent than target-aligned words (34% vs. 50%, $p < .05$). Additional research is needed to explore this more closely, as this is the first experiment using this paradigm that did not see the expected inhibition pattern (i.e., target-aligned words inhibited to a greater extent than non-aligned words), which has been robustly observed in previous studies (see, Dewald & Sinnott, 2011a; Dewald & Sinnott, 2011b; Dewald, Sinnott, & Dumas, 2010; Dewald, Sinnott, & Dumas, 2011).

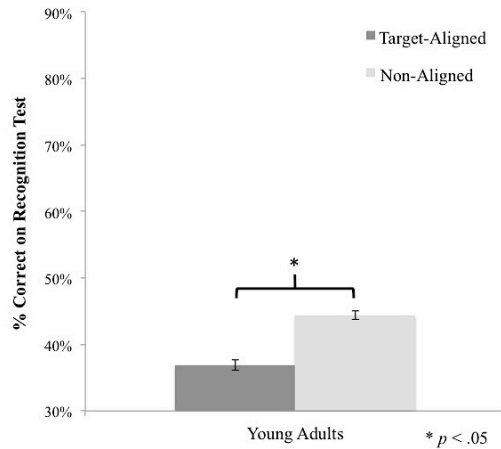


Figure 7 – Young Adult Performance on Target-Alignment (Exp. 1): Graph depicting recognition for target-aligned words (dark grey bar) compared to non-aligned words (light grey bar) for young adults in Experiment 1. Target-aligned words were recognized significantly less often than non-aligned words. Error bars represent standard error.

Older Adult Performance Accuracy

Performance for the older adult group was analyzed in the same way. Participants ($n = 25$) obtained an average hit rate of 37% ($SE = .032$). The miss rate was 62% ($SE = .032$). The FA rate was 0.9% ($SE = .003$). The hit rate was significantly lower than the miss rate [$t(25) = 3.93, p < .001$]. The hit rate was significantly above chance [$t(25) = 9.55, p < .001$] indicating successful detection of picture repetitions on the primary task. For the primary task, chance is defined here in the same manner as it was for younger adults (i.e., 7%).

Overall word recognition on the surprise recognition test was 33% ($SE = .036$), which was significantly different from chance [$t(25) = 4.64, p < .001$]. Recognition for target-aligned words ($n = 13, M = 32\%, SE = .055$) was significantly different from

chance [$t(12) = 3.18, p < .008$], and recognition for non-aligned words ($n = 13, M = 34\%$, $SE = .047$) was also significantly different from chance [$t(12) = 3.29, p < .007$] (see Figure 8).

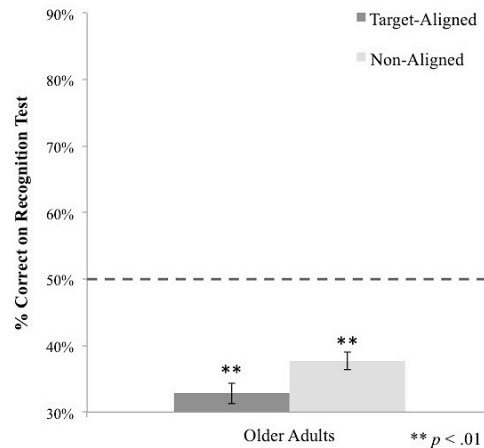


Figure 8 – Older Adult Performance Against Chance (Exp. 1): Graph depicting recognition rates for target-aligned words (dark grey bar) and non-aligned words (light grey bar) against chance for older adults in Experiment 1. Recognition for both word types was significantly different from chance. Error bars represent standard error.

Recognition for target-aligned words was not significantly different from non-aligned words [$t(24) = .253, p = .401$] (see Figure 9). Again, there was no correlation between performance on the primary task and performance on the surprise recognition test [$r(26) = .306, p = .209$].

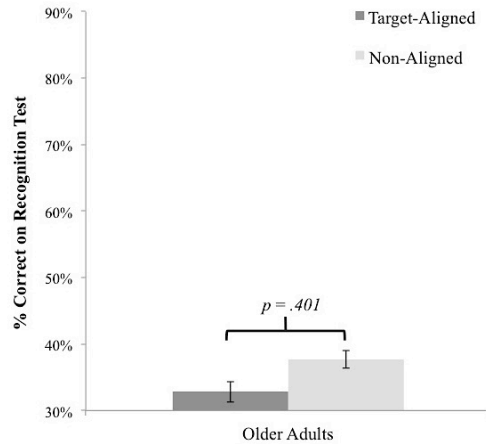


Figure 9 – Older Adult Performance on Target-Alignment (Exp. 1): Graph depicting recognition for target-aligned words (dark grey bar) compared to non-aligned words (light grey bar) for older adults in Experiment 1. There was no significant difference in recognition rates between target-aligned and non-aligned words. Error bars represent standard error.

Age Comparisons: Accuracy

Overall accuracy performance for older and young adults on the primary task of detecting immediate picture repetitions during the exposure stage was analyzed. An independent sample t-test revealed that older adults accuracy (hit rate: 37%, SE = .032) was significantly lower than young adults (hit rate: 58%, SE = .031) when detecting picture repetitions on the primary task [$t(62) = 4.64, p < .001$]. There was no significant difference in FA rates for older adults (M = 0.9%, SE = .003) compared to young adults (M = 0.7%, SE = .001) [$t(62) = .783, p = .218$]. This means that older adults were less able to identify immediate picture repetitions compared to the young adults, while both groups had very low FA rates (i.e., <1%).

In order to assess whether age group modulated overall word recognition, a two-way ANOVA was conducted on recognition test performance with target-alignment (target-aligned vs. non-aligned) and age group (young vs. old) as between subject factors, and accuracy as the dependent variable. There was a marginal main effect for age [$F(1, 64) = 3.35, p = .07$]. This suggests 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 target-aligned word recognition ($M = 35\%$, $SE = .030$) was not significantly lower than non-aligned ($M = 40\%$, $SE = .026$) [$F(1, 64) = 1.75, p = .190$] and no interaction [$F(1, 64) = .495, p = .485$] (see Figure 10). Once more, there was no correlation between overall performance (combining both age groups) on the primary task and performance on the surprise recognition test [$r(63) = .139, p = .277$].

To further evaluate group performance, planned t-tests were conducted to determine if any significant differences exist in performance on target-aligned and non-aligned words between age groups.

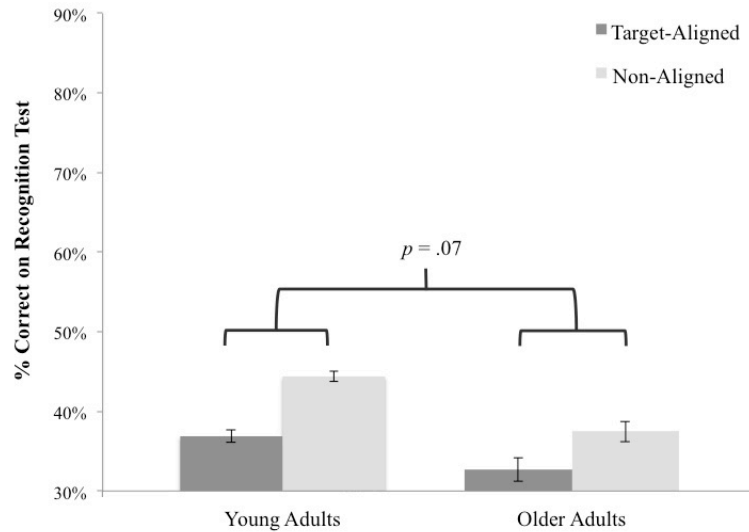


Figure 10 – Age Comparison by Accuracy (Exp. 1): Graph depicting overall recognition rates between young and older adults in Experiment 1. The ANOVA revealed a marginal main effect for age ($p = .07$) suggesting that, overall, older adults recognized fewer words than young adults. There was no main effect for target-alignment and no interaction.

Error bars represent standard error.

Group Comparison of Performance by Target Alignment

Recognition rates of target-aligned words between older adults ($n = 13$, $M = 32\%$, $SE = .055$) and young adults ($n = 19$, $M = 37\%$, $SE = .033$), were not significantly different [$t(30) = .733$, $p = .235$]. Older adults recognized non-aligned words ($n = 13$, $M = 34\%$, $SE = .047$) significantly less often than young adults ($n = 19$, $M = 44\%$, $SE = .027$) [$t(30) = 1.95$, $p < .03$] (see Figure 11). Comparing the magnitude of inhibition between target-aligned and non-aligned words for older adults ($n = 13$, $M = 2\%$, $SE = .082$) and young adults ($n = 19$, $M = 7\%$, $SE = .044$) revealed that there was no significant difference between the two age groups [$t(30) = .655$, $p = .259$]. This was

surprising considering there was no significant difference in recognition rates between word types for the older adults, while the younger adults recognized non-aligned words more frequently than target-aligned words. Regardless, it is evident that both age groups are inhibiting word processing.

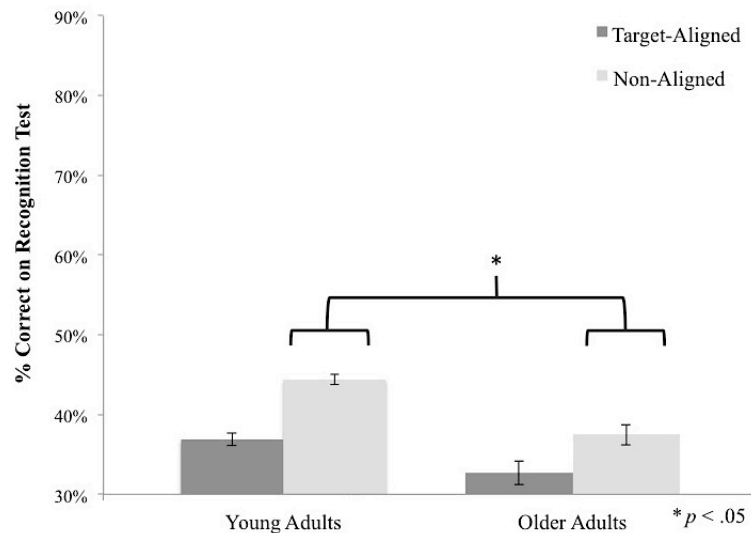


Figure 11 – Group Comparison by Target-Alignment (Exp. 1): Graph depicting recognition for target-aligned words (dark grey bar) and non-aligned words (light grey bar) between young and older adults in Experiment 1. Older adults recognized non-aligned words significantly less often than younger adults. There was no significant difference in recognition rates to target-aligned words between these age groups. Error bars represent the standard error.

Young Adult Performance Speed

Average RT to presented targets on the primary task of picture repetition detection was 411ms (SE = 5ms). Overall average speed on the surprise recognition test was 1117ms (SE = 50ms). RTs to target-aligned words (M = 1141ms, SE = 77ms) were

not significantly different from non-aligned words ($M = 1093\text{ms}$, $SE = 66\text{ms}$) [$t(36) = .469$, $p = .321$] (see Figure 12).

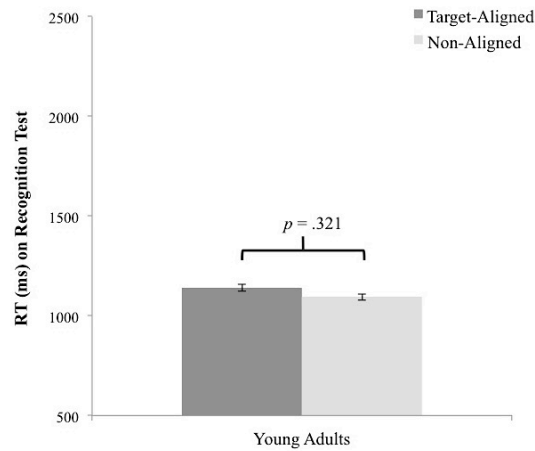


Figure 12 – Young Adult Speed (Exp. 1): Graph depicting reaction time (ms) to target-aligned words (dark grey bar) and non-aligned words (light grey bar) for young adults in Experiment 1. There was no significant difference in reaction time to each word type.

Error bars represent the standard error.

Older Adult Performance Speed

Average RT to presented targets on the primary task of picture repetition detection was 435ms ($SE = 8\text{ms}$). Overall speed on the surprise recognition test was 1949ms ($SE = 159\text{ms}$). RTs to target-aligned words ($M = 2066\text{ms}$, $SE = 261\text{ms}$) were not significantly different from non-aligned words ($M = 1831\text{ms}$, $SE = 189\text{ms}$) [$t(24) = .729$, $p = .236$] (see Figure 13).

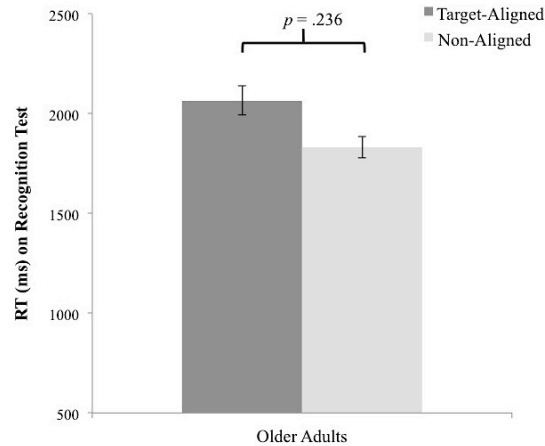


Figure 13 – Older Adult Speed (Exp. 1): Graph depicting reaction time (ms) to target-aligned words (dark grey bar) and non-aligned words (light grey bar) for older adults in Experiment 1. There was no significant difference in reaction time to each word type.

Error bars represent the standard error.

Age Comparison: Speed

An independent sample t-test revealed that older adults responded to target picture repetitions ($M = 435\text{ms}$, $SE = 8\text{ms}$) significantly slower than young adults ($M = 411\text{ms}$, $SE = 5\text{ms}$) on the primary task [$t(62) = 2.68$, $p < .01$].

In order to assess whether age group modulated overall processing speed on the surprise recognition test, a two-way ANOVA was conducted on participant's RTs with target-alignment (target-aligned vs. non-aligned) and age group (young vs. old) as between subject factors, and accuracy as the dependent variable. A main effect for age [$F(1, 64) = 32.75$, $p < .001$] demonstrated that older adults responded to words on the surprise recognition task significantly slower ($M = 1949\text{ms}$, $SE = 159\text{ms}$) than young adults ($M = 1117\text{ms}$, $SE = 50\text{ms}$). There was no main effect for target alignment [$F(1,$

64) = .751, $p = .389$] indicating that RTs to target-aligned word ($M = 1517\text{ms}$, $SE = 139\text{ms}$) were not significantly slower than non-aligned words ($M = 1393\text{ms}$, $SE = 106\text{ms}$), and no interaction [$F(1, 64) = .411$, $p = .524$] (see Figure 14). To further evaluate group speed, planned t-tests were conducted to determine if any significant differences exist between RT to target-aligned and non-aligned words between age groups.

Group Comparison of Speed by Target Alignment

Older adults responded to target-aligned words ($M = 2066\text{ms}$, $SE = 261\text{ms}$) significantly slower than young adults ($M = 1141\text{ms}$, $SE = 77\text{ms}$) [$t(30) = 3.96$, $p < .001$]. Older adults also responded to non-aligned words ($n = 13$, $M = 1831\text{ms}$, $SE = 189\text{ms}$) significantly slower than young adults ($n = 19$, $M = 1093\text{ms}$, $SE = 66\text{ms}$) [$t(30) = 3.68$, $p = .002$] (see Figure 14).

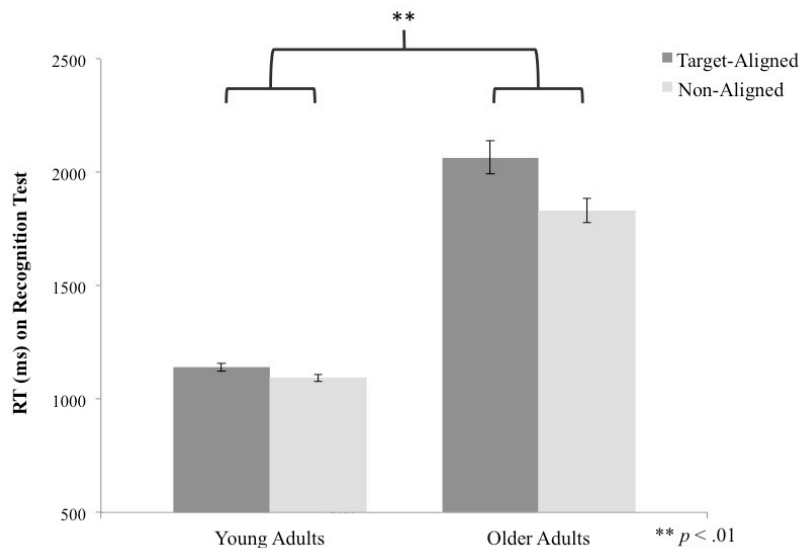


Figure 14 – Age Comparison by Speed (Exp. 11): Graph depicting overall reaction times (ms) between young and older adults in Experiment 1. The ANOVA revealed a main effect for age suggesting that, overall, older adults responded to words significantly more slowly than young adults. No main effect for target-alignment and no interaction.

iii. Discussion: Experiment 1

The findings from the young adult group of Experiment 1 are partially in line with research conducted by Dewald et al. (2011). Their findings demonstrated below chance performance for target-aligned words and chance performance for non-aligned words. For similarly aged participants here, both word types were recognized at below chance levels, however, it should be noted that non-aligned performance was only marginally significant ($p = .06$). Furthermore, target-aligned words were, indeed, inhibited to a significantly greater extent than non-aligned words, which is in line with previous findings. When examining results from the older adult group, a different trend in recognition rates was observed. In this case, both target-aligned and non-aligned words were recognized at rates significantly lower than chance, but there was no significant difference in recognition rates between word types. This suggests that older adults may have experienced a more global inhibition for word processing compared to young adults.

Considering the ANOVA conducted on participant accuracy scores, there was a marginal main effect for age ($p = .07$) suggesting that, overall, older adults may have recognized fewer words on the surprise recognition test compared to younger adults. Surprisingly, a main effect of target-alignment was not observed nor was an interaction. This finding would seemingly suggest that neither age group recognized the target-aligned words less often than the non-aligned words and recognition patterns were not different between age groups. However, recall that when directly comparing target-aligned and non-aligned performance for each age group, there was no difference for older adults ($p = .401$), while there was a significant difference for the young adult group ($p = .04$). It is probable that this trend would continue and become more significant with

additional participants, in which case a main effect and an interaction would likely be observed.

When comparing differences in recognition rates to the target-aligned words between older and younger adults we failed to observe a significant difference. This implies that processing for target-aligned words was inhibited for both age groups (note, recognition for target-aligned words was significantly lower than chance in each age group). However, older adults recognized non-aligned words significantly less often than the younger adults ($p = .03$). This implies that older adults may have inhibited processing for non-aligned words to a greater extent than the younger adults. Thus, it appears that younger adults might employ a more *selective* inhibitory control over the presented words. This *selective* inhibitory control results in a greater inhibition of processing for target-aligned words compared with non-aligned words. On the other hand, older adults appear to employ a more global inhibitory process, thus filtering both target-aligned and non-aligned words, resulting in an overall higher degree of inhibition on the primary task, which may be indicative of a disturbance in inhibitory control for this age group.

The two-way ANOVA conducted on participant RTs also revealed a main effect for age ($p < .001$) suggesting that, overall, older adults responded to words (both target-aligned and non-aligned) significantly more slowly than young adults on the surprise recognition test. While, it was anticipated that overall RTs to the target-aligned words would be significantly longer compared to RTs for non-aligned words (indicating inhibition), this was not the case. There was no main effect for target-alignment and no interaction. This means that neither the young nor the older adults responded to the target-aligned words significantly slower than to the non-aligned words during the

surprise recognition test. This finding suggests that while temporally aligning an ignored item with an attended target stimulus inhibits the processing of that information, it does not affect the speed at which that information is responded to in a later recognition test. However, it should be noted that the surprise recognition task was not speeded (i.e., participants were not required to respond as quickly as possible). Recall that the words were presented and left on the screen until participants made their decision. Therefore RT results for the surprise recognition test must be interpreted with caution. Future studies may want to consider making the surprise recognition task speeded in order to investigate this further.

Comparing overall performance and processing speed during the primary task of detecting picture repetitions, we found that older adults had poorer performance on the primary task than younger adults. This suggests that the primary task may have been more difficult for the older adults, which may account for the more global inhibition that was observed in this age group. We also found that older adults responded to targets significantly slower than the younger adults (435ms and 411ms, respectively). This suggests that it took the older adults longer to process and therefore respond to the presented stimuli during the repetition detection task, which may be an indication of a reduction in overall processing speed.

Overall, The findings from Experiment 1 would seem to suggest that in addition to a generalized slowing of information processing (see Salthouse, 1996), a decline in selective inhibitory control may be responsible for the reduced difference in overall performance accuracy for older participants. This finding differs slightly from what was expected by inhibitory deficit theory (Hasher & Zacks, 1988), which would predict

chance performance for target-aligned and non-aligned words among older adults due to a reduced ability to suppress processing for the irrelevant stimuli. Here we see that older adults inhibited processing for both target-aligned and non-aligned words while young adults selectively inhibited target-aligned words to a greater extent than non-aligned words. This would suggest that older adults are less able to employ inhibitory control selectively, which is suggestive of a disturbance in inhibitory function. The first experiment explored potential age related differences associated with information processing speed and the extent to which inhibitory mechanisms may be attenuated in older individuals compared to younger participants. Experiment 2 was designed to explore whether or not facilitatory control is mediated through increased exposure to target-aligned words.

II. Experiment 2: Facilitation

i. Participants

For Experiment 2, participants for each age group were recruited using the same methods employed in Experiment 1.

Sixteen healthy control participants (12 female, mean age of 22.5) were recruited from undergraduate courses at the University of Hawai`i at Mānoa in exchange for course credit. The results from three participants were excluded from analyses due to a failure to perform the repetition detection task. The final analyses were conducted with the remaining thirteen participants (9 female, mean age of 22.8). Participants were able to utilize devices designed to correct visual or auditory impairments.

Ten healthy older adult participants (8 female, mean age of 80) were recruited, on a voluntary basis, from local retirement communities around Honolulu, Hawai`i as well

as from continuing education programs for seniors through the University of Hawai‘i at Mānoa such as the Osher Life Long Learning (OILL) and Student Equity Excellence Diversity (SEED) programs. As with the younger population, participants were able to utilize devices designed to correct visual or auditory impairments.

ii. Stimuli

The conditions and stimuli were similar to those in Experiment 1 and the picture and word combinations were created using the exact same method as in Experiment 1, except for the following differences. The total number of pictures was decreased from 100 to 50. The total number of words was decreased from 150 to eight. As in Experiment 1, each picture was duplicated to create a matched pair and superimposed with one of eight high frequency English words. Again, care was taken to ensure that picture-word combinations did not have any semantic relationship. For the exposure stage (primary task), a stream of 960 combined picture-word items (height and width not exceeding 10cm) were created. Repeated pictures in the rapid serial visual presentation (RSVP) stream acted as the task-relevant targets in the identification task. The RSVP stream was broken into eight blocks of 120 trials. The presentation was pseudorandomized so that in each block an immediate picture repetition occurred an average of one out of every eight trials, creating a mean of 15 task-relevant targets (picture repetitions) per block. This resulted in a total of 120 trials of exposure to a task-relevant target and a repeated task-irrelevant target-aligned word.

Of the eight words that were superimposed over the pictures in the 960 trial RSVP stream, one was randomly selected to appear in temporal alignment with the task-relevant target. In other words, a single word was selected and always paired with the presentation

of an immediately repeated picture target. Eight iterations of this experiment were created for which each of the eight words acted as the word that was target-aligned with the picture repetitions. To control for any possible differences that may exist with regard to individual word saliency, the presentation was randomized between participants. This was done to replicate the dependent measure and parallel the quantity of items and exposure to irrelevant stimuli employed by Dewald et al, 2012 (see also Watanabe et al., 2003).

The later surprise recognition test was, again, similar to Experiment 1, except for the following differences. It consisted of a total of only 16 words, eight of which came from the previously viewed visual stream, while the other eight consisted of never before seen foil words. Recall that one of the eight previously presented words exclusively appeared only with picture repetitions. The foil words were never used in the exposure stage of the experiment, but were taken from the same database (average frequency of 236 per million; range of 165 to 399).

iii. Procedure

The procedure for Experiment 2 was identical to that used in Experiment 1, with the exception that every picture repetition was superimposed with the same, unchanging, target-aligned word (see Figure 15).

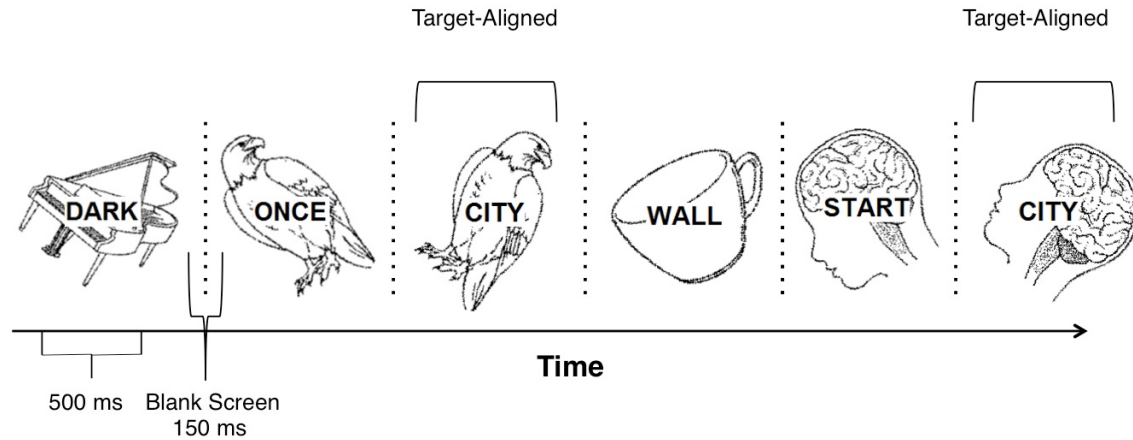


Figure 15 – Example of Stimuli in Experiment 2: Schematic representation of the primary task in Experiment 2. Note that the target-aligned words are now the same.

v. Results

Young Adult Performance Accuracy

Participants ($n = 13$) obtained an average hit rate of 45% ($SE = .031$). The miss rate was 55% ($SE = .031$). The hit rate was lower than the miss rate, which trended toward significance [$t(13) = 1.61, p = .06$]. The false alarm (FA) rate was 0.3% ($SE = .001$). During the exposure stage a target appears, on average, in one of every eight trials. Therefore chance is calculated as the probability of obtaining a hit in any given presentation of eight trials (i.e., 12.5%). The hit rate was significantly above chance [$t(12) = 10.69, p < .001$] indicating successful detection of picture repetitions on the primary task.

Overall word recognition on the surprise recognition test was 72% ($SE = .070$), which was significantly different from chance [$t(12) = 3.11, p < .006$]. Recognition for target-aligned words ($M = 85\%$, $SE = .104$) was significantly different from chance [$t(12)$

= 3.32, $p < .006$], while recognition for non-aligned words ($M = 59\%$, $SE = .085$) was not significantly different from chance [$t(13) = 1.09$, $p = .295$] (see Figure 16).

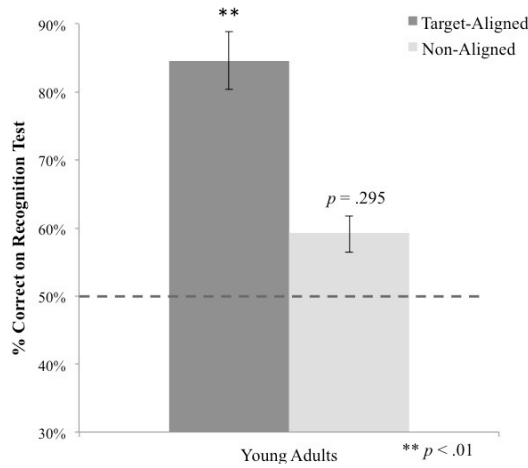


Figure 16 – Young Adult Performance Against Chance (Exp. 2): Graph depicting recognition rates for target-aligned words (dark grey bar) and non-aligned words (light grey bar) against chance for young adults in Experiment 2. Recognition for target-aligned words was significantly different from chance. Error bars represent standard error.

Recognition for target-aligned words was significantly higher than non-aligned words [$t(13) = 3.66$, $p < .003$] (see Figure 17). There was no correlation between performance on the primary task and performance on the recognition test [$r(13) = -0.06$, $p = .846$] suggesting that performance on the primary task had no significant influence on later recognition rates.

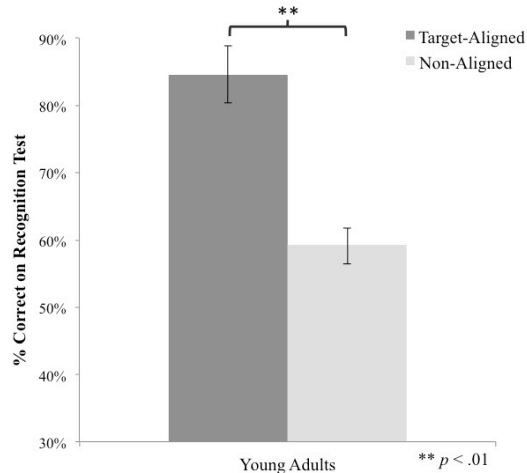


Figure 17 – Young Adult Performance on Target-Alignment (Exp. 2): Graph depicting recognition for target-aligned words (dark grey bar) compared to non-aligned words (light grey bar) for young adults in Experiment 2. Target-aligned words were recognized significantly more often than non-aligned words. Error bars represent standard error.

Older Adult Performance Accuracy

Participants ($n = 10$) obtained an average hit rate of 35% ($SE = .049$). The miss rate was 65% ($SE = .049$). The hit rate was significantly lower than the miss rate [$t(9) = 3.06$, $p < .01$]. The FA rate was 2% ($SE = .007$). The hit rate was significantly above chance [$t(9) = 4.55$, $p < .001$], indicating successful detection of picture repetitions on the primary task.

Overall word recognition on the surprise recognition test was 73% ($SE = .081$), which was significantly different from chance [$t(9) = 2.64$, $p < .03$]. Recognition for target-aligned words ($M = 80\%$, $SE = .133$) was also significantly different from chance [$t(9) = 2.25$, $p < .02$] while recognition for non-aligned words ($M = 63\%$, $SE = .077$) was not significantly different from chance [$t(9) = 1.66$, $p = .131$] (see Figure 18).

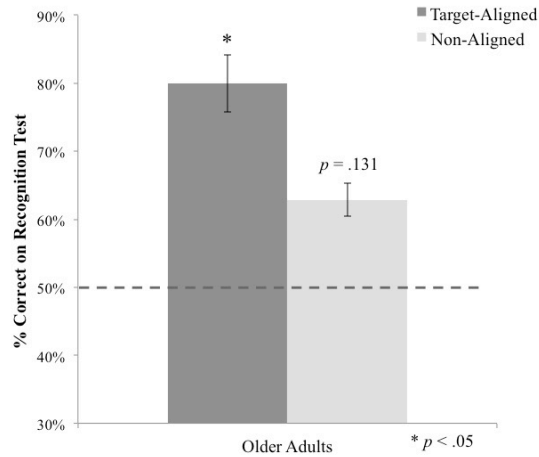


Figure 18 – Older Adult Performance Against Chance (Exp. 2): Graph depicting recognition rates for target-aligned words (dark grey bar) and non-aligned words (light grey bar) against chance for older adults in Experiment 2. Recognition for target-aligned words was significantly different from chance. Error bars represent standard error.

Surprisingly, recognition for target-aligned words was not significantly higher than non-aligned words using a one-tailed paired samples t-test [$t(9) = 1.17, p = .134$] (see Figure 19). There was no correlation between performance on the primary task and performance on the recognition test [$r(10) = .242, p = .501$], again, suggesting that performance on the primary task had no significant influence on later recognition rates.

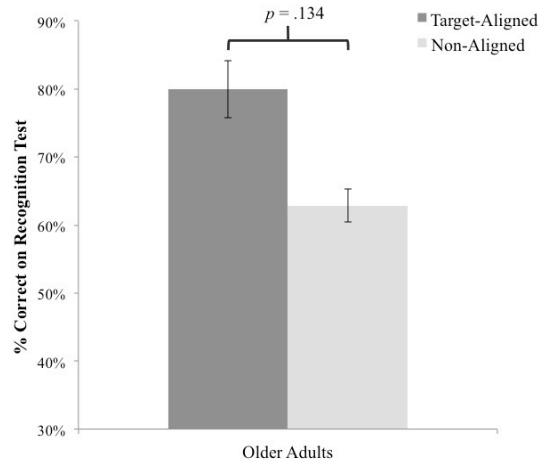


Figure 19 – Older Adult Performance on Target-Alignment (Exp. 2): Graph depicting recognition for target-aligned words (dark grey bar) compared to non-aligned words (light grey bar) for older adults in Experiment 2. There was no significant difference in recognition rates between target-aligned and non-aligned words. Error bars represent standard error.

Age Comparisons: Accuracy

An independent sample t-test revealed that older adults accuracy (hit rate: 35%, SE = .049) was significantly lower than young adults (hit rate: 45%, SE = .031) when detecting picture repetitions on the primary task [$t(21) = 1.86, p < .03$]. Older adults also had significantly more FAs (M = 2%, SE = .007) compared to young adults (M = 0.3%, SE = .001) [$t(21) = 5.32, p < .001$]. This suggests that the task may have been more demanding for older adults.

In order to assess whether age group modulated overall word recognition, a two-way repeated measures ANOVA was conducted on recognition test performance with target-alignment (target-aligned vs. non-aligned) as a within subjects factor, age group

(young vs. old) as between subject factors, and accuracy as the dependent variable. A main effect for target alignment demonstrated that target-aligned word recognition ($M = 83\%$, $SE = .075$) was significantly higher than non-aligned recognition ($M = 61\%$, $SE = .056$) [$F(1, 21) = 8.05, p < .01$]. There was no main effect for age [$F(1, 21) = .009, p = .965$] and no interaction [$F(1, 21) = .296, p = .592$] (see Figure 20). Once more, there was no correlation between overall performance (combining both age groups) on the primary task and performance on the surprise recognition test [$r(23) = -0.12, p = .580$].

To further evaluate group performance, planned t-tests were conducted to determine if any significant differences exist in performance on target-aligned and non-aligned words between age groups.

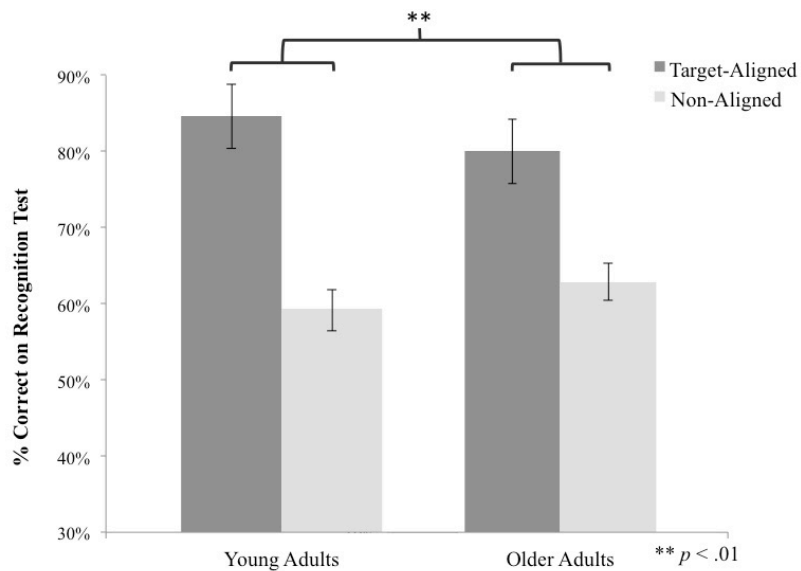


Figure 20 – Age Comparison by Accuracy (Exp. 2): Graph depicting overall recognition rates between young and older adults in Experiment 2. The ANOVA revealed a main effect for target-alignment ($p < .01$) suggesting that, overall, target-aligned words (dark grey bar) were recognized more often than non-aligned words (light grey bar). There was no main effect for age and no interaction. Error bars represent standard error.

Group Comparison of Performance by Target Alignment

Recognition rates of target-aligned words between older adults ($n = 10$, $M = 80\%$, $SE = .133$) and young adults ($n = 13$, $M = 85\%$, $SE = .104$) showed no significant difference [$t(21) = .277$, $p = .784$]. There was no significant difference in recognition rates for non-aligned words between older adults ($M = 63\%$, $SE = .077$) and young adults ($M = 59\%$, $SE = .085$) [$t(21) = .296$, $p = .770$] (see Figure 21). Comparing the magnitude of facilitation between target-aligned and non-aligned words for older adults ($M = 17\%$, $SE = .146$) and young adults ($M = 25\%$, $SE = .069$) revealed that there was no significant difference between the two age groups [$t(21) = .544$, $p = .592$]. This suggests that older adults facilitated processing of the target-aligned words to the same extent that the younger adults did.

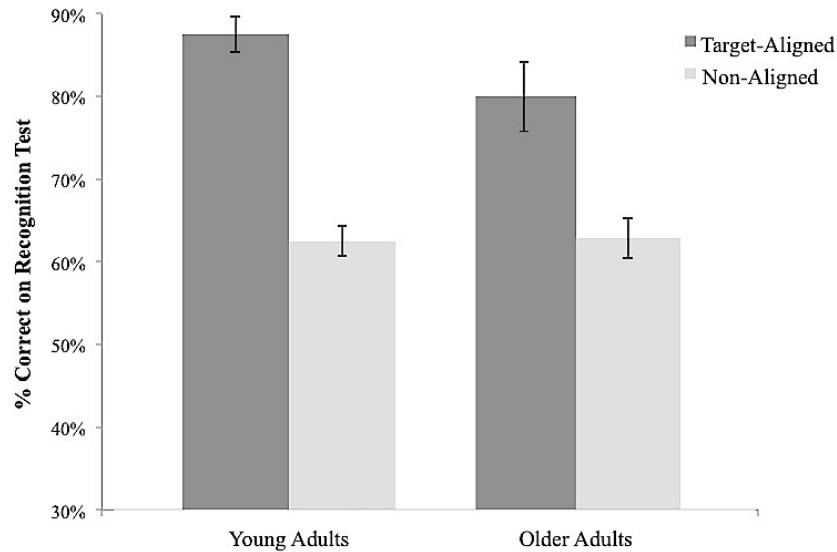


Figure 21 – Group Comparison by Target-Alignment (Exp. 2): Graph depicting recognition for target-aligned words (dark grey bar) and non-aligned words (light grey bar) between young and older adults in Experiment 2. There was no significant difference in recognition rates to between these age groups. Error bars represent the standard error.

Young Adult Performance Speed

Average RT to presented targets on the primary task of picture repetition detection was 461ms (SE = 6ms). Overall speed on the surprise recognition test was 1211ms (SE = 180ms). RTs to target-aligned words (M = 1246ms, SE = 503ms) were not significantly different from non-aligned words (M = 1200ms, SE = 198ms) [$t(12) = .101$, $p = .921$] (see Figure 22).

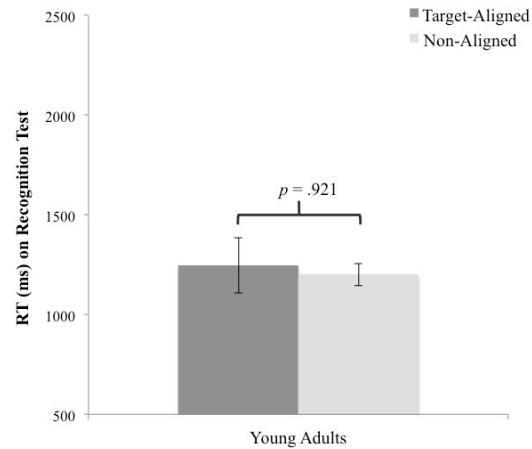


Figure 22 – Young Adult Speed (Exp. 2): Graph depicting reaction time (ms) to target-aligned words (dark grey bar) and non-aligned words (light grey bar) for young adults in Experiment 2. There was no significant difference in reaction time to each word type.

Error bars represent the standard error.

Older Adult Performance Speed

Average RT to presented targets on the primary task of picture repetition detection was 555ms (SE = 16ms). Overall speed on the surprise recognition test was 2076ms (SE = 295ms). RTs to target-aligned words (M = 2271ms, SE = 561ms) were not significantly different from non-aligned words (1881ms, SE = 214ms) [$t(9) = .658, p = .527$] (see Figure 23).

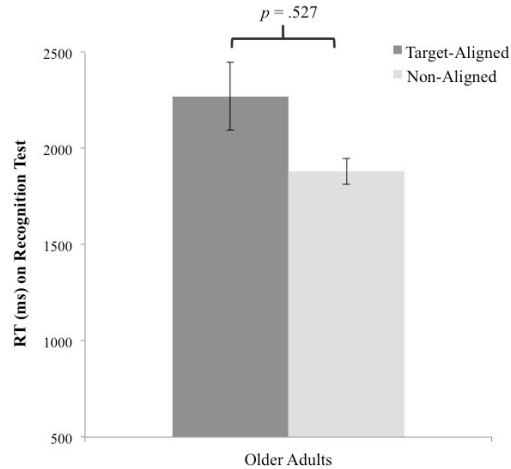


Figure 23 – Older Adult Speed (Exp. 2): Graph depicting reaction time (ms) to target-aligned words (dark grey bar) and non-aligned words (light grey bar) for older adults in Experiment. There was no significant difference in reaction time to each word type. Error bars represent the standard error.

Age Comparison: Speed

An independent sample t-test revealed that older adults responded to target picture repetitions ($M = 555\text{ms}$, $SE = 16\text{ms}$) significantly slower than young adults ($M = 461\text{ms}$, $SE = 6\text{ms}$) on the primary task [$t(21) = 5.396$, $p < .001$]. In order to assess whether age group modulated overall processing speed, a two-way repeated measures ANOVA was conducted participants RTs with target-alignment (target-aligned vs. non-aligned) as a within subjects factor and age group (young vs. old) as a between subject factor, and RT as the dependent variable. Though no main effect for age was found, the results suggest a trend towards older adults responding to words slower (2076ms , $SE = 295\text{ms}$) than young adults (1211ms , $SE = 180\text{ms}$) [$F(1, 21) = 3.27$, $p = .08$]. There was no main effect for target-alignment [$F(1, 21) = .374$, $p = .547$] indicating that RTs to target-aligned words

(M = 1691ms, SE = 381ms) were not significantly faster than non-aligned words (M = 1496ms, SE = 159ms) and no interaction [$F(1, 21) = .504, p = .485$] (See Figure 24). To further evaluate group speed, planned t-tests were conducted to determine if any significant differences exist between RT to target-aligned and non-aligned words between age groups.

Group Comparison of Speed by Target Alignment

A trend toward significance suggests that older adults may have responded to target-aligned words ($n = 10, M = 2271\text{ms}, SE = 561\text{ms}$) slower than young adults ($n = 13, M = 1246\text{ms}, SE = 503\text{ms}$), although this failed to reach accepted levels of significance [$t(21) = 1.355, p = .09$]. Older adults responded to non-aligned words ($n = 10, M = 1881\text{ms}, SE = 214\text{ms}$) significantly slower than young adults ($n = 13, M = 1200, SE = 198\text{ms}$) [$t(21) = .2.31, p < .01$] (see Figure 24).

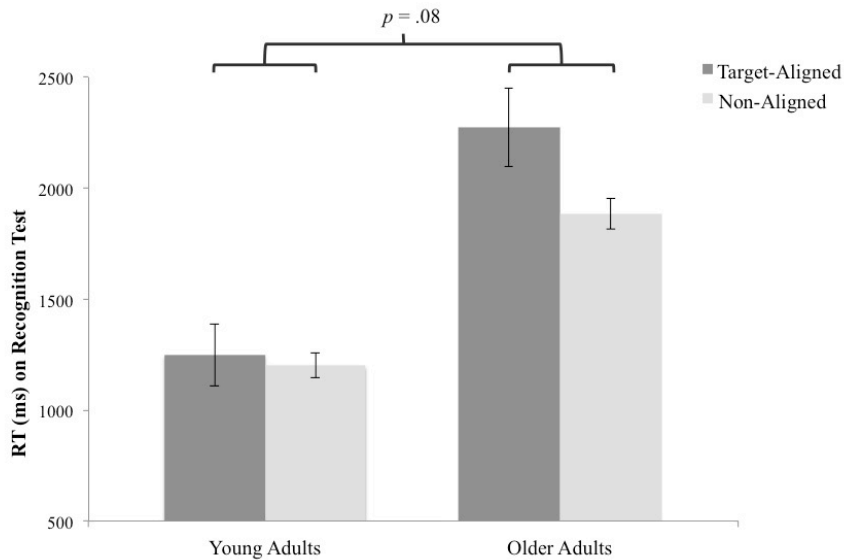


Figure 24 – Age Comparison by Speed (Exp. 2): Graph depicting overall reaction times (ms) between young and older adults in Experiment 2. The ANOVA revealed a marginal main effect for age ($p = .08$) suggesting that, overall, older adults may have responded to words significantly more slowly than young adults. There was no main effect for target-alignment and no interaction.

v. Discussion: Experiment 2

The findings from the young adult group of Experiment 2 are in line with previous research conducted by Dewald et al., (2012) and may extend to an older population as well. We found that for both older and young adults, target-aligned words were recognized significantly better than chance while non-aligned words were not. Young adults recognized target-aligned words (85%) significantly more often than the non-aligned words (59%), however, the older adults did not exhibit a significant difference in recognition rates between target-aligned (80%) and non-aligned words (63%). Despite the lack of significance within the older group, the trend in performance

was very similar for both young and older adults and there was no significant difference in recognition rates to target-aligned and non-aligned words between the two age groups. Therefore, it appears that both young and older adults experienced facilitated processing for the target-aligned words compared to the non-aligned words. Moreover, given the numerical trend in these data it is likely that an increase in the number of older adult participants would lead to significant differences. Also, due to the very high exposure rate, and therefore longer exposure time to the unattended stimuli during the attention-demanding repetition detection task, higher rates of attrition are likely to occur for both age groups. As a result of this longer exposure time, inhibitory control over the unattended stimuli may decline, especially among older adults.

Considering the ANOVA conducted on participant accuracy scores, there was a main effect for target-alignment, however there was no main effect for age and no interaction. This finding is interesting considering that the difference in recognition rates for target-aligned and non-aligned words did not reach significance among the older adults. Overall, this result lends even greater support that target-alignment may facilitate processing of unattended stimuli across age groups. It is possible that older adults and younger adults use a facilitatory mechanism in much the same way. While an overall disturbance in inhibitory control may be occurring in older individuals as observed in Experiment 1, an intact facilitatory mechanism may be operating to bolster processing for the unattended items due to the high rate of presentation and extended exposure time in Experiment 2.

The two-way ANOVA conducted on participant RTs suggested a trend towards older adults responding to words more slowly in the surprise recognition test than young

adults ($p = .08$). Older adults also exhibited marginally significant slower RTs to target-aligned words compared to the young adults (2271ms and 1246ms, respectively, $p = .09$) and significantly slower RTs to non-aligned words (1881ms and 1200ms, respectively, $p = .01$). Therefore it is likely that this trend would reach significance with additional participants resulting in a main effect for age. While, it was anticipated that overall RTs to the target-aligned words presented in Experiment 2 would be significantly faster compared to RTs for non-aligned words (indicating facilitation), this was not the case statistically, despite the numerical trend. It is clear that more data collection is necessary in order for a more complete understanding of the response time findings in this condition.

Older adults had poorer performance and a higher number of FAs on the primary task of detecting picture repetitions when compared with younger adults. This suggests that the task may have been more demanding for the older adults. We also found that older adults responded to targets significantly slower than the younger adults (555ms and 461ms, respectively). As in Experiment 1, this demonstrates that it took the older adults longer to process and therefore respond to the presented stimuli during the repetition detection task, which may be an indication of a reduction in overall processing speed.

The findings from Experiment 2 would seem to suggest that a generalized slowing of global information processing may be responsible for the slower RTs observed in older adults, as predicted by processing speed theory (Salthouse, 1996). However, it appears the older adults do not experience a disturbance in facilitatory attentional control, which may be functioning to increase information processing for frequently presented irrelevant stimuli, and may be more resilient to age related decline.

IV. General Discussion

The research conducted in this thesis examined potential age related declines for inhibitory and facilitatory attentional mechanisms. The goal was to determine if any observed age related decline in these mechanisms might be attributable to one of two previously theorized accounts. First, processing speed theory (Salthouse, 1996) suggests that age related decline in attentional tasks might be due to a generalized slowing of global information processing. This means that as individuals progress into old age, the speed at which they process information may decline resulting in decrements in attentional processes. Second, inhibitory deficit theory (Hasher & Zacks, 1988) suggests that, in addition to a slowing in processing speed, aging also results in a decline in the ability to inhibit the processing of information, thereby resulting in declines in performance on attentional tasks due to higher rates of distractibility and incidental processing of irrelevant information. The approach taken here was ideal as the paradigm is able to selectively measure inhibition or facilitation, and specific predictions can be made that would favor either theoretical stance for why cognitive decline is observed in an aging population.

In Experiment 1, processing speed theory (Salthouse, 1996) would predict that older adults have significantly slower RTs on the surprise recognition test as well as slower RTs and poorer performance on the primary task compared to younger adults. This theory would also predict that both young and old participants should show significantly *lower* recognition rates for target-aligned words compared to non-aligned words (i.e., inhibition for target-aligned words). Indeed, older adults exhibited slower RTs compared to the younger adults on the primary task as well as the surprise

recognition test, which is consistent with other studies that have compared RTs between younger and older adults (Carlson et al., 1995; Cerella, 1985, 1990; Lustig et al., 2006; Milham et al., 2002; Wang et al., 2012) suggesting a generalized slowing of information processing. However, older adults exhibited a different pattern in recognition rates compared to the young adults, which would lend support to the inhibitory deficit theory.

As conceptualized by Hasher and Zacks (1988), the inhibitory deficit theory would predict that, in addition to global slowing of information processing, older adults have a difficulty in inhibiting irrelevant information, which should lead to more similar accuracy scores between word types and possibly near chance performance for both word types. This theory was only partially supported in that younger adults exhibited inhibited processing for target-aligned words (37%) while non-aligned words were recognized at near chance levels (44%), but this was not the case for older adults. Rather, older adults recognized target-aligned and non-aligned words at similar rates, (32% and 34% respectively), which were both significantly lower than chance. This finding suggests that instead of older adults having difficulty inhibiting information, they seemingly inhibited more information than necessary. Older adults also recognized words, overall, significantly less often than the younger adults. If this account can be taken at face value, then the findings from Experiment 1 would suggest 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 words during the exposure stage, regardless of target alignment. Thus, the findings of Experiment 1 suggest that older adults do indeed experience a slowing in information processing as well as diminished

inhibitory attentional control, which may explain the reduced difference in overall performance accuracy for older participants.

In the second experiment, processing speed theory (Salthouse, 1996) would predict that older adults have significantly slower RTs on the surprise recognition test as well as slower RTs and poorer performance on the primary task compared to younger adults (identical to Experiment 1). This theory would also predict that older participants should show significantly *higher* recognition rates for target-aligned words compared to non-aligned words, much like is seen in younger adults (i.e., facilitation for target-aligned words). The findings of Experiment 2 appear to support this account, as older adults exhibited slower RTs compared to the younger adults on the primary task of detecting repetitions, and a strong trend in this direction in the surprise recognition test, suggesting a generalized slowing of information processing. Older adults also exhibited a similar trend in responses compared to the younger adults. Here young adults recognized target-aligned words significantly more often than non-aligned words (85% and 59% respectively) and, again, non-aligned words were recognized at chance levels, as expected. Older adults recognized target-aligned words significantly above chance levels (80%) while non-aligned words were not (63%), but a significant difference between word types was not observed, despite the large numerical difference (17%). It is possible that the low number of participants in the older adult sample could account for the lack of significant differences in this case. Regardless, the overall findings from this experiment would seem to suggest that older adults have an intact facilitatory mechanism that may be operating to bolster processing for the unattended items much the same way it does in younger adults. Thus, the findings of Experiment 2 suggest that while a generalized

slowing of global neurological processing may account for the overall longer RTs, facilitatory attentional control remains widely unaffected resulting in similar performance accuracy between the two age groups.

Taken together, it appears that older adults likely experience a generalized slowing of information processing which was exhibited by significantly slower RTs during the primary task of detecting repetitions in Experiment 1 and Experiment 2. We also observed that older adults exhibited significantly slower RTs during the surprise recognition test during Experiment 1 with a similar trend in Experiment 2. Additionally, the accuracy results from Experiment 1 point towards a difficulty with inhibitory processes among the older adult group. That is, while younger adults showed selective inhibition for target-aligned words, compared to non-aligned words, older adults appeared to inhibit processing of all words presented during the primary task. This suggests that older adults may experience a reduced ability to selectively inhibit word processing resulting in a more global inhibition of processing words presented during the primary task, regardless of target alignment. This global inhibition may be due to the primary task being more difficult for the older adults, thus requiring more concentration and attention in order to identify immediate picture repetitions.

The similar trend in response rates observed in Experiment 2 appear to suggest that a separate, facilitatory mechanism may be operating in tandem with the inhibitory mechanism. This facilitatory mechanism may be functioning to increase processing of irrelevant information that is presented frequently, and may be more resilient to age related decline. This interpretation falls in line with previous research on cognitive aging demonstrating that other cognitive mechanisms which fall under the category of

‘executive function’ such as multi-tasking and fluid intelligence are separable cognitive factors supported by distinct neural subsystems within the prefrontal cortex that are also differentially susceptible to age related decline (Kievit et al., 2014). Therefore, it is possible that the aging process may differentially affect inhibitory and facilitatory mechanisms, such that the latter is less susceptible to age related decline.

Furthermore, in cases of frequent presentations as seen in Experiment 2, the facilitatory mechanism also seems to ‘override’ the inhibition seen in Experiment 1. Indeed, the increased inhibition for older adults observed in Experiment 1 is entirely mitigated in Experiment 2, resulting in seemingly identical performance levels between age groups. This suggests that any facilitatory mechanism in the older adults might be used as a compensatory mechanism to aid in information processing. This interpretation corresponds with research suggesting that older adults exhibit greater facilitatory benefits from multisensory presentations and a broader window of enhancement than younger individuals (Laurienti, Burdette, Maldjian, & Wallace, 2006; Mahoney, Li, Oh-Park, Verghese, & Holtzer, 2011; Peiffer, Mozolic, Hugenschmidt, & Laurienti, 2007). Thus, older adults may employ multisensory cues more readily than younger adults in order to compensate for declines in individual sensory modalities much the way a facilitatory mechanism may be employed as a compensatory mechanism to enhance information processing.

In order to examine potential age related differences further, additional studies may examine performance on similar tasks in different sensory modalities, or even across modalities. This would offer the opportunity to establish if these attentional mechanisms operate similarly between young and older individuals across sensory systems and

whether the same types of declines are present. More research is also necessary to determine the extent to which, if at all, these mechanisms are indeed independent. Future research may also incorporate imaging measures such as functional magnetic resonance imaging (fMRI) to help establish correlations between behavioral observations and areas of neurological activity for young and old individuals on both versions of the paradigm.

6. Future Directions

Based on the findings from Experiment 1 and Experiment 2 it is clear that increasing the sample size would be of critical importance for future research. Recruiting older adults is a challenge, especially in an isolated location such as Hawai‘i. Making contact with retirement facilities and other organizations that are receptive to psychological research is time consuming and requires a large network and resources. Furthermore, locating older adults that meet the inclusion criteria also limits the number of older adults that can participate in the research. Currently, steps are being taken to increase enrollment rates, particularly among the older adult sample. Future studies will incorporate recruitment methods that may be able to reach a wider population and rely less on cooperation from organizations such as recruitment flyers and postcards.

A potential methodological problem is also worth discussing. It should be noted that there was a difference in surprise recognition test administration between Experiment 1 and Experiment 2. Recall that in Experiment 2 there were a total of eight words in each version of the experiment, one target-aligned word and seven non-aligned words. During the surprise recognition test, participants were shown 16 words in total, the eight words from the experiment plus eight never before seen foil words. This allowed for a within subject analysis of accuracy performance between target-aligned and non-aligned words.

In Experiment 1, the increased number of words presented, 50 target-aligned and 50 non-aligned, prevented us from administering a comprehensive surprise recognition test. This is because a test of that nature would have comprised of 200 words in total and it would be particularly cumbersome and taxing for the participants to complete. Thus, as observed in all previous research using this paradigm, the surprise recognition test was divided into two versions testing target-aligned words in one and non-aligned words in another, which did not allow for a within subject analysis of performance.

To address this, the paradigm in Experiment 1 is being modified so that the surprise recognition test contains a subset of both target-aligned and non-aligned words. A pilot study is currently being conducted with a population of healthy young adults to determine if the results from this version of the paradigm will be comparable with the original version. Once comparability is established, this new version will be incorporated into future studies, replacing the original version. Furthermore, the recognition test in Experiment 2 is quite short, 16 items total, whereas the recognition test for Experiment 1 is nearly seven times longer, consisting of 100 items. When comparing performance across groups one must be cognizant of the differing effects the length of the test may have on performance of those in the older adult group compared to those of the younger group. Again, modifying the surprise recognition test to include a subset of the target-aligned and non-aligned words may attenuate this issue.

In addition to addressing the potential issues listed above, future research will also examine how these mechanisms operate within the auditory sensory modality, and cross-modally as well, in an aging population. To do this the current, visually presented, paradigm will be adapted. The visual images will be replaced with auditory sounds and

the written words will be replaced with auditory recordings of spoken words. Participants will be instructed to monitor the sounds stream for immediate repetitions while ignoring the spoken words. Later, a surprise recognition test for the spoken words will be presented in the auditory modality. In order to examine how these attentional mechanisms operate cross-modally, participants will be presented with one of several auditory and visual combinations of the previously mentioned stimuli. For example, participants may be asked to monitor a visual stream of images while ignoring spoken words. Later they would be tested on the ignored auditory words. Likewise, they may be asked to monitor an auditory sounds stream for immediate repetitions while ignoring visually presented words. Later, participants would be tested on the visually presented words. The surprise recognition test can also be augmented so that the manner in which participants are tested on the ignored stimuli can be congruent with initial presentation (e.g. both visually) or incongruent (e.g. presented visually, tested aurally). Together, these additional experiments will provide a wealth of knowledge regarding how attentional mechanisms and information processing may change over the course of one's lifespan.

Appendices

A. Participant Consent Form – older adult participants



The UNIVERSITY OF HAWAII AT MANOA

Department of Psychology
University of Hawaii
Phone: 808.956.6272

Consent Form

Information processing within and across sensory modalities

Principal Investigator: Dr. Scott Sinnett, Department of Psychology, University of Hawaii at Manoa. Phone: (808) 956-6272, Email: ssinnett@hawaii.edu.

Introduction and Purpose

This study aims to gain a deeper understanding of how humans direct attention and perceive auditory and visual information in our environments. One of the goals of this project is to determine how we perceive information that arrives at the same time at our eyes and ears, when compared with when we process information only with our eyes or our ears alone. We are also interested in determining how our ability to pay attention and process information changes as we age. These studies should help us to develop broader knowledge of how information in our environment is processed across the human lifespan. This is a relatively understudied area of science and therefore very important. A better understanding of how our attention and perception changes with age could one day help us to improve cognitive abilities in general, or at least slow down any potential cognitive decline.

Consent

Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time. Withdrawal or the decision to not participate will have no effect whatsoever on your care or any services provided for you by the Kahala Nui Retirement Home. Please feel free to ask the experimenter any additional questions you may have about the study.

Study Procedures

If you agree to participate, the experiment will take about 30-60 minutes of your time. You will spend most of this time seated in front of a computer monitor. You will participate in one or possibly two tasks. If you do participate in two, they will be done consecutively (i.e., not at the same time). The tasks all involve visual and/or auditory presentations of information on a computer. On the screen you will see a stream of objects. At the same time you will hear words or sounds originating from speakers placed beside the screen, or a pair of headphones. The sounds will be presented at a comfortable volume level (i.e., no louder than a regular conversation). Your task will be to respond to specific items that occur in the sound or visual stream by pressing different keys on the keyboard. Before beginning the experiment, you will receive ample instruction and training on the task. If you are not sure about any instructions, or wish to have more practice, do not hesitate to ask. Throughout the experiment, you may take a break whenever you need. Furthermore, you may discontinue your participation at any time without any repercussion.

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Department of Psychology
University of Hawaii
Phone: 808.956.6272

Possible Risks

To the best of our knowledge, there are no foreseeable risks to participating in this experiment. However, like any computer task you might become fatigued, or possibly feel disoriented or distressed. Thus, you are welcome to take breaks whenever necessary. If you exhibit any signs of fatigue or distress, we will discontinue the experiment. Likewise, if you feel any fatigue or distress please tell us and we will stop the experiment. As you know, Kahala Nui has a top-of-the-line First Responders Unit that can be anywhere on the property within two minutes for any type of emergency.

Benefits

There are no direct benefits to you, however your participation will contribute to the enhancement of our understanding of human cognition and how our mental abilities change over time.

Pre-existing conditions

If you suffer from any pre-existing conditions or risk factors that you feel would prevent you from safely participating in this study, please do not participate. This will in no way effect the services or level of care that is provided to you by the Kahala Nui Retirement Home.

Confidentiality

Your identity will be kept strictly confidential. All documents will be identified only by a subject code number and kept in a locked filing cabinet. You will not be identified by name in any reports of the completed study. Data that will be kept on a computer hard disk will also be identified only by your subject code number and will be password protected so that only the principle investigator, Dr. Scott Sinnett, his graduate students, and research assistants will have access to it. Following the completion of the study, the data will be transferred to a CD and stored in a locked filing cabinet. Note, the results of this study will be used to write a scientific report.

Contact for information about the study

This study is being conducted by Dr. Sinnett, the principal investigator. Please call him if you have any questions about this study. Dr. Sinnett may be reached at (808) 956-6272 or ssinnett@hawaii.edu.

Contact for concerns about the rights of research subjects

If you have any concerns about your treatment or rights as a research subject, you may contact the IRB Committee on Human Studies at (808) 956-5007.

Signature: _____

Date: _____

B. Participant Consent Form – younger adult participants

The UNIVERSITY OF HAWAII AT MANOA



Department of Psychology
University of Hawaii
Phone: 808.956.6272

Consent Form

Information processing within and across sensory modalities

Principal Investigator: Dr. Scott Sinnett, Department of Psychology, University of Hawaii at Manoa. Phone: (808) 956-6272, Email: ssinnett@hawaii.edu.

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Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time without prejudice or loss of compensation.

Study Procedures

If you agree to participate, the experiment will take about 30-60 minutes of your time. You will spend most of this time seated in front of a computer monitor. On the screen you will see a stream of objects. At the same time you will hear words or sounds originating from speakers placed beside the screen, or a pair of headphones. The sounds will be presented at a comfortable volume level (i.e., no louder than a regular conversation). Your task will be to respond to specific items that occur in the sounds or visual stream. Before beginning the experiment, you will receive ample instruction and training on the task. If you are not sure about any instructions, or wish to have more practice, do not hesitate to ask. While you are engaging in this task a remote, non-invasive camera called an eye-tracker will monitor your eye gaze. This tool is designed to monitor the direction of your eye gaze only and will not collect any additional or identifying information about you. This technology is perfectly safe and has never lead to any adverse effect.

Risks

To the best of our knowledge, there are no foreseeable risks to participating in this experiment. However, like any computer task you might become fatigued, or possibly feel disoriented or distressed. Thus, you are welcome to take breaks whenever necessary. If you exhibit any signs of fatigue or distress, we will discontinue the experiment. Likewise, if you feel any fatigue or distress please tell us and we will stop the experiment.

The UNIVERSITY OF HAWAII AT MANOA

Department of Psychology
University of Hawaii
Phone: 808.956.6272



Benefits

There are no direct benefits to you, however your participation will contribute to the enhancement of our understanding of human cognition and how our mental abilities change over time. The information collected here will be compared to an aging population and this comparison may be used to enhance our knowledge of mental decline with age and contribute to a greater understanding of human cognition in general.

Pre-existing conditions

If you suffer from any pre-existing conditions or risk factors that you feel would prevent you from safely participating in this study, please do not participate. Your non-participation will in no way effect your compensation.

Confidentiality

Your identity will be kept strictly confidential. All documents will be identified only by a subject code number and kept in a locked filing cabinet. You will not be identified by name in any reports of the completed study. Data that will be kept on a computer hard disk will also be identified only by your subject code number and will be password protected so that only the principle investigator, Dr. Scott Sinnett, his graduate students, and research assistants will have access to it. Following the completion of the study, the data will be transferred to a CD and stored in a locked filing cabinet. Note, the results of this study will be used to write a scientific report.

Contact for information about the study

This study is being conducted by Dr. Sinnett, the principal investigator. Please call him if you have any questions about this study. Dr. Sinnett may be reached at (808) 956-6272 or ssinnett@hawaii.edu.

Contact for concerns about the rights of research subjects

If you have any concerns about your treatment or rights as a research subject, you may contact the IRB Committee on Human Studies at (808) 956-5007.

Signature: _____

Date: _____

C. Debriefing Form

The University of Hawai'i at Manoa

Debriefing Attention and Perception

Dear Participant,

During this study, you were asked to participate in one or more activities via computer, which included auditory, visual, or text displayed on the computer. You were asked to respond to a stream of objects by pressing different keys on the keyboard, or a foot pedal under your foot. You'll notice that we did not tell you that you were going to be asked to identify some of the objects we told you to ignore during the first part of the experiment. We did not tell you about this part of the experiment because if you had known that we were going to ask you about the objects later the results of the study would be compromised. It is important that future participants are also unaware of this aspect of the study so please keep this information confidential and do not discuss the nature of the experiment with anyone.

You are reminded that your original consent document included the following information: Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time without jeopardy to your class standing.

If you have questions about your participation in the study, please contact me at maegenw@hawaii.edu or my faculty advisor, Dr. Sinnett at ssinnett@hawaii.edu

If you have questions about your rights as a research participant, you may contact the UH Human Studies Program, by phone at (808) 956-5007, or University of Hawai'i Institutional Review Board at uhirb@hawaii.edu.

Please again accept our appreciation for your time, participation and cooperation.

Sincerely,

Maegen Walker

D. IRB approval of proposed project



UNIVERSITY
of HAWAII[®]
MĀNOA

Office of Research Compliance
Human Studies Program

MEMORANDUM

February 6, 2014

TO: Scott Sinnett, Ph.D.
Principal Investigator
Psychology Department

FROM: Denise A. Lin-DeShetler, MPH, MA
Director

A handwritten signature in black ink, appearing to read "Denise A. Lin-DeShetler".

SUBJECT: CHS #21455 – “Information Processing Within and Across Sensory Modalities”

Your application for the Human Studies Program approval of a proposed change for the study identified above was approved by the Human Studies Program on February 4, 2014. The approved change was for the small questionnaire. This application qualified for Expedited Review under CFR 46.110 and 21 CFR 56.110, Category (b). Note that this approval date is for the proposed revision, and does not reset the annual study expiration date. Please refer back to your most recent IRB approval letter (initial application or continuing review) for the study's expiration date. Regulations require that continuing review be conducted on or before the one-year anniversary date of IRB approval.

If future revisions to your study are required, please seek the Human Studies Program approval prior to their implementation. If a change is necessary to protect the safety or welfare of study participants, it is permissible to make the change without prior approval. However, you must notify the Human Studies Program as soon as possible, requesting approval for the change.

When seeking approval to modify a Human Studies Program-approved document, please submit the document using “Track Changes” to identify the proposed modifications. Clearly explain the reason for the change on the Human Studies Modification form.

Please contact the Human Studies Program office at 956-5007 if you have any questions or require assistance.

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