Are age-related differences uniform across different inhibitory functions?

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Abstract

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The Inhibitory Deficit Hypothesis (Hasher, Zacks, & May, 1999) posits age-related declines in three inhibitory functions: 1) Access: filtering out irrelevant information 2) Deletion: suppressing no longer relevant information, and 3) Restraint: inhibiting the production of prepotent responses. However, it is unclear if the magnitude of age-related decline is comparable across all three inhibitory functions. One obstacle to addressing this question is the use of different measures, which introduces task specific variance. To circumvent this problem, I used a modified Sequential Flanker Task (Li & Dupuis, 2008) to measure all three inhibitory functions. Twenty-four young (18-35 yrs.) and 20 older adults (60-75 yrs.) first memorized a series of eight animal words in fixed order. In the test phase, these stimuli were presented randomly, and participants responded ‘yes’ or ‘no’ based on the prelearned sequence. Occasionally, the stimuli were presented with flanker words, which were either ahead of the current target (+1, +2…+7 lags) or previously selected items (-1, -2…-7 lags). To measure Access, extra-list flanked trials were compared to positive lag flanked control trials. To measure Deletion, pooled negative lag flanked trials were compared with -1 lag flanked control trials. To measure Restraint, participants were given flanker cues (XXXX) to withhold their response on 20% of trials. Age-related differences favouring the young adults were greatest for Restraint followed by Deletion. These findings suggest that age-related differences in inhibitory functions are not uniform, in line with previous research on aging and inhibition.

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Several areas of research converge to suggest age-related declines in cognitive functioning. Compared to young adults, older adults show reduced performance in a wide variety of cognitive tasks, including tests of perceptual speed (Lustig, Hasher, & Tonev, 2006), spatial and reasoning abilities (Salthouse, 1992), mental rotation (Band, & Kok, 2000), visual search (Scialfa, Esau, & Joffe, 1998), reading speed and comprehension (Carlson, Hasher, Connelly, & Zacks, 1995; Connelly, Hasher, & Zacks, 1991; Li, Hasher, Jonas, Rahhal, & May, 1998), working memory (Lustig & Hasher, 2002; May, Hasher, & Kane, 1999; Rowe, Hasher & Turcotte, 2008), problem solving and decision making (May, 1999; Tentori, Osherson, Hasher, & May, 2001), attentional regulation (May, Kane, & Hasher, 1995; Butler, Zacks, & Henderson, 1999; May & Hasher, 1998), episodic memory (Gerard, Zacks, Hasher, & Radvansky, 1991; Lustig & Hasher, 2001, Rowe, Valderrama, Lenartowicz & Hasher, 2006; Zacks, Radvansky, & Hasher, 1996), coordination ability (Mayr & Kliegl, 1993; Mayr & Kliegl, & Krampe, 1996) and task switching (Mayr, Spieler, & Kliegl, 2001).

These empirical findings reflect age-related differences in a wide variety of cognitive tasks, cutting across domains and mapping onto different stages of information processing. A major challenge of cognitive aging research, therefore, is to identify a subset of basic mechanisms or cognitive primitives that can explain these age-related deficits (Verhaeghen, Cerella, Bopp, & Basak, 2005). It is well documented that the observed age-related cognitive deficits are related to decline in some basic cognitive mechanisms, such as processing speed (Salthouse, 1991, 1996), working memory capacity (WMC; Engle & Kane, 2004; Kane et al., 2007) and inhibition (Dempster, 1992; Hasher, Lustig, & Zacks, 2007; Hasher, Zacks, & May, 1999).

According to one prominent theory of cognitive aging, the Inhibitory Deficit Hypothesis (Hasher et al., 2007, 1999), older adults' deficits in complex cognitive tasks are a result of the inefficient operation of three inhibitory functions, namely Access, Deletion and Restraint. The Access function prevents the entry of irrelevant information into conscious awareness (i.e., working memory) while the Deletion function suppresses no-longer relevant information and the Restraint function prevents the execution of inappropriate habitual responses. The common function of these three inhibitory processes, therefore, is to reduce the disruptive effects of interference and help focus on goal related information.

While a growing number of studies point to age-related differences favoring young adults in Access (e.g., Carlson et al., 1995), Deletion (e.g., May, Zacks, Hasher, & Multhaup, 1999) and Restraint (e.g., Butler et al., 1999), it is still unclear whether the magnitude of age-related declines is comparable across the three inhibitory functions. The purpose of the current experiment is to examine which inhibitory function is most susceptible to age-related declines. Given that researchers typically measure each inhibitory function by different types of cognitive tasks, it is possible that the magnitude of age-related declines is confounded by task-specific variance. In the current experiment, therefore, Access, Deletion and Restraint were examined within a single cognitive task, thereby controlling for task specific characteristics.

In the following section, I will first describe a few of the general theories of cognitive aging, namely processing speed, and executive control functions. Under the most frequently postulated executive control functions, I will elucidate how WMC and inhibitory frameworks have been proposed as the likely candidates to explain age-related differences in complex cognition. Then, I will argue that the relative magnitude of age-related differences across different inhibitory functions may be confounded by task-specific characteristics (e.g., task-specific attentional demands and interference conditions). Finally, I will describe the current research objectives, rationale, and predictions.

Age-related Declines in Processing Speed

One dominant view in the aging literature is that the rate or speed of processing is important for cognitive performance, and processing speed declines with age (Salthouse, 1991, 1996). According to the Processing Speed hypothesis, older adults' performances in many cognitive tasks are limited by general processing constraints. These constraints in turn have been attributed to demyelination and consequent slowing of neural transmission. Accordingly, at the behavioral level, when older adults execute a subset of a cognitive operation, they are typically unsuccessful in completing the relevant operation within a particular temporal window. This slowdown in one subset affects the overall cognitive operation, as the later processing operations are either less effective or only partially completed.

The Processing Speed model thus predicts that older adults are slower not only in complex cognitive tasks as reflected by an overall slowdown in cognitive operations, but also on simple tasks that place little or no demands on successive operations. These predictions are in line with evidence suggesting that older adults are slower compared to younger adults irrespective of the type of cognitive task, and the time taken by older adults is a linear function of the time taken by young adults (for overviews, see Cerella, 1990; Salthouse, 1996; for meta-analysis see, Cerella, Poon, & Williams, 1980; Myerson, Hale, Wagstaff, Poon, & Smith, 1990). Consistent with the Processing Speed hypothesis, a growing number of studies show that processing speed explains most of the age-related variance in memory (Bryan & Luszcz, 1996; Clarys, Isingrini, & Gana, 2002), general intelligence and reasoning (Hertzog & Bleckley, 2001; Zimprich & Martin, 2002), and spatial abilities (Finkel, McArdle, Reynolds, & Pedersen, 2007)

Further evidence in support of the Processing Speed hypothesis and age-related declines in cognitive functioning comes from cognitive neuroscience. For example the caudate nucleus, a brain region that is associated with general cognitive slowing (Dubois, Boller, Pillon, & Agid, 1991; Rubin, 1999), is shown to decline in volume with age (Eggers, Haug, & Fischer, 1984; Jernigan et. al, 1991; Krishnan et al., 1990). Similarly, recent neuroimaging studies suggest that the age-related differences in white matter integrity in the whole brain may also be responsible for the generalized slowing (see Gunning-Dixon, Brickman, Cheng, & Alexopoulos, 2009; Penke et al., 2010; Salami, Eriksson, Nilsson, & Nyberg, 2011).

Taken together, both the behavioral and neuroimaging data bolster the argument that processing speed may qualify as a true cognitive primitive, that is, a variable that influences cognitive system without being further reducible to other psychological constructs (Verhaeghen et. al., 2005). However, as noted by Kramer, Humphrey, Larish, Logan, and Strayer (1994) empirical evidence suggesting a generalized slowdown in older adults is more descriptive rather than theoretical in nature (but see Cerella, 1990). That is, without knowing the cognitive processes underlying complex task performance, it is hard to understand how basic slowing translates to observed performance. Another problem with the Processing Speed hypothesis is that often times the proportional slowdown as predicted by general slowing is not supported. In fact, older adults show disproportionate slowing, beyond what is predicted by a linear function. Given these theoretical limitations of the general slowing model, declines in executive control functions such WMC and inhibition have been proposed to explain older adults' disproportionate slowing in complex tasks. In the following section, before describing the WMC and the inhibitory theories, I will briefly present an overview of age-related differences in executive control functions.

Age-related Declines in Executive Control Functions

Unlike the Processing Speed hypothesis, theories of executive control functions argue that older adults show decline in specific higher order control mechanisms that modulate the operation of various cognitive sub-processes. At the outset of executive functions research, higher level concepts such as planning and problem solving were used as indices of executive control (see Rabbitt 1997, for a review). In recent years, however, these higher level concepts have been refined into a number of more basic executive functions such as task switching, working memory and inhibition (e.g., Baddeley, 1996; Logan, 1985; Lyon & Krasnegor, 1996; Miyake et al., 2000, Rabbitt, 1997a; Smith & Jonides, 1999). For example, by using confirmatory factor analysis, Miyake et al. (2000) showed that a) switching between tasks or mental sets b) updating and monitoring of working memory representations and c) inhibition of pre-potent responses are separable constructs that fall within the general class of executive control functions.

The neuropsychological rationale for executive function theories is that the age-related structural and functional changes in the frontal cortex lead to specific declines in executive abilities which in turn lead to more general cognitive deficits. Consistent with these predictions, neuroimaging studies have shown that the efficiency of executive control functions is related to the integrity of the frontal lobes, which in turn are the most vulnerable to advancing age (see Raz & Rodrigue, 2006; Raz, Rodrigue, Kennedy, & Acker, 2007; West, 1996). In addition to the evidence supporting the relation between the frontal lobes, executive control functions and aging, numerous studies suggest that the age-related declines in executive control functions play a mediating role in other cognitive sub-processes such as age-related declines in memory (Clarys, Bugaiska, Tapia, & Baudouin, 2009; Parkin, 1997), strategy and meta-cognition cognition (Bouazzaoui et al., 2010; Taconnat et al., 2006) and activities of daily living (Vaughan & Giovanello, 2010).

The executive control functions pertinent to this experiment are working memory and inhibition. With respect to working memory, Miyake et al. (2000) pointed out that updating of working memory representations requires more than simple maintenance of task-relevant information. In fact, the essence of ‘updating’ lies in the requirements to actively manipulate goal-related information in conscious awareness. Based on this definition of working memory, researchers often use the idea of working memory ‘limits’ or ‘capacity’ to index an individual’s ability to manipulate goal-related information as demanded by task instructions. Thus, high working memory capacity (WMC) can be attributed to more efficient manipulation of goal-related information, rather than the absolute number of items held in conscious awareness. As will be described below, two related but slightly different theories (i.e., Executive Attention theory and Inhibitory Deficit hypothesis) attempt to explain the causal mechanisms responsible for WMC declines in older adults.

Age-related Declines in WMC

One prominent WMC theory is the Executive Attention account (Engle & Kane, 2004; Kane et al., 2007). According to this view, individual differences in Executive Attention are the causal mechanisms for variation in tests of WMC and fluid intelligence. Executive Attention refers to one's ability to flexibly allocate attentional resources to goal related information while actively suppressing goal irrelevant information. According to the Executive Attention view, working memory is seen as an integrated memory and attentional system. Drawing from Cowan's (1995) model of working memory, the Executive Attention framework postulates that when goal related representations from long-term memory are activated above threshold, only limited representations enter into conscious awareness while the remaining goal relevant information lies outside the focus of attention. Then, the role of Executive Attention is to recover and maintain the non-accessible goal relevant information against decay and interference. Thus, Executive Attention is assumed to control two separate mechanisms: activation of goal relevant information and suppression of irrelevant information.

In much of the prior work to test Executive Attention theory, complex span tasks have been used to measure working memory limits, and thereby estimate individual differences in Executive Attention. Typically, in complex span tasks participants have to maintain memoranda for a short duration in conscious awareness in the face of processing demands. For example, in the Reading Span task (Daneman & Carpenter, 1980) participants read a series of short sentences for comprehension and then recall the sentence-final words from the series. Therefore, participants not only have to maintain goal relevant information in awareness (i.e., recall of sentence-final words), but also have to allocate attentional resources to processing demands (i.e., comprehension of sentences) and actively suppress all the irrelevant words from interfering with the target memoranda. A key finding from past research is that performance in complex span tasks correlates with a wide range of other cognitive abilities, such as reading comprehension, problem solving, and reasoning (e.g., Conway et al., 2005; Daneman et al., 1980; Daneman & Merikle, 1996; De Beni, Borella, & Carretti, 2007; Kyllonen, 1996). With respect to age-related differences, older adults show reduced performance in complex span tasks, both in verbal and spatial domains (e.g., Hale et al., 2011).

By this model, age-related differences in complex cognition should be due to older adults' decline in both activation of goal relevant information and suppression of goal irrelevant information. However, this is often not the case. For example, a number of findings suggest that older adults show preserved cognitive activation of goal-related information (see Hasher et al., 1999). In addition, contrary to the Executive Attention view, evidence from neuroimaging data suggests that older adults show greater or more distributed activation for goal-relevant information in both frontal and posterior regions (for a review, see Reuter-Lorenz & Lustig, 2005). If goal activation is age invariant, then what mechanisms are responsible for age-related differences in complex cognition?

Age-related Declines in Inhibitory Functions

Similar to the Executive Attention framework, the Inhibitory Deficit hypothesis (Hasher et al., 2007, 1999) posits that individual and age differences in suppression of irrelevant information are crucial for performance in a wide range of cognitive tasks. However, the Inhibitory framework does not assume that a third variable, such as Executive Attention, is responsible for working memory limits by flexibly allocating attention between goal maintenance (activation) and suppression of irrelevant information (inhibition). Instead, according to the Inhibitory framework, activation is largely automatic and is presumed to be equivalent across groups and circumstances. What differs between the young and older adults then, is the ability to successfully inhibit goal irrelevant information.

To this end, Hasher and colleagues conceptualized three inhibitory functions: Access, Deletion and Restraint which keep limited capacity working memory free of clutter. In the early processing stream, the Access function prevents entry of goal irrelevant information from entering into working memory. Once the goal related information has been successfully processed, the Deletion function suppresses the no-longer relevant information. Finally, at the response level, the Restraint function prevents the execution of incorrect predominant responses and facilitates goal relevant responses.

The Inhibitory Deficit hypothesis predicts that older adults exhibit decline in all three inhibitory functions. In support of age-related declines in the Access function, Connelly et al., (1991) showed that in text reading, older adults were slower and made more comprehension errors than younger adults when the target text was interspersed with semantically related distractors in unpredictable locations. Presumably, poorer performance by older adults was due to decline in Access-type inhibition. These results are consistent with findings from the visual search literature in which older adults were slower to detect targets amidst distractors, and made more errors as the number of distractors increased in the selection environment (e.g., Madden, 1983; Plude & Hoyer, 1981, 1985, 1986; Rabbitt, 1965; Scialfa, Kline, & Lyman, 1987).

Support for age-related differences in the Deletion function comes from directed-forgetting tasks (Zacks et al., 1996; Andres, Van der Linden & Pamentier, 2004), updating tasks (De Beni & Palladino, 2004), text comprehension requiring meaning revision (Hamm & Hasher, 1992) and memory for alternate sentence completion (Charlot & Feyereisen, 2004; Hartman & Hasher, 1991; Hasher, Quig, & May, 1997; May & Hasher, 1998). Recently, in support of age-related declines in the Deletion function, Blair, Vadaga, Shuchat, and Li (2011) examined the age-related differences in intrusion error rates in the Sequential Action Control Task (Li, Blair, & Chow, 2010; Li, Lindenberger, Rünger, & Frensch, 2000). In this task, participants respond to items based on a pre-learned sequence. If the presented item is not a target, then participants have to withhold their response. Compared to young adults, older adults made more intrusion errors to previously responded targets, suggesting age-related decline in Deletion-type inhibition (Blair et al., 2011; Li et al., 2010).

In support of age-related declines in the Restraint function, by using an antisaccade task (Hallet, 1978), Butler et al., (1999) showed that older adults have difficulty suppressing predominant responses. In most versions of the antisaccade task, participants are instructed to move their eyes in the opposite direction from the presented peripheral cue. Therefore, to successfully perform the task, the participants have first to suppress their reflexive saccade (i.e., looking towards the presented cue) so that an eye movement in the opposite direction can be executed. Older adults had a harder time suppressing their reflexive responses, as measured by an increase in the proportion of saccade direction errors. The other evidence of age-related declines in the Restraint function comes from the Stop signal task (Kramer et al., 1994; May & Hasher, 1998;

Williams, Ponesse, Schachar, & Logan, 1999) and Stroop task (Davidson, Zacks, & Williams, 2003; but see Verhaeghen & De Meersman, 1998).

Taken together, the reviewed studies suggest age-related declines in all three inhibitory functions. Given that each inhibitory function operates at different stages of information processing (Friedman & Miyake, 2004), such that the Access function prevents the entry of irrelevant information at an input stage, the Deletion function dampens the already activated information in working memory and the Restraint function prevents the activated incorrect response at the output level, it is unlikely that older adults would show decline in all three inhibitory functions to the same degree. It is possible that one inhibitory function is more age sensitive than the others. The purpose of the current experiment was to examine the relative age-sensitivity of the three inhibitory functions.

In the prior literature, the relative magnitude of age-related differences in Access, Deletion, and Restraint-type inhibitory functions has been partly confounded as a result of how the inhibitory functions were measured. Typically, researchers select one or more tasks that measure a specific inhibitory function and then compare the performance between young and older adults. For example, the Access function is typically measured by selective attention tasks where the participants selectively focus on the target in the midst of distractors. The difference in latencies between the distractor and no-distractor condition is taken as an index of Access-type inhibition (e.g., Eriksen Flanker task: Heitz & Engle 2007; Shape matching: Friedman et al., 2004). In contrast, typical tasks used to measure the Deletion function emphasize memory retrieval processes. For example, a typical Deletion task would entail learning words from different lists. The intrusions from previous lists are taken as an index of the Deletion-type inhibition (e.g. Paired-Associates task: Rosen & Engle, 1998; Brown-Peterson task: Kane & Engle, 2000; Directed forgetting paradigm: Zacks et al., 1996). Therefore, if stimulus characteristics and task demands vary considerably among three inhibitory functions, then it is likely that older adults will show a greater decline in one inhibitory function over the other. This differential decline in turn can be attributed to task specific attentional demands rather than to the underlying processes such as Access, Deletion, or Restraint.

To further illustrate how task specific attentional demands confound the interpretation of age-related declines in a specific inhibitory function, two sets of findings related to the Deletion function from the literature are compared. For example, the Directed forgetting task is used in the literature to measure Deletion-type inhibition. In this task, participants are given lists of items either to remember or forget. In the final test, participants are instructed to recall items from both the ‘remember’ list as well the ‘forget’ list. If there are age-related declines in the Deletion function, then older adults should show relatively smaller differences between the ‘remember’ list and the ‘forget list’ items. Presumably, the smaller difference reflects older adults’ inability to effectively suppress ‘forget’ items. These predictions are consistent with the established findings (Zacks et al., 1996). However, if the Deletion function is measured in tasks where there is little demand on memorial processes, such as visual attention or task switching, then there is little support for age-related declines. For example, in the visual attention literature, inhibition of return (IOR) can be viewed as an index of Deletion-type inhibition. The IOR effect refers to findings of increased response times to visual targets when they appear at previously attended locations, compared to response times for targets at new locations. If older adults are hypothesized to have declines in the Deletion function, then they should show a diminished IOR effect relative to young adults. In most cases, equivalent IOR effects have been found for young and older adults (Faust & Balota, 1997; Hartley & Kieley, 1995; Langley, Fuentes, Hochhalter, Brandt, & Overmier, 2001).

Similar to the notion that task-specific attentional demands might confound the interpretation of age-related declines, the level of interference imposed by a given experimental task may have a similar effect. The level of interference can be defined either in terms of quantity (e.g., number of distractors), relatedness (e.g., perceptual, semantic), proximity (i.e., how close the distractor is to the target in time and space) or expectancy. If the interference in a given task is high, in any of the four dimensions, then there is a greater need for inhibitory processes to resolve that interference. Therefore, if the levels of interference vary across different inhibitory tests, then the tests will vary in the degree to which inhibitory processes are invoked, which in turn could affect the magnitude of age-related differences in a specific inhibitory function.

To illustrate, as described earlier, in support of the Access function decline in older adults, Connelly et al., (1991) showed that in text reading, older adults were slower and made more comprehension errors than younger adults when the target text was interspersed with semantically related distractors in unpredictable locations. When the locations of the distractors were predicable or the distractors were strings of Xs then the magnitude of age related-differences was not as large (see also Li et al., 1998 for similar results). Similarly, Li (1999) showed that when the level of interference was minimized, the typical age differences found in WM operation span tasks were eliminated.

The findings from the above mentioned studies converge to suggest two interrelated ideas. The age-related differences in three inhibitory functions are possibly influenced by the nature of attentional demands and the levels of interference among tasks. Therefore, if one were to examine the relative age-related differences in three inhibitory functions, it would be advisable to measure each inhibitory function under comparable attentional demands and interference conditions. Using this experimental approach, recently, Li and Dupuis (2008) and Dumas and Hartman (2008) measured Access- and Deletion-type processes within a single task. Results from these two studies indicate that older adults were as efficient as younger adults in both Access-and Deletion-type inhibition. Given that prior research examined only two inhibitory functions at a time and null findings by themselves do not imply a lack of age-related inhibitory declines, the purpose of the current experiment was to examine the magnitude of age-related differences in all three inhibitory functions.

Current study

To examine whether there are uniform age-related differences across Access, Deletion, and Restraint functions of inhibition, the Sequential Flanker Task was modified (SFT: Li et al., 2008) to measure each inhibitory function while holding the interference and task demands constant. In the SFT, participants memorized a fixed sequence of word stimuli and responded to the items based on the learned sequence. In the current study, flanked stimuli (i.e., a central item with identical distractors above and below) were shown in Access, Deletion, and Restraint trials. The Access trials included flankers drawn from the irrelevant list, whereas the flankers for the Deletion trial comprised previously attended targets. The Restraint trials included a Flanker cue (XXXX) to withhold their response on 20% of the trials. In this way, task specific demands such as retrieval, updating, response mappings, and interference were comparable across the three critical trial types. Based on the effect sizes from previous research on age-related declines in the three inhibitory functions (Feyereisen & Charlot, 2008), I predicted that the current operationalization of the Restraint function in the SFT should be most age-sensitive followed by Deletion.

Method

Participants

Participants included 24 young adults (M_{age} = 22.75 years, *SD* = 3.77) and 20 older adults (M_{age} = 66.68 years, *SD* = 3.83), recruited from the Psychology Department at Concordia University, and the Montreal community, respectively. Participants were excluded if they reported any conditions that might impair perceptual abilities, concentration, or fine motor performance. Younger adults were compensated with partial course credit, whereas older adults were compensated with a $20 honorarium. Older adults had more years of formal education (*M* = 16.52, *SD* = 2.37) compared to younger adults (*M* = 15.25, *SD* = 1.32), $t(41) = 2.25$, $p < .05$. Both groups however were similar in general health status (younger: *M* = 3.91, *SD* = 0.63; older: *M* = 3.84, *SD* = 0.76), $t(41) = .34$, $p = .73$, with options 1 through 5 representing poor, fair, good, very good and excellent, respectively.

Materials

Background measures. Four standardized measures - The WAIS Digit-Symbol Substitution test (Wechsler, 1981), the Stroop task (adapted from Spreen & Strauss, 2001) a modified version of the Reading Span Task (Daneman & Carpenter, 1980), and Extended Range Vocabulary Test (ERVT Form V2; Educational Testing Service, 1976) were given to better describe the cognitive abilities of our sample and ensure that participants' scores were within the normative ranges.

In the WAIS Digit-Symbol Substitution test (Appendix B), participants write in the symbols corresponding to each of the randomly ordered digits, according to the key shown at the top of the worksheet. The outcome variable is the number of symbols substituted correctly within 90 seconds. In the aging literature, the score on this task has been used to index cognitive processing speed (e.g., Salthouse & Babcock, 1991).

The Stroop task was used to measure interference control across both the age groups. In the baseline congruent condition, participants indicated verbally the ink color printed on neutral stimuli (XXX). In the incongruent condition, participants avoided reading the word (e.g., “blue”) and verbally indicated the ink color in which it was printed (e.g., “red”). The outcome variable was the proportional slowdown from the congruent to the incongruent condition.

The Reading Span Task (Appendix B) was used to measure WMC. The task was computerized and programmed with Superlab V. 4.7. The task comprised short sentences presented on a desktop monitor in Black, 22 point Times New Roman font on a white background. Sentences were presented one at a time, and participants were asked to read them out loud and make a key press response indicating whether they made semantic sense or not. The task began with sets of two sentences, and after every two trials the set size increased by one sentence, up to six sentences per set. After the completion of each set, the participants were cued to recall the last word of each sentence in the order they were presented. In order to eliminate any idiosyncratic strategies that participants might employ for recall, I followed the administration suggested by Friedman et al. (2004), in which participants were explicitly told to make an immediate key press response once they had read the last word of each sentence. The outcome variable for the WMC was the total number of end words recalled correctly (out of 40).

Sequential Flanker Task (SFT). The stimuli for the SFT consisted of eight animal words that were presented on a desktop monitor in yellow, 22 point Times New

Roman font on dark blue background. Each animal word was presented either singly, or with flankers (irrelevant information). On flanked trials, three items appeared on the screen in a column 2 cm high, and spacing between them was kept constant. In keeping with previous studies (Li et al., 2008), I followed the methodology of Shaw's (1991) study of aging and flanker effects in terms of visual angle and viewing distance. On any flanked trial, the flanker words were presented above and below the middle item and were always identical, but always non-identical to the middle item. Given that it is easier to ignore visual distraction presented at the same location (Carlson et al., 1995; Li et al., 1998; 2008), the stimuli were presented randomly at five different screen locations to maximize the effects of flanker trials. At each location, the distance between central and flanker items was preserved. The inter-stimulus interval (ISI) was kept constant throughout the experiment at 1500 ms.

At the beginning of the task, participants were asked to memorize eight animal words (i.e., Butterfly, Camel, Tiger, Ladybug, Zebra, Wolf, Bird and Elephant) in a predefined order. Once they were able to recall all the words in the set order without errors, they were given further instructions about the task. In the SFT, the participants' objective was to determine whether the presented animal word was a target or a distractor based on the pre-learned sequence and make a speeded key press response accurately. Thus, a typical trial would begin with participants looking for the first animal word - Butterfly (target condition). If the target word was found, then the participants responded by pressing a "yes" key; otherwise they pressed a "no" key (distractor condition). The participants were given an option to choose among the two arrow keys on the keyboard for 'yes' and 'no' response. Once the participants responded to the first target, then they looked for second target (i.e., Camel) and so on, until they reached the final target (i.e. eighth animal word). Since the stimuli were presented in a scrambled order, the participants had to constantly update and activate the target word in working memory based on the pre-learned sequence.

Flanked Trials. As mentioned earlier, flanked trials comprised three words one above the other. The participants were explicitly instructed to focus only on the middle word while ignoring the flanker words. Although participants attempt to ignore the flanker words, it has been shown that when flankers are within one degree of visual angle of the target they affect both speed and accuracy (Eriksen & Eriksen, 1974). This pattern of results has been commonly viewed as evidence for parallel activation of the response channels of both the targets and flankers thus resulting in competition at the response activation level (Eriksen et al., 1974; Eriksen & Schultz, 1979). If the response channel of a given flanker is well suppressed then one should expect faster RTs on the corresponding trial. Therefore in the SFT, identity of flankers was manipulated to index the efficiency in different inhibitory functions. In general, there were five types of flankers. 1) *Extra list flankers*: In this condition, flankers were from outside the current set of eight animal words and included items from different categories (e.g. valley, cloud, guitar, etc.). 2) *XXXX Flanker:* In this condition, flankers were strings of X's. 3) *Positive lag flankers*: Lags refer to the relative position of the presented animal word with respect to all other animal words. For example, in this predefined sequence: 1. Butterfly, 2. Camel, 3. Tiger, 4. Ladybug, 5. Zebra, 6. Wolf, 7. Bird and 8. Elephant, if the participants were looking for the fourth animal word – Ladybug, and Ladybug appeared on the screen (target condition) then 'Wolf' would be a lag +2 flanker. Thus the positive lag flankers refer to all the animal words that are ahead of the presented word. 4) *Lag -1 flankers*: In the above example, ‘Tiger’ would be a lag -1 flanker, as it was responded to in the preceding trial. 5) *Pooled negative lag flankers*: All the previously responded items other than the just preceding item (i.e., lag -1) are referred to as pooled negative lag flankers. In the above example, Camel (lag -2) and Butterfly (lag -3) would constitute pooled negative lag flankers. In general, within set flankers were either ahead of the target (positive lags) or previously completed (negative lags).Thus, lags could vary between Lag -7 to Lag +7.

Operationalization of three inhibitory functions. Recall that the Access function refers to suppression of irrelevant information. In the SFT, a typical Access trial included flankers that were irrelevant to the current target word. Thus, the RTs on the *Extra list flanked trials* and the *Positive lag flanked trials* served as an index of the Access function. The latencies on these trial types were compared against the unflanked (baseline) condition. The Deletion function refers to suppression of previously relevant, but currently irrelevant information. Accordingly, in the SFT, the trials that were analyzed to test the Deletion effect were: *Lag -1 flankers* and *Pooled negative lag flankers*. Since negative lags were the central items seen in the previous trials, it fits well with the definition of the Deletion function: negative lags were previously relevant, but currently irrelevant. The latencies on the Deletion trial types were compared against the baseline unflanked condition. The Restraint function refers to the suppression of habitual or over-learned responses. The operationalization of the Restraint function was modeled on the lines of the go/no-go paradigm (Donders, 1969). The participants were instructed to make a speeded response to every presented word (either ‘yes’ or ‘no’ response). It is assumed that after many trials, this response pattern would become habitual. In 20% of all trials, the flankers were "XXXXX", indicating that participants should withhold their response. Thus, inability to withhold their response (i.e., response errors on Restraint trials) was considered a failure of Restraint. In short, the trial types on all the three inhibitory functions were flanked and had similar perceptual and retrieval demands. The only difference between the three inhibitory functions was the identity of the lags. Note that the correct RTs for both the target and distractor condition were pooled for both the unflanked and flanked trial types. Similarly, response errors on the Restraint trials included both the target and distractor conditions.

Trial construction. Overall there were 928 trials, grouped in 7 blocks. The first block of 128 trials was considered practice, and these data were not included in the statistical analyses. All the trial types were equally represented. That is, targets and distractors were of equal proportion (464 trials each), and the baseline trials (unflanked condition, 17%), Access trials (Positive lag flankers, 17%; Extra list flankers, 15%), Deletion trials (lag -1 flankers, 19%; Pooled negative lag flankers, 15%) and Restraint trials (XXXXX flankers, 20%) were also equally represented.

Sequences of trials were constructed with the constraint that there could be no more than three consecutive "yes" or "no" responses. A similar constraint was used for flanked and unflanked trials. Following errors of omission or commission, error screens indicated that an error had occurred and oriented participants to the next sequence item. Fig. 1 illustrates one partial trial and includes examples of flanked, unflanked, Access, Deletion, and Restraint trials.

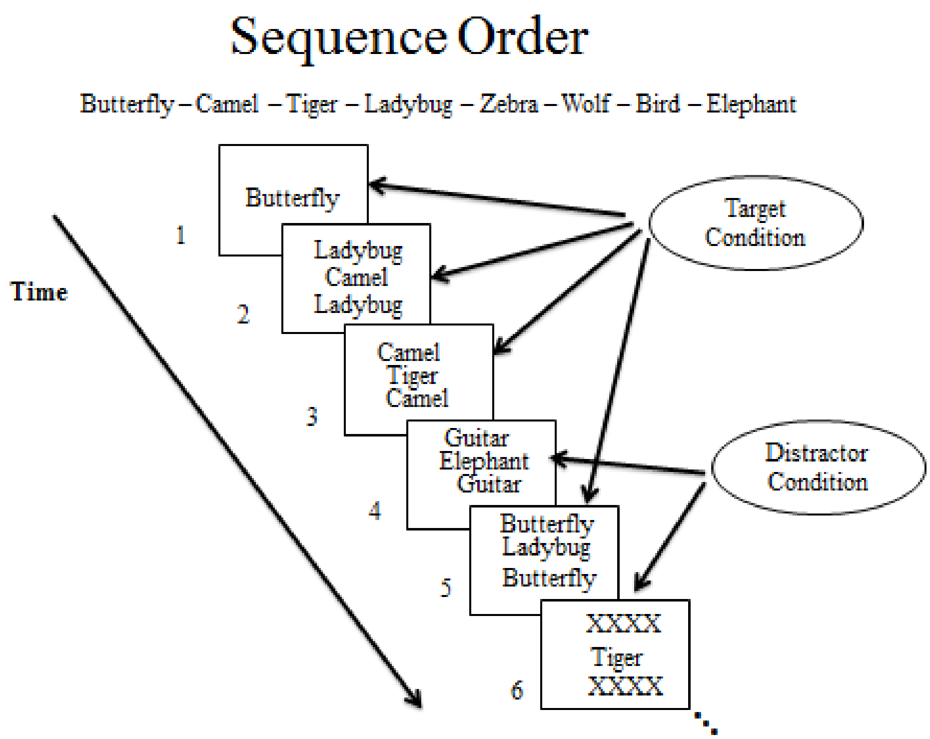

Figure 1. Sequential Flanker task stimuli for one partial run. Flanked trials (items 2, 3, 4, 5 and 6) are intermixed with unflanked trials (item 1). Participants should respond "yes" to target condition and "no" to distractor condition. Item 1 is an unflanked trial. Item 2 is a positive lag flanker trial (lag +2). Item 3 is a lag - 1 flanker trial. Item 4 is an extra-list flanked trial. Item 5 is a pooled negative lag flanker (lag -4). Item 6 is a Restraint trial.

General Procedure

The participants were tested in the Adult Development and Aging Laboratory at Concordia University. A consent form and demographic questionnaire (age, years of education, general health status, and current medications) were given early in the session. Before the commencement of the SFT, the participants completed a stimulus familiarization procedure and eight practice trials. A short break was provided after the completion of three blocks, during which the Digit-Symbol Substitution task and Stroop task were administered. After the completion of the SFT, the participants performed the Reading Span Task, after which they were debriefed and compensated. Each session lasted approximately 90 minutes.

Data Trimming and Outlier Analyses

In the SFT, the RTs were trimmed at ± 3 *SD*s, computed on the basis of each individual's correct RT distributions. The RTs from commission errors were excluded from analysis. Since both commission and omission errors were followed by an error screen cueing the participants about the upcoming target, the RTs for items following an error screen were excluded from further analysis. The RTs for trials immediately following the Restraint trial (where participants are to withhold a response) were also not included in the analysis, as it was likely that withholding of a response would provide extra time to prepare for the next trial. If any participant exceeded ± 3 *SD*s from the group mean on the SFT, such data were excluded from the main analyses. Accordingly, one older adult's data were excluded.

Results

Sample Characteristics

The background measures (i.e., WAIS Digit-Symbol Substitution Test, Stroop Task and Reading Span task), and SFT were approximately normally distributed with acceptable values of skewness and kurtosis of less than 3 and 10 respectively (Kline, 2009). Means and standard deviations on the background measures are shown in Table 1. On the WAIS Digit-Symbol Substitution Test, older adults ($M = 57.58$, $SD = 8.75$) were slower compared to younger adults ($M = 69.66$, $SD = 8.91$), $t(41) = 4.48$, $p < .05$, reflecting an age-related slowdown in psychomotor speed. Similarly, on the Stroop task older adults ($M = 0.46$, $SD = 0.18$) showed larger Stroop interference compared to younger adults ($M = 0.29$, $SD = 0.12$) $t(41) = -3.66$, $p < .05$. Age-related differences were also observed in the Reading Span task, where older adults ($M = 20.31$, $SD = 2.93$) had lower recall scores compared to younger adults ($M = 23.67$, $SD = 4.34$) $t(41) = 2.88$, $p < .05$. On the ERVT, however, older adults ($M = 14.60$, $SD = 6.24$), had higher vocabulary scores compared to younger adults ($M = 7.23$, $SD = 3.64$) $t(41) = -4.83$, $p < .05$.

Age-related differences in three inhibitory functions

The main goal of the current experiment was to examine relative age-related differences across the three inhibitory functions. Given that Age X Treatment statistical interactions on mean differences can have a multiplicative or proportional influence of general slowing (Salthouse, 1996), such that the absolute differences between age groups increase with the magnitude of the treatment effect (e.g., Cerella, 1990; Cerella, Poon, & Williams, 1980), I used proportional scores to examine age-related differences on the Access and the Deletion functions, thereby taking into account age-related proportional slowing.

Table 1

Means and Standard Deviations on the Background measures by Age Group

Age Group	Digit Symbol [a]	Stroop Interference [b]	Reading Span task [c]	ERVT [d]
Young	69.66	0.29	23.67	07.23
	(8.91)	(0.12)	(4.34)	(3.64)
Older	57.58	0.46	20.31	14.60
	(8.75)	(0.18)	(2.93)	(6.24)

Note. Values reflect average score per group; standard deviations are shown in parenthesis. [a] Wechsler Adult Intelligence Scale-Revised (WAIS-R) Digit Symbol Substitution. The values reflect number of items completed in 90 seconds. [b] The values reflect proportional slowdown in the Stroop task, from the congruent to incongruent condition. [c] The values reflect total number of correct final words recalled in the Reading span task. [d] Extended Range Vocabulary Test- Form V2. The values reflect correct items endorsed after correcting for errors.

To examine the relative magnitude of age-related differences in each inhibitory function, I estimated the effect size (Cohen's D) by means of the formula $d = 2t/\sqrt{df}$. See Table 2 for descriptive statistics and reliability estimates for all trial types in the SFT.

The Access function. To review, the Access function prevents the entry of irrelevant information into working memory. In the current experiment, irrelevant information included two critical trial types: positive lag flankers and extra list flankers. It was predicted that both age groups would be faster in the extra list flanker trials compared to the positive lag flanker trials. The proportional slowdown for the Access function was calculated as:

(RTs of critical trial type – RTs of unflanked trials) / RTs of unflanked trials.

These proportional scores were subjected to 2 X 2 mixed factorial ANOVA with age group as a between-subjects factor and condition (proportional slowdown from positive lag flankers and extra list flankers) as a within-subjects factor. There was a main effect of trial type, $F(1, 41) = 31.03$, $p < .01$, $MSE = 0.19$, $\eta^2 = .43$, however, opposite to what was predicted, both young and older adults were slower in the extra list flanker trials (young adults: $M = 0.10$, $SD = 0.03$; older adults $M = 0.10$, $SD = 0.03$) compared to positive lag flankers condition (young adults: $M = 0.07$, $SD = 0.03$; older adults $M = 0.07$, $SD = 0.03$). There was no significant main effect of age group $F(1, 41) = .14$, $p = .71$ nor a significant interaction between the age group and type of irrelevant information, $F(2, 82) = 0.92$, $p = .34$, $\eta^2 = .02$. The effect size between the two age groups for the proportional slowdown from extra list flankers was small ($d = -.07$).

Table 2

Descriptive statistics and reliability estimates for the Sequential flanker Task by age group

	Baseline	Access		Deletion		Restraint
	Unflanked	Positive lag flankers	Extra list flankers	-1 lag flankers	Pooled negative flankers	
Young	644.36 [a] (71.87)	691.75 [a] (72.08)	707.64 [a] (72.94)	710.80 [a] (71.27)	731.68 [a] (75.42)	5.0% [b] (0.03)
Older	792.40 [a] (76.34)	844.95 [a] (82.68)	873.71 [a] (92.96)	874.27 [a] (93.84)	918.28 [a] (96.53)	9.3% [b] (0.04)
Reliability Estimates [c]						
Young	.91	.91	.92	.93	.91	.63
Older	.94	.91	.93	.93	.94	.59

Note. [a] Median reaction times in milliseconds. [b] Percentage of commission errors on the Restraint trials. Standard deviations are in parenthesis. [c] Reliability was calculated by adjusting split-half correlations with the Spearman-Brown formula.

The Deletion Function. Deletion refers to the suppression of previously relevant but currently irrelevant information. In the context of SFT, the Deletion function included two critical trial types: lag -1 flankers and pooled negative lag flankers (lag -2 to lag -6). It was predicted that the pooled negative lag flankers would be more disruptive to performance compared to the lag -1 flankers. The proportional scores for the Deletion function were calculated similarly to that of the Access function:

(RTs of critical trial type – RTs of unflanked trials) / RTs of unflanked trials.

These proportional scores were subjected to 2 X 2 ANOVA with age group as a between-subjects factor, and condition (proportional slowdown from lag -1 flankers and pooled negative lag flankers) as a within-subjects factor. As predicted, there was a significant main effect of trial type, $F(1, 41) = 76.62$, $p < .01$, $MSE = 0.04$, $\eta^2 = .65$, suggesting that both young and older adults were slower in the pooled negative lag flanker condition (young adults: $M = 0.14$, $SD = 0.04$; older adults: $M = 0.16$, $SD = 0.04$) compared to lag -1 flanker condition (young adults: $M = 0.10$, $SD = 0.04$; older adults: $M = 0.10$, $SD = 0.03$). There was no main effect of age group $F(1, 41) = .90$, $p = .35$, but there was a significant interaction of age group and Deletion trial type, $F(2, 82) = 5.57$, $p = .02$, $\eta^2 = .12$. The effect size between the two age groups for the proportional slowdown from pooled negative lag flanker condition was moderate ($d = -0.53$).

The Restraint Function. To review, Restraint refers to the suppression of prepotent responses. In the SFT, the commission errors on Restraint trials served as an index of Restraint-type inhibition. An independent samples *t*-test revealed that compared to young adults ($M = 0.05$, $SD = 0.03$) older adults ($M = 0.09$, $SD = 0.04$) $t(41) = -4.03$, $p < .01$ committed more errors on Restraint trials. Given the concern that older adults are typically more error prone in any cognitive task, I examined if there was a statistically significant correlation between Restraint-type commission errors and other commission errors in the SFT. Interestingly, the correlation between Restraint type errors and other commission errors was significant only for younger adults [young adults: $r(23) = 0.67$, $p < 0.01$; older adults: $r(18) = -0.13$, $p = 0.59$]. In other words, older adults' efficiency in the Restraint function was not related to their general accuracy in the SFT. Nevertheless, I computed the standardized residual Restraint scores by partialling out the variance from other commission errors in the SFT. In spite of this conservative approach, older adults ($M = 0.43$, $SD = 1.17$) still had a higher Restraint scores, compared to young adults ($M = -0.34$, $SD = 0.65$), $t(41) = -2.72$, $p < .01$. The effect size between the two age groups for the Restraint-type commission errors (residual scores) was large ($d = -0.84$).

Discussion

The purpose of the current experiment was to examine whether there are uniform age-related differences in Access, Deletion, and Restraint functions of inhibition. The current findings support the a priori hypothesis that there should be larger age differences in the Restraint function followed by the Deletion function. However, contrary to the predictions of the Inhibitory Deficit hypothesis, no age effects were found for the Access function. Within the context of the SFT then, it is reasonable to assume that in the early stages of information processing, older adults are as efficient as young adults in filtering out irrelevant information. By contrast, once the no-longer relevant information has to be dampened, this is where the older adults begin to show decline. The most age-related decline, however, appears to be in suppressing incorrect well learned responses at the response level. The novelty of the current experiment was to measure all three inhibitory functions in a single task, thereby allowing for the operationalization of each inhibitory function under comparable attentional demands and interference conditions. Thus, the observed pattern of age-related differences and age-equivalence are more clearly attributable to inhibitory processes than to task-specific characteristics. The current findings are generally consistent with the Inhibitory Deficit hypothesis and extend this theory by demonstrating how age-related declines in inhibitory functions are related to different stages of information processing.

Age-related differences in the Access function

As mentioned previously, the Access function prevents the entry of irrelevant information from gaining access to working memory. In the current experiment, the Access function was tested by using two types of irrelevant information: positive lag flankers and extra list flankers. In both trial types, older adults were as efficient as young adults (*d* = -.07). In fact, the effect sizes from the current experiment correspond to the one reported by Feyereisen et al. (2008),who used a word problem solving task (May, 1999) and a reading with distraction task (Connelly et al., 1991) to measure age-related differences in the Access function. In the problem solving task, participants were presented with cue words remotely associated with the solution (e.g. cues = fruit, trunk, family; solution = tree). In the distractor condition, additional cue words were presented that were either leading or misleading to the generation of the solution. In fact, age equivalence was found for both the leading and misleading condition (*d* = -.04) reflecting older adults preserved efficiency in Access-type inhibition. Similarly, in the reading with distraction task, older adults were as efficient as young adults in suppressing the distractor words while reading the text (*d* = -.08). Taken together, the age equivalence in the Access function found in the current experiment is indeed consistent with some of the previous empirical work.

However, how does one reconcile the current findings with those reported in the literature, where age-related differences in the Access function were found in visual search tasks (e.g., Scialfa et al., 1998) and reading with distraction tasks (e.g., Carlson et al., 1995)? As noted by Kramer and Madden (2008) age-related differences in Access-type inhibition do not occur invariably, but rather occur in relation to particular task demands. For example, in visual search tasks, older adults are differentially slowed only when the distractor items are similar to the target (e.g., a vertical target among a vertical distractor) and not when they are dissimilar (e.g., a vertical target among a horizontal distractor) (Farkas & Hoyer, 1980). Similarly, age-related differences are found in the reading with distraction task, only when distractors are in unpredictable locations (Carlson et al., 1995; Connelly et al., 1991).

Another important factor to consider when examining age-related differences is whether Access-type inhibitory processes operate in a top-down or a bottom-up fashion (Connor, Egeth, & Yantis, 2004; Egeth & Yantis, 1997; Yantis, 2005). Broadly defined, top-down or goal-directed attention refers to individuals' expectations about the environment. In contrast, bottom-up or stimulus-driven attention involves the control of attention by the characteristics of the environment, independent of individuals' expectations or experience (Kramer et al., 2008). Many models of attention argue that both the top-down and bottom-up attentional processes jointly determine the success of suppressing irrelevant information (Chun & Wolfe, 2001; Duncan, 2004; Quinlan, 2003; Wolfe, 1994; Wolfe & Horowitz, 2004). Therefore in the current experiment, the positive lag flankers and the extra list flankers were used to elicit top-down and bottom-up Access-type inhibitory processes, respectively. For instance, when the positive lag flankers are presented, it is assumed that the top-down control processes prepare the participants to maintain the set order of the targets in their working memory to effectively deal with the distraction. Whereas, when novel items are presented such as extra list flankers, bottom-up atentional processes (also referred to as attentional capture) help deal with the distraction.

As noted by Kramer et al. (2008), top-down guidance of selective attention corresponds to executive control processes and a likely candidate for age-related declines. However, the finding that young and older adults were faster in the positive lag flanker trials compared to the extra list flanked trials suggests that both the age groups were equally efficient in initiating top-down Access-type inhibitory processes. In addition, the lack of statistically significant age-related differences in the extra list flankers suggests preserved bottom-up Access-type inhibitory processes for older adults.

Age-related differences in the Deletion function

Unlike the age constancy found in the Access function, results from the current experiment suggest moderate age-related differences in the Deletion function. As mentioned previously, the Deletion function refers to suppression of no-longer relevant information from working memory. In the context of the SFT, Deletion-type inhibition was defined in terms of two critical trial types: lag -1 flankers and pooled negative lag flankers (-2 to -6). Both these trial types involved flankers that were previously attended and responded to, but the critical difference between these two trial types was whether or not the flanker was an immediately preceded item. There was age invariance on the lag -1 flankers. However, in the pooled negative lag flanker condition, older adults were differentially slowed. Notably, the effect size found in the pooled negative flanker condition (d = -0.53) parallels the one reported by Feyereisen et al. (2008), who used a listening span task (d = -0.68) and the directed forgetting task (d = -0.98) to measure age-related differences in the Deletion function.

The listening span task in Feyereisen and colleagues' study was modeled on the basis of traditional complex span tasks (e.g., reading span task) where participants were instructed to recall the final words from the list of six common names that had to be processed for meaning. The list size was increased gradually, and the intrusions from the previous list were taken as measure of deletion-type inhibition. By contrast, the directed forgetting task was modeled on the lines of episodic memory tests where participants were given lists of items either to remember or forget. In the final test, participants were instructed to recall items from both the 'remember' list as well the 'forget' list. The differences between the 'forget list' and the 'remember list' was taken as an index of deletion-type inhibition. Taken together, the magnitude of age-related differences in the pooled negative flanker condition is consistent with some of the previous empirical work.

However, within the context of the SFT, why do older adults show relatively reduced performance only in the pooled negative flanker lag condition? According to the Inhibitory Deficit hypothesis, the main purpose of deletion-type inhibition is to reduce proactive interference (PI) generated by previously processed information. PI refers to the empirical observation of reduced performance in a given cognitive task, because of prior performance of the same or related task. Typically, the first trial has no PI (Wickens, Born, & Allen, 1963). The second trial is subjected to PI from the first trial, and the third trial in turn is subjected to PI from the first and second trials and so forth (Keppel & Underwood, 1962). The Inhibitory Deficit hypothesis predicts that the effect of PI builds up faster for older adults compared to young adults. The current findings are consistent with such an argument. For example, the age invariance on the lag -1 flankers, suggests that older adults were as efficient as young adults in resolving the negligible proactive interference (PI) from the immediately preceding trial. The finding that both young and older adults were slower in the pooled negative flanker condition, compared to lag-1 flanker trials suggests a buildup of PI from previously responded items. However, differential slowdown for older adults in the pooled negative flanker condition suggests that older adults have difficulty suppressing the effect of PI build up.

An alternative interpretation of the current differences in age effects between the two trial types might be that young and older adults have sufficient inhibitory ‘strength’ to handle distraction from immediately preceding trials. However, older adults might have difficulty sustaining the inhibition for as long as young adults. Consequently, when a past target re-appears as a flanker, they are likely to be more active in working memory for older adults. Future work on the time course differences between young and older adults would be needed to address this possibility directly.

Age-related Differences in the Restraint Function

The findings from the current experiment suggest that older adults show the largest declines in the Restraint function (d = -0.84), relative to the other two inhibitory functions. Once again, the effect size corresponds to the one reported by Feyereisen et al. (2008) for the Restraint function (-0.80 for the Stroop task and -0.98 for the Hayling task). Of the three inhibitory functions examined in the current experiment, the Restraint function is widely accepted as the prototypical form of inhibitory control. For example, in Norman and Shallice’s, (1986) classic model of executive control, overriding habitual response is the primary function of the supervisory attentional system (SAS). Similarly, suppression of pre-potent responses qualifies as the sole inhibitory construct in Miyake et al’s. (2000) taxonomy of executive control functions.

In the current experiment, the Restraint function was modeled after the go/no-go task. The go/no-go task is used widely in the developmental (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009), aging (Rush, Barch, & Braver, 2006), and neuroimaging (Wager et al., 2005) literatures as an index of response inhibition. The rationale is that response inhibition is achieved by a race between two competing and independent processes: a go process and a stop process (Logan & Cowan, 1984). The go process is triggered by an automatic response tendency, whereas the stop process is triggered by the identification of the no-go stimulus. When the no-go cue is presented, the stop signal is activated through the retrieval of no-go cue and stop associations (Logan et al., 1984). Older adults decline in the Restraint-type inhibition, therefore, could be a result off overly fast ‘go’ process, or a slow ‘stop’ process. Prior research suggests that the speed of ‘go’ processes show marked declines in older adults with somewhat preserved efficiency in ‘stop’ process (Williams et al., 1999).

Inhibitory Functions in the Context of Information Processing

The taxonomy of three inhibitory functions is a starting point in understanding age-related differences in inhibitory efficiency. The information processing model proposed by Friedman et al. (2004) offers a useful framework in which to consider the differing functions of inhibition. It may be that the cognitive mechanisms (presumably inhibitory processes) involved in resolving interference vary in strength in older adults depending on the stage at which they are initiated. For example, the Deletion function is initiated only after it is determined that the information is irrelevant either by internal or external cue. Therefore, Deletion reflects a more effortful suppression mechanism. In contrast, when inhibitory mechanisms are initiated at the pre-stimulus stage of processing (e.g., Access function) perhaps less effortful inhibitory processes are engaged. By contrast, the Restraint function is hypothesized to operate in the last stage of information processing (Friedman et al., 2004) when less familiar responses are selected over habitual ones. The inhibitory mechanisms involved in suppressing highly habitual responses can be considered proactive in nature (Braver, Gray, & Burgess, 2007). This proactive control mechanism ensures that the rules for selecting appropriate responses, as in the go/no-go task, are consistently mapped in working memory (Shiffirin & Schneider, 1977). It is likely that age-related differences in the Restraint function may be a result of older adults' failure to exert proactive control and maintain appropriate responses in working memory in a dynamic task context.

While the current experiment sheds light on age-related differences in three inhibitory functions, it should be noted that under different attentional demands and interference conditions, the effect sizes of age-related differences in different inhibitory functions are likely to change. The current experiment is perhaps limited in that it used a single task to measure Access, Deletion and Restraint functions of inhibition. However, in order to maintain similar attentional demands across all the three inhibitory functions this was a necessity. An alternative approach is to create latent variables of the three inhibitory functions based on well-accepted paradigms. However, as mentioned in the introduction, many of the tasks used to measure Access-type inhibition come from the low level tasks targeting early processing, whereas those used to measure Deletion and Restraint involve markedly different task demands. Therefore, the choice of tasks to include in the factor analysis in part may determine outcomes and conclusions.

Summary

The purpose of the current experiment was to examine whether there are uniform age-related differences in the Access (suppression of irrelevant information), Deletion (suppression of previously relevant information) and Restraint (suppression of pre-potent responses) functions of inhibition. It is argued that in the prior literature the relative age-related differences in three inhibitory functions may have been influenced by task specific characteristics. The novelty of the current experiment was to measure all three inhibitory functions in a single task, thereby allowing for the operationalization of each inhibitory function under comparable attentional demands and interference conditions. The findings from the current experiment suggest that older adults are at a disadvantage in the Restraint followed by the Deletion function compared to younger adults. These findings are generally consistent with the Inhibitory Deficit hypothesis and extend this theory by demonstrating how age-related declines in inhibitory functions are related to different stages of information processing.

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Appendix A

CONSENT FORM TO PARTICIPATE IN SEQUQNTIAL FLANKER TASK

This is to state that I agree to participate in a research study being conducted by Kiran Vadaga (514-848-2424, ext.2247 or karenlilab@gmail.comunder the supervision of Dr.Karen Li (514-848-2424, ext.7542 or Karen.li@concordia.ca in the psychology department of Concordia University.

A. PURPOSE

I have been informed that the purpose of the research is to understand examine age-related changes in suppressing irrelevant information

B. PROCEUDRES

The research will be conducted on the Loyola Campus at Concordia University in the Labarotory-Py017. Each participant will be asked to complete a series of background questionnaires, standard paper- and- pencil tests, and one computerized test of attention and memory. The computerized test will involve responding word stimuli in a particular order by using the key press response. The session will last 90 to120minutes. Each participant will receive 2 participation pool credits or $ 20 as compensation.

C. RISKS AND BENEFITS

The risks of the study are very low. The benefits of the study are to gain knowledge about the cognitive processes on the ability to regulate s sequence of actions.

D. CONDITIONS OFPARTICIPATION

- I understand that I am free to withdraw my consent and discontinue my participation at any time without negative consequences.
- I understand that my participation in this study is CONFIDENTIAL
- I understand that the group results of the study may be published

I HAVE CAREFULLY READ THE ABOVEAND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND VOLUNTARILY AGREE TO PARTICPATE IN THISSTUDY.

NAME (please print):…………………………………………………………………………

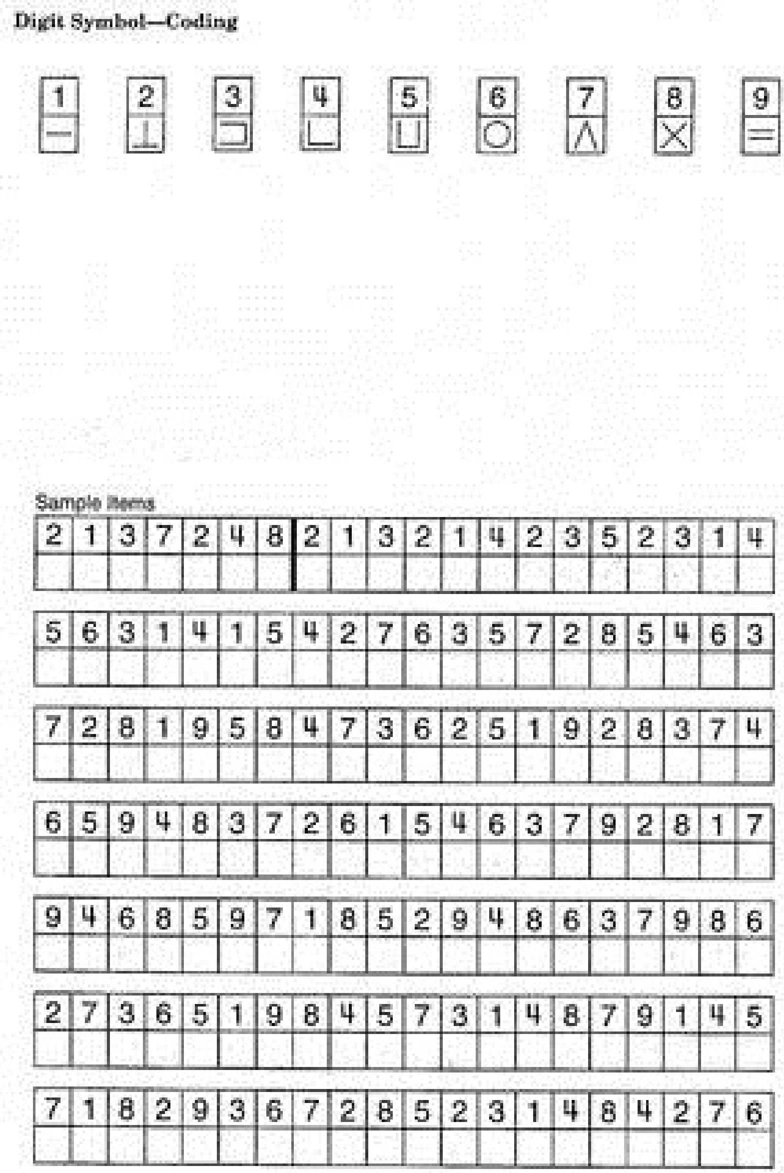
SIGNATURE:……………………………………………………………………………

Please call me again for participation in other research YES ☐ NO ☐

If any time you have questions about your rights as a research participant, please contact Adela Reid, compliance officer, Concordia University, at (514) 848-2424 ext. 7481 or by email at areid@alcor.concordia.ca

Appendix B

WAIS Digit Symbol Substitution Test



Appendix C

Reading Span Sentences

Sets of two:

The house quickly got dressed and went to **work.**

I took a knapsack from my shovel and began removing **the earth.**

The lamp bucked and sent the horse tumbling to the **ground.**

The cop spent a good half-hour questioning his trusted **friend.**

Sets of three:

The murky swamp slipped into the waters of the **crocodile.**

The castle sat nestled in the refrigerator above the tiny **village.**

It wasn't all her fault that her marriage was in **trouble.**

The man fidgeted nervously, once again checking his **watch.**

Clouds of cigar smoke wafted into the open **eraser.**

Convictions for all offences increased from the turn of the **century.**

Sets of four:

They waited at the water's edge, the raft bobbing up and **down.**

I let the potato ring and ring, but still no **answer.**

The red wine looked like blood on the white **carpet.**

The children put on their closets and played in the **snow.**

He stood up and yawned, stretching his arms above his **head.**

The young girl wandered slowly down the winding **path.**

The purpose of the course was to learn a new **language.**

The sock set the table, while I made **dinner.**

Sets of five:

Three of the pillows were dead, and he was **next.**

My escape out of the telephone was blocked by a wire **fence.**

She turned around a sucked in a startled **breath.**

They ran until their lungs felt like they were going to **burst.**

The additional evidence helped the verdict to reach their **jury.**

No one ever figured out what caused the crash to **plane.**

His eyes were bloodshot and his face was **pale.**

As a full time university student, he studied **hard.**

The CN tower raced across the sail boat to the finish **line.**

Somewhere in the deepening twilight, a loon sang its haunting evening **song.**

Sets of six:

Trails are supposed to stay on the hikers, but they usually **don't.**

He stormed out without giving me so much as a backward **glance.**

The paperclip was flaked white and red with **sunburn.**

Returning with an eagle, a branch breaks to land at its **nest.**

A television droned from the dark interior of the **apartment.**

They talked about what the world would be like after the **war.**

His mouth was twisted into an inhuman **smile.**

Silverware clunked, drawers slammed, and closet doors were wrenched **open.**

A welt was forming on his bottle where the forehead made **contact.**

I'd been naïve to think he would fall into my **trap.**

The piercing yellow eyes glowed hauntingly in the **mist.**

The beach hung down over the window, filtering the moonlight from **outside.**

Appendix D

Extended Range vocabulary Test V3 Part I: ID # ________

1. cottontail a) squirrel b) poplar c) boa d) marshy plant e) rabbit	**7. evoke** a) wake up b) surrender c) reconnoiter d) transcend e) call forth	**13. placate** a) rehabilitate b) plagiarize c) depredate d) apprise e) conciliate	**19. curtailment** a) expenditure b) abandonment c) abridgment d) improvement e) forgery
2. marketable a) partisan b) jocular c) marriageable d) salable e) essential	**8. unobtrusive** a) unintelligent b) epileptic c) illogical d) lineal e) modest	**14. surcease** a) enlightenment b) cessation c) inattention d) censor e) substitution	**20. perversity** a) adversity b) perviousness c) travesty d) waywardness e) gentility
3. boggy a) afraid b) false c) marshy d) dense e) black	**9. terrain** a) ice cream b) final test c) tractor d) area of ground e) weight	**15. apathetic** a) wandering b) impassive c) hateful d) prophetic e) overflowing	**21. calumnious** a) complimentary b) analogous c) slanderous d) tempestuous e) magnanimous
4. gruesomeness a) blackness b) falseness c) vindictiveness d) drunkenness e) ghastliness	**10. capriciousness** a) stubbornness b) courage c) whimsicality d) amazement e) greediness	**16. paternoster** a) paternalism b) patricide c) malediction d) benediction e) prayer	**22. illiberality** a) bigotry b) imbecility c) illegibility d) cautery e) immaturity
5. loathing a) diffidence b) laziness c) abhorrence d) cleverness e) comfort	**11. maelstrom** a) slander b) whirlpool c) enmity d) armor e) majolica	**17. opalescence** a) opulence b) senescence c) bankruptcy d) iridescence e) assiduity	**23. clabber** a) rejoice b) gossip c) curdle d) crow e) hobble
6. bantam a) fowl b) ridicule c) cripple d) vegetable e) ensign	**12. tentative** a) critical b) conclusive c) authentic d) provisional e) apprehensive	**18. lush** a) stupid b) luxurious c) hazy d) putrid e) languishing	**24. sedulousness** a) diligence b) credulousness c) seduction d) perilousness e) frankness

Appendix E

Debriefing Form

The purpose of this study is to examine age- related differences in suppressing different types of irrelevant information.

During the testing session, you completed a consent form and a brief demographic questionnaire. Before beginning the computer task, you were asked to become familiar with the stimuli. The computer task began with a series of practice trials. Midway through the computer test, you performed the WAIS-R Digit Symbol Task, to measure cognitive processing speed, and Reading Span task to measure working memory. After completing the computer task you were given some questions to answer regarding that task. The experiment concluded with the Extended Range Vocabulary test a measure of verbal knowledge.

We thank you for your participation and if you have any questions please feel free to contact Dr. Karen Li, faculty supervisor, at 514-848-2424 ext. 7542 or by email at karen.li@concordia.ca.

Suggested Readings:

Li, K. H. H., Lindenberger, U., Rünger, D., & Frensch, P. A. (2000). The role of inhibition in the regulation of sequential action. Psychological Science, 11, 343-347.

Li, K. Z. H., & Dupuis, K. (2008). Attentional switching in the sequential flanker task: Age, location, and time course effects. *Acta Psychologica*, *127*(2), 416-427. doi:10.1016/j.actpsy.2007.08.006