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Cognitive plasticity of inhibition in older adults

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COGNITIVE PLASTICITY OF INHIBITION IN OLDER ADULTS

by

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Abstract

Cognitive plasticity has been well documented in the cognitive aging literature; however, little work has been done to investigate the plasticity of inhibition among older adults. Inhibition functions to keep irrelevant information outside the focus of attention, and has been demonstrated to be of central importance to a variety of cognitive abilities known to decline with normal aging (Hasher et al., 2007). Using the Stroop task (Stroop, 1935), 28 older adults were trained across six sessions. Participants were randomly assigned to two feedback groups: summary feedback (SF) and individualized and adaptive feedback (IAF), to evaluate whether the type of feedback provided during training impacted performance gains. Findings indicated that older adults had improved inhibitory performance across sessions regardless of the type of feedback received. Furthermore, it was demonstrated that individuals with slow speed of processing and low executive control benefited the most from inhibition training.

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Cognitive Plasticity of Inhibition in Older Adults

Cognitive research has increasingly become intrigued by the notion of cognitive plasticity within an aging population. Cognitive plasticity is the ability to improve cognitive performance through training (Baltes & Lindenberger, 1988). An investigation of the literature showed that little research has examined the plasticity of inhibition, the ability to keep irrelevant information outside the focus of attention (Hasher, Lustig, & Zacks, 2007), within an aging population. Therefore, the main question addressed in the current study was whether inhibition efficiency could be improved in an aging population. On a related note, a rarely asked, but very relevant question is what techniques could optimize performance gains in a training program geared towards older adults. As such, the second research question addressed was whether the type of feedback provided during training affected performance gains in older adults. Given that knowledge regarding who benefits the most from a training program will help in the design of future training programs, the third question to be addressed was what baseline cognitive performance or demographic variables predict inhibition training gains in older adults.

Cognitive Plasticity and Aging

It has been well documented in the literature that cognitive abilities change as a function of normal aging (Baltes & Mayer, 1999; Schaie, 1996). Although some cognitive abilities (e.g., crystallized intelligence or cognitive pragmatics, such as world knowledge and vocabulary) are likely to remain stable with age, many other cognitive abilities (e.g., fluid intelligence or cognitive mechanics, such as reasoning, processing speed, memory, and executive functions) decline with increased age (Baltes & Mayer, 1999; Birren & Schaie, 2006; Craik & Salthouse, 2000; Salthouse, 2006; Schaie, 1996). According to the United Nations (2008), 14.9% of the world population, and 27.5% of the Canadian population, is projected to be 60 years of age or older by the year 2025. In the context of a rapidly growing aging population, the well-documented age-related cognitive declines have spurred an increasing interest in research on how the aging brain copes with these cognitive declines (see Greenwood, 2007 for a review).

A growing body of literature suggests that older adults can slow down or even reverse age-related cognitive declines through training (e.g., Baltes & Lindenberger, 1988; Thompson & Foth, 2005). Training-induced cognitive plasticity has been demonstrated in a wide variety of cognitive functions that are subject to age-related decline, including reasoning, processing speed, memory, and executive functions (e.g., Ball et al., 2002; Baltes & Lindenberger, 1988; Baltes, Sowarka, & Kliegl, 1989; Bherer et al., 2005; Calero & Navarro, 2007; Dahlin, Nyberg, Bäckman, & Neely, 2008; Edwards et al., 2002; Levine et al., 2007; Yang, Krampe & Baltes, 2006; Yang, Reed, Russo & Wilkinson, 2009). Of these abilities, executive functions play a particularly important role in mediating age-related cognitive declines and the execution of a variety of activities of daily living (e.g., Dempster, 1992; Edwards et al., 2005; Hasher & Zacks, 1988; Johnson, Lui & Yaffe, 2007; Jones et al., 2006; Rabbitt, Lowe, & Shilling, 2001; van Iersel, Kessels, Bloem, Verbeek, & Olde Rikkert, 2008; West, 1996). Since prolonging and optimizing executive functions in older adults has far-reaching implications for maintaining an active and independent life, the current study specifically focused on the plasticity of an executive function in older adults.

Executive Functions, Aging, and Plasticity

The Definition of Executive Functions

Executive functions (also referred to as executive control processes) have long been considered to guide and control lower-level cognitive abilities (Friedman et al., 2008; Miyake et al., 2000; Persson, Welsh, Jonides, & Reuter-Lorenz, 2007). Recent studies have yielded evidence of at least three separate executive functions: updating (i.e., the ability to continuously update and refresh the contents of working memory), shifting or task-switching (i.e., the ability to switch focus from one task set to another), and inhibition (i.e., the ability to inhibit irrelevant or distracting information and withhold an automatic, prepotent response; Miyake et al., 2000). Though, the literature also suggests that in a broader context, executive functions also involve the ability to maintain focused attention (i.e., attention), the ability to plan and organize task sequences (i.e., planning) and the ability to coordinate two simultaneously performed tasks (i.e., dual-task performance; Smith & Jonides, 1999).

Plasticity of Executive Functions

Plasticity of executive functions among older adults is important for several reasons. First, it has been consistently demonstrated that executive functions are severely compromised in older adults. Executive functions are regulated by the frontal lobe, an area of the brain that is disproportionately affected by increasing age (Goldberg, 2001; Jones et al., 2006; Levine et al., 2007; Rabbitt et al., 2001; Raz, 2000). According to the frontal-lobe hypothesis of aging, the frontal lobe is the first area of the brain that undergoes age-related declines, including a reduction in size and synaptic density, and an increase in plaque formation. Consequently, older adults perform disproportionately worse on executive function tasks that make use of the frontal lobe (Dempster, 1992; West, 1996). Second, executive functions moderate most age-related declines in cognition (Hasher & Zacks, 1988; Jones et al., 2006; Rabbitt et al., 2001; West, 1996). For example, research has demonstrated that age-related declines in memory and speed of processing are moderated by executive functions (e.g., Gazzaley, Cooney, Rissman & D'Esposito, 2005; Hamm & Hasher, 1992; Lustig, Hasher & Tonev, 2006). Furthermore, research has shown that maintaining executive functions may reduce the rate of cognitive decline in older adults. Bialystok, Craik, Klein, and Viswanathan (2004) suggest that frequently suppressing an inactive language and switching between different language systems gives bilinguals extensive practice in certain executive functions (i.e., inhibition and switching) (Bialystok et al., 2004; Costa, Hernández, & Sebastián-Gallés, 2008). In Bialystok (2004), older bilinguals demonstrated an advantage over monolinguals in a cognitive task that required attentional control, suggesting that constantly exercising executive functions buffers against normal age-related declines in cognition (e.g., attentional control). Strikingly enough, the lifelong practice of attentional control in bilinguals could delay the onset of symptoms of dementia by about four years (Bialystok, Craik, & Freedman, 2007). Lastly, executive functions have been demonstrated to impact the ability to perform activities of daily living in older adults, whereby declines in executive functions have been linked to increased difficulties with walking, dressing and bathing (Johnson et al., 2007; van Iersel et al., 2008).

Given the importance of executive functions in older adults, an emerging body of literature has investigated the plasticity of various executive functions in an older population. For example, Dahlin et al. (2008) demonstrated that the ability to update the contents of working memory (i.e., updating) could be improved with training in an older population. In this study, participants were presented with lists of items (e.g., numbers and letters) and had to continuously update the contents of their working memory with the last four presented items. When the list ended (at a non-predictable time) participants had to correctly identify, as quickly as possible, the last four presented items. Older adults in the training group substantially improved their performance on the task compared to a non-training control group, suggesting plasticity of the executive function updating in older adults.

Furthermore, Kramer et al. (1999) demonstrated that the ability to efficiently switch attention from one task to another (i.e., switching) could be substantially improved in older adults after four training sessions. In this study, participants were exposed to number strings of varying length (e.g., '3333' or '33'). Participants had to switch between responding according to the *value* of the digit presented (i.e., '3') and responding according to the *number* of digits presented (i.e., four or two). Switching costs were used to assess performance and were measured by subtracting RT of non-switch trials from that of switch trials. Although older adults had extremely large switching costs in earlier sessions, their switching costs decreased dramatically across sessions, and surprisingly, after training, even reached the level of switching-costs observed in younger adults (younger adults' switching costs remained relatively stable across sessions). Therefore, these findings illustrate that the executive function task-switching remains plastic in old age.

Bherer et al. (2005) demonstrated improved dual-task performance in older adults across five training sessions. Dual-task performance was measured by the ability to perform two tasks concurrently, such as classifying a letter as a 'C' or a 'B' while simultaneously deciding whether a tone was high or low. During each training session participants completed 720 trials (a mixture of single and dual-task trials). The authors found comparable dual-task training benefits, indexed by decreased reaction time (RT), in both younger and older adults and, interestingly, a larger training benefit in older adults with regards to accuracy. This study provides evidence of enhanced training gains (in terms of accuracy) in older adults, supporting the plasticity of dual-task performance in this population.

Research on training executive functions in older adults has primarily focused on three executive functions: updating (e.g., Dahlin et al., 2008), shifting (or task switching) (e.g., Kramer et al., 1999), and dual-task performance (e.g., Bherer et al., 2005). At the present time, little research has been conducted on the plasticity of inhibition in an older population (see Davidson et al., 2003; Dulaney & Rogers, 1994).

Inhibition, Aging, and Plasticity

The Definition of Inhibition

Inhibition is generally defined as an executive function that works to keep irrelevant information from entering the focus of attention, and suppress automatic, prepotent responses that are inappropriate for the task at hand (English and English, 1958; Friedman et al., 2008; Hasher et al., 2007; Hasher, Quig, & May, 1997; Hasher &

Zacks, 1988; Lustig, Hasher, & Zacks, 2007; Macmillan, 1996; Miyake et al., 2000; Smith & Jonides, 1999).

Hasher and colleagues (e.g., Hasher & Zacks, 1988; Hasher et al., 2007) propose three functions of inhibition: access, deletion, and restraint. The *access* function of inhibition guides attention by blocking task-irrelevant information from entering the focus of attention. As a result, when the access function of inhibition is working effectively, the amount of interference encountered from irrelevant environmental stimuli is reduced.[1] If, however, irrelevant information does enter the focus of attention (either due to a deficit in the access function of inhibition or because said information was at one time relevant to the task), the *deletion* function of inhibition may come into play. The deletion function of inhibition serves to eliminate (or *delete*) irrelevant information from conscious awareness. Lastly, the *restraint* function of inhibition suppresses automatic, prepotent responses to allow for other, perhaps more appropriate, responses to be considered and carried out in accordance with the task goals (Hasher et al., 2007).

Inhibition in Cognition and Cognitive Aging

The importance of inhibition for overall cognitive functioning is best understood by examining how it relates to working memory, a short-term memory system that briefly stores and processes information in the service of a goal (Baddeley, 1986; Stoltzfus, Hasher & Zacks, 1996). It is specifically the central executive, a core component of

[1] Without inhibition, interference (e.g., from irrelevant information) impedes performance (Arbuthnott, 1995). Inhibition and interference are often incorrectly regarded as one and the same. Inhibition *should* be interpreted as the mechanism by which interference is resolved (Arbuthnott, 1995; Dempster & Corkill, 1999). Therefore, it would be logical to assume that as interference effects increase, inhibition decreases, or vice versa.

Baddeley's working memory model, which is most closely related to the concept of inhibition. It is theorized that the central executive supervises and controls what information is attended to in the environment (Baddeley, 1986). Efficient attention requires not only the activation of the to-be-attended items, but also, importantly, the suppression of the to-be-ignored items (Houghton & Tipper, 1994; Jonides et al., 2002; Kok, 1999; Smith & Jonides, 1999; Stoltzfus, Hasher, Zacks, Ulivi & Goldstein, 1993). Therefore, the role of the central executive is inhibitory in that one of its functions is to keep irrelevant information from accessing the focus of attention. Hasher and colleagues suggest that inhibition is a fundamental mechanism underlying working memory, it plays a central role in general intelligence, and that it is involved in a wide variety of cognitive abilities. These include problem solving, memory, language processing and reading comprehension (Hasher, 2007; Stoltzfus et al., 1996).

Inhibitory Deficits in Older Adults

The inhibitory deficit hypothesis of aging, initially proposed by Hasher and Zacks (1988), asserts that age-related cognitive declines are modulated by decreases in inhibitory processing. Specifically, Hasher and colleagues propose that older adults' deficits in inhibition (i.e., access, deletion, restraint) negatively affect their ability to control thought and action, ultimately influencing cognitive performance in a variety of other domains (Hasher & Zacks, 1988; Hasher et al., 2007; Lustig et al., 2007).

For example, declines in memory performance may partially result from deficient inhibition. Specifically, because inhibitory deficits result in an inability to keep irrelevant information from entering the focus of attention, both relevant and irrelevant information clutter the working memory storage space. Having a cluttered working memory slows down the speed with which to-be-remembered items can be retrieved from memory and also increases the likelihood of incorrectly selecting a to-be-ignored item during retrieval. In this way, deficits in inhibition contribute to poor memory performance in older adults (Hasher & Zacks, 1988; Hasher et al., 2007).

Gazzaley et al. (2005) recently demonstrated, using functional magnetic resonance imaging (fMRI), that older adults were poor at suppressing cortical activity to task irrelevant information. Specifically, older adults demonstrated similar levels of brain activation to items that they were instructed to ignore and those that they were instructed to passively view. Contrastingly, younger adults had significantly lower cortical activity to the to-be-ignored compared to passively viewed items. These findings suggested that older adults were attending to and processing the to-be-ignore items more than younger adults. Furthermore, the older adults demonstrated poorer memory performance for the to-be-remembered items compared to younger adults. This finding suggests that the inability to inhibit task-irrelevant information may have contributed to poorer memory performance in older adults.

Furthermore, Lustig et al. (2006) demonstrated that, for older adults, an increase in distracting, irrelevant information reduced speed of processing, whereas reducing irrelevant information increased speed of processing. In contrast, for younger adults, the removal of distracting information did not affect speed of processing. These findings suggest that older adults' inability to suppress irrelevant information reduces speed of processing.

Overall, a large body of evidence supports the inhibitory deficit hypothesis. Deficits in the various functions of inhibition - access (e.g., Gazzaley et al., 2005; Rowe, Valderrama, Hasher & Lenartowicz, 2006; Yang & Hasher, 2007), deletion (e.g., Hamm & Hasher, 1992) and restraint (e.g., Bojko, Kramer, & Peterson, 2004; Bulter & Zacks, 2006; Nieuwenhuis, Ridderinkhof, de Jong, Kok, & van der Molen, 2000) - impact performance in a variety of cognitive abilities known to decline as a function of normal aging (e.g., memory and speed of processing).

Although various tasks have been used in the cognitive literature to assess inhibition, the Stroop task (Stroop, 1935) is a classical paradigm commonly used to assess inhibition (e.g., Davidson, Zacks & Williams, 2003; Dulaney & Rogers, 1994; Little & Hartley, 2000; Milham et al., 2002; Mutter, Naylor, & Patterson, 2005; Verhaeghen & De Meersman, 1998; West, 1999; West & Alain, 2000). This task is simple to administer and is ideally suited for modification into a training protocol. Therefore, the current study adopted a Stroop task paradigm to train inhibition in older adults.

Measure of Inhibition: The Stroop Task

In a typical Stroop task, participants are presented with one of three types of trials and asked to name the ink colour of the stimuli. Trials consist of congruent (e.g., the word "RED" printed in red ink, respond red), incongruent (e.g., the word "RED" printed in blue ink, respond blue) or neutral stimuli (e.g., "XXX" printed in red ink, respond red) (e.g., MacLeod, 1991, following Stroop, 1935). Empirical data consistently demonstrate that responses are slower and less accurate on incongruent relative to neutral trials, Poorer performance on incongruent trials is thought to arise from the conflict between the two incoming sources of information (i.e., word and colour), both of which are vying for attention (Cohen, Dunbar & McClelland, 1990; Faust & Balota, 2007; Jonides, Badre, Curtis, Thompson-Schill, & Smith, 2002; MacLeod, 1991; MacLeod, 1998; Milham et al., 2002; Stroop, 1935). The level of disruption in performance on incongruent trials (termed Stroop interference) is thought to reflect inhibitory efficiency in that the extent of irrelevant word suppression modulates the amount of interference. For example, effectively suppressing the irrelevant word information reduces interference from the conflicting word information, thus making colour naming faster and more accurate (Faust & Balota, 2007; Milham et al., 2002; West & Alain, 2000).

Stroop Interference

Stroop interference scores are calculated by the difference in performance (RT and accuracy) between incongruent (e.g., the word "RED" printed in blue ink, respond blue) and neutral trials (e.g., "XXX" printed in red ink, respond red; MacLeod, 1991; Milham et al., 2002; West & Alain, 2000). Stroop interference scores are consistently demonstrated to be higher for older as compared to younger adults (e.g., Davidson et al., 2003; Dulaney & Rogers, 1994; Milham et al., 2002; Mutter et al., 2005; West, 1996; West & Alain, 2000). Using brain-imaging techniques, empirical studies have offered evidence to suggest that deficits in inhibition are contributing to the enhanced and robust Stroop interference effect seen in older adults (e.g., Milham et al. 2002; West & Alain, 2000).

Milham et al. (2002) examined age differences in neural activity during the Stroop task. Older adults showed less activation in the dorsolateral prefrontal cortex (DLPFC), a structure believed to be involved in maintaining representations in working memory, and, therefore, also involves attentional control. The DLPFC is thought to keep relevant representations in working memory, which also necessitates keeping irrelevant information outside the focus of attention. Specifically, older adults showed less activation in the DLPFC, on trials that required additional attention (i.e., incongruent trials). Furthermore, older adults showed greater activation of the ventral visual processing regions, which suggested deeper processing of the irrelevant word information (i.e., irrelevant word information was gaining access to the focus of attention). Taken together, Milham et al. (2002) suggested that the increased Stroop interference effect seen in older adults was related to their difficulty in inhibiting task irrelevant word information and keeping it outside the focus of attention. Furthermore, West and Alain (2000) found two dampened event-related potential (ERP) modulations, representing a lack of suppression of word information, on incongruent trials in older, but not in younger adults. This finding suggests that older adults were not actively suppressing the irrelevant word information on incongruent trials, which contributed to the increased Stroop interference effect seen in older adults.

The attentional control framework, proposed by Balota and Faust (2001), highlights the importance of effective inhibition in Stroop interference effects. According to this framework, the attentional control system must not only effectively select the task-appropriate colour pathway, but also must suppress or inhibit the task-inappropriate word pathway. Faust and Balota (2007) assert that individuals with weak attention control systems (e.g., older adults) have large Stroop interference scores because they require additional time to effectively inhibit the inappropriate word pathway. Therefore, the efficiency with which one inhibits the irrelevant word pathway directly contributes to the size of the Stroop interference effect.

Stroop Facilitation

Typically, Stroop facilitation is thought to occur when performance is enhanced because the word and colour dimensions match (i.e., congruent trials, e.g., "GREEN" printed in green ink, respond green) and thus both pathways (word and colour) are inputting the same information (MacLeod, 1991; Cohen et al., 1990). Specifically, Stroop facilitation scores are calculated by the difference in performance between congruent and neutral trials (MacLeod, 1998; Milham et al., 2002).

However, recent views of the Stroop facilitation effect suggest that enhanced performance on congruent trials is the result of inadvertent word reading (MacLeod & MacDonald, 2000). Since word reading is automatic and thus faster than colour naming (Cohen et al., 1990), reading the colour word (instead of naming the colour) on a congruent trial would result in a faster RT on congruent relative to neutral trials, yielding Stroop facilitation effects (MacLeod & MacDonald, 2000). Dunbar and MacLeod (1984) offered empirical support for the inadvertent word reading hypothesis by showing that increasing word reading difficulty (e.g., by flipping the word upside-down) made facilitation scores disappear, and left interference scores unaffected.

The well-documented age-related deficit in inhibition has reliably been demonstrated with the Stroop task (e.g., Davidson et al., 2003; Dulaney & Rogers, 1994;

Mutter et al., 2005; West, 1996; West & Alain, 2000). According to the inhibitory deficit hypothesis, inhibitory deficits modulate a variety of age-related declines in cognition (e.g., memory, and speed of processing) (Gazzaley et al., 2005; Hasher & Zacks, 1988; Hasher et al., 2007; Lustig et al., 2006). Given a growing body of literature illustrating the importance of inhibition to cognitive aging, and the pronounced inhibitory deficits seen in older adults, it is surprising that little work has been done to investigate the plasticity of this fundamental and integral process in older adults.

Plasticity of Inhibition

Although little research has explored the plasticity of inhibition in older adults, some studies have examined plasticity of inhibition in younger adults. For example, MacLeod (1998) conducted a study where he examined the effects of training on Stroop interference and facilitation scores in younger adults across a 5 and 10-session training program. Overall, Stroop interference scores were large at earlier sessions and quickly reduced, while this reduction plateaued at later sessions. Interestingly, Stroop facilitation scores were small and stable across sessions. The author interpreted the minimal training effects on facilitation scores as support for the assumption that different mechanisms were underlying Stroop interference and facilitation effects. Within the view that interference scores are modulated by the inhibition of irrelevant word information, the reduction in Stroop interference scores across sessions, suggest that younger adults were improving their inhibitory processing with training. As such, these findings support plasticity of inhibition in younger adults; however, the question of whether inhibition can be trained in an older population remains understudied.

Davidson et al. (2003) and Dulaney and Rogers (1994) investigated age differences in Stroop practice effects across blocks within, for the most part, a single-session. The two studies found comparable reductions in Stroop interference scores across practice blocks for both younger and older adults. In addition, Davidson et al. (2003) looked at the change in facilitation scores across practice blocks. If practice with the Stroop task led to the suppression of the automatic word reading response, then facilitation scores should also reduce across blocks. Similar to the findings of MacLeod (1998), Davidson et al. (2003) found little change in facilitation scores across practice blocks, which further support the assumption that different mechanisms are underlying Stroop interference and facilitation effects. Nonetheless, these studies provide preliminary insight into the existence of plasticity in inhibition among older adults and thus set a solid foundation for the current study.

Inspired by the substantial empirical evidence for cognitive plasticity in older adults (e.g., Ball et al., 2002; Baltes & Lindenberger, 1988; Baltes et al., 1989; Edwards et al., 2005; Yang et al., 2006; Yang et al., 2009) and the importance of inhibition in cognitive aging (e.g., Hasher and Zacks, 1988; Hasher et al., 2007), the current study focused on exploring the plasticity of inhibition in older adults, a largely ignored, yet crucial, executive function. The primary question addressed in the current study was whether inhibition could be trained in older adults. Given that the plasticity of inhibition in older adults has not yet been evaluated in a multiple-session training program, a six session Stroop task training program spread over two weeks was adopted to investigate this question. Inspired by the preliminary findings of training-induced improvement in inhibition across multiple sessions in younger adults (MacLeod, 1998), and across practice blocks within a single session in older adults (Davidson et al., 2003; Dulaney & Rogers, 1994), it was hypothesized that older adults would show plasticity in inhibitory processes (indexed by a drop in interference scores) in a multiple-session training program. Since the pattern of change in facilitation scores across multiple sessions has yet to be examined in older adults, the current study also evaluated this change. However, facilitation may reflect a different underlying mechanism than interference, and thus, based on previous findings, may not change with training (MacLeod, 1998).

The Role of Feedback in Cognitive Training

The differential impact of feedback on executive function training gains has, to date, not been empirically evaluated. Past literature supports the positive influence of feedback on executive function training gains in older adults. For example, Kramer et al. (1999) presented *summary feedback* (SF) at the end of each testing block (and accuracy feedback at each trial) in a task-switching training program, and Bherer et al. (2005) presented trial-by-trial, *individualized and adaptive feedback* (IAF) in a dual-task training program. Specifically, in Kramer et al. (1999), participants completed 18 blocks of trials and received SF on overall speed and accuracy at the end of each block (a tone also signaled whenever an error was committed). Contrastingly, in Bherer et al. (2005) participants received trial-by-trial, IAF that was custom tailored to the performance of each participant. The IAF was displayed in the form of bar graphs presented in the top left corner of the computer screen, which depicted mean RT of the previous five trials. Furthermore, the bar graphs appeared in red and would turn to yellow and then to green as performance increased (i.e., RT decreased).

Both SF and IAF approaches to training have proven to be successful in eliciting executive function training gains among older adults; however, no research to date has systematically compared two types of feedback in an executive function training program to determine whether one approach was more beneficial than the other. Therefore, the second research question to be addressed in the current study was whether the type of feedback provided during training affected performance gains. To this end, I manipulated and compared two types of feedback: SF and IAF. While the SF group received summary feedback at the end of each training block, the IAF group received trial-by-trial, individualized and adaptive feedback (see *Feedback Manipulation* section for more details). Participants were randomly assigned to one of the two feedback groups, which were compared on demographic and baseline cognitive variables measured at a pretest session to ensure that the two groups did not differ significantly. There was no a priori hypothesis regarding which type of feedback would be more beneficial to performance gains for several reasons. First, both types of feedback (SF and IAF) have been successfully implemented in executive function training programs in older adults (see Kramer et al., 1999; Bherer et al., 2005). Second, these two types of feedback have never been compared in terms of effectiveness in eliciting executive function training gains. Third, a multiple session inhibition training program has, to date, never been implemented in an aging population; therefore, what works best to elicit inhibition performance gains has not been empirically tested. Although, there is no strong empirical foundation on which to build an informed hypothesis, evaluating the differential impact of feedback on inhibitory training gains within an aging population is integral to further understand how cognition changes with age and how to best approach these cognitive deficits when aiming to optimize them.

Given that the maintenance of cognitive abilities, or improvement of cognitive abilities with training, holds significant implications for prolonged independence and well-being in older adults (see Thompson & Foth, 2005 for a review), it is important to determine and thus develop age-appropriate and effective training approaches for older adults. Comparing the differential benefits of feedback on inhibition training gains in older adults holds significant implications for the development of cognitive interventions, and training programs to compensate for age-related declines in cognition.

Predictive Variables of Training Effects

The present study addressed the predictive factors that may moderate inhibition training gains. Establishing cognitive profiles for individuals who will benefit the most from an inhibition training program will help in the creation of training programs in the future and will allow for a better understanding of cognitive factors that may be underlying inhibitory processing. However, with virtually no research on the benefits of inhibitory training in an older population, predictors of inhibition training gains have not been thoroughly studied in the literature. To fill this gap, the current study will systematically address some potential predictive factors that may moderate the training gains. To this end, a battery of demographic questionnaires and cognitive tasks were administered at a pretest session to assess demographic information and baseline cognitive performance as potential predictors of inhibitory training gains (see Table 1 for a list of the cognitive measures).

Cognitive Measure	Targeted Ability	Reference
Attention Network Test (ANT)	Attention	Fan, McCandliss, Sommer, Raz, & Posner, 2002
Letter Series (LS)	Reasoning	Blieszner, Willis, & Baltes, 1981
Digit Symbol Substitution Test (DSST)	Processing Speed	Wechsler, 1981
Trail Making Test (TMT) (Parts A & B)	Executive Control	Reitan Neuropsychology Laboratories, University of Arizona
Go – No Go	Inhibition	Donders, 1868/1969
Shipley Vocabulary Test	Vocabulary	Shipley, 1940

Table 1: Cognitive Measures used to Evaluate Predictors of Inhibition Training Gains

Within the general cognitive aging literature, age, education, reasoning, speed of processing, and vocabulary has often been investigated as potential predictors of cognitive training gains (Ball, Edwards & Ross, 2007; Hill & Bäckman, 2000; Kliegl, Smith & Baltes, 1990). The predictive value of age has not consistently been reported but has always been considered a significant variable. Furthermore, the role of education has not been explored but is nonetheless believed to have a significant impact on training gains (Hill & Bäckman, 2000). Given that reasoning is defined as the ability to use old information to derive new information (e.g., problem solving; Sternberg, 1982), it is likely that this ability would be useful during cognitive training (e.g., memory mnemonic training). Therefore, reasoning may also be a significant predictor of training gains. In addition, baseline processing speed predicts training gains in processing speed and memory in older adults (Ball et al., 2007; Hill & Bäckman, 2000; Kliegl, Smith & Baltes, 1990). Speed of processing is involved in a wide variety of cognitive abilities such as selective attention and memory (e.g., the rate at which people retrieve mnemonic strategies and decode representations in memory; Kliegl et al., 1990). Furthermore, Ball et al., (2007) found that individuals with slow speed of processing benefited the most from a Useful Field of View (speed of processing) training program, indicating that the training was most beneficial to individuals who were experiencing the most amount of trouble at baseline. Similarly, it has been suggested that individuals with high verbal ability (as measured by vocabulary test scores) benefited the most from memory training (Hill & Bäckman, 2000).

Given that training gains in a given cognitive domain are often best predicted by deficits in that cognitive domain (see Ball et al., 2007), it intuitively follows that deficits in inhibitory processing will predict training gains in inhibition. Additionally, attention and inhibition are often regarded as two cognitive abilities that work together, whereby effective attention necessitates successful inhibition of distracting information (Houghton & Tipper, 1994; Hasher et al., 2007; Kok, 1999). These two abilities have been combined as a subset of executive control processes (i.e., attention and inhibition) (Smith & Jonides, 1999). Therefore, in addition to age, education, reasoning, speed of processing, and vocabulary, I evaluated inhibition, attention and executive control as potential correlates of inhibition training gains (see Table 1 for cognitive abilities and associated measures). It was hypothesized that some of these demographic and baseline cognitive variables would relate to and predict inhibition training gains. Investigating predictors of inhibition training gains is important, as it will contribute to a better understanding of what mechanisms may be underlying inhibition, and will aid in the building of effective inhibitory training programs geared at optimizing performance.

In summary, the following three questions were addressed in this study: 1) Do older adults show plasticity in inhibition, specifically can they improve their ability to inhibit irrelevant word information through cognitive training with a Stroop task training protocol?; 2) Does the type of feedback, specifically SF vs. IAF, impact training benefits in inhibition?; 3) Which demographic variables (i.e., age and years of education) and baseline cognitive performance (i.e., reasoning, speed of processing, vocabulary, inhibition, attention, and executive control) relate to and predict inhibition training gains? Based on literature reviewed above, it was hypothesized that 1) older adults would show plasticity in inhibition, indexed by decreased Stroop interference scores across sessions. This improvement would be steep at earlier sessions and then level off at later sessions. Given that facilitation and interference scores were suggested to have different underlying mechanisms, facilitation scores were not expected to change across sessions; 2) no a priori hypothesis was developed for the type of feedback affecting training benefits; and 3) the training gains would be related to and best predicted by some demographic (i.e., age, years of education) and cognitive factors (i.e., reasoning, speed of processing, inhibition, attention and executive control).

Method

Participants

Twenty-eight older adults (age range = 63 – 84 years; $M = 71.57$, $SD = 6.13$) were recruited from the older adult participant pool at Ryerson University and compensated $90 for their participation in this study. One participant dropped out half way through the study due to health complications and was compensated $10/hr for their time commitment and consequently replaced. No participants had colour blindness, based on their scores on the Dvorine Pseudo-Isochromatic Plates (Harcourt, Brace & World, Inc.). No participants scored over 20/70 on near acuity measured by the Rosenbaum near acuity pocket screener (Merck Sharp & Dohme Canada), suggesting reasonable to normal near vision. They were screened for potential Dementia-related cognitive impairment with the Short-Blessed Test (SBT; Katzman et al., 1983) and no participants scored above the cutoff score of 6. Furthermore, no participants scored above the cutoff score of 25 on the Beck Anxiety Inventory (BAI), indicating that none of them suffered from severe anxiety (Beck, Epstein, Brown, & Steer, 1988). A brief Computer Experience Questionnaire was created (see Appendix 1), and all of the participants reported having had used a computer in the past and agreed (to varying degrees) that they were comfortable using a computer in the current study.

Participants were randomly assigned to the two feedback groups: summary feedback (SF) or individualized and adaptive feedback (IAF). There were 14 participants (four men and ten women) in each feedback group. At a pretest session participants completed a battery of cognitive tasks, surveys and demographic questionnaires. Because differences in baseline cognitive performance and demographic variables could impact training gains and feedback effects, independent t-tests were run to compare these variables across the two feedback groups. A set of independent t-tests suggested that the two groups did not differ in terms of demographic variables (i.e., age, education, health, near acuity, SBT, and BAI), *ps* >.18; or baseline cognitive functions measured at the pretest session, *ps* >.2 (i.e., reasoning, processing speed, vocabulary, attention, inhibition, and executive control, see *Cognitive Measures* section for a detailed description of measures) (see Table 2 for the sample characteristics).

Materials

A 17-inch monitor PC computer system was used for all the computerized tasks at the pretest and training sessions. Participants were comfortably seated in a well-lit testing room. The viewing distance was 60 cm.

Characteristics	SF Group (n =14)		IAF Group (n = 14)		Independent t-test *p-values* (SF vs. IAF)
	Mean	*SD*	Mean	*SD*	
Age (yrs)	70.43	6.24	72.71	6.03	.33
Formal Education (yrs)	16.39	3.81	15.79	4.00	.69
Self-Report Health Rating	8.54	1.01	8.43	1.02	.78
Near Acuity (20/--)	30.71	5.84	36.43	14.20	.18
Short-Blessed Test (SBT)	0.71	1.68	1.43	1.83	.29
Beck Anxiety Inventory (BAI)	7.79	6.04	7.64	6.32	.95
Attention Network Test (ANT) (altering)	18.98	29.43	34.45	32.72	.2
ANT (orienting)	76.55	47.56	81.13	35.15	.78
ANT (executive control)	116.46	9.87	105.39	63.56	.58
Go – No Go (false alarms)	8.21	4.42	7.14	5.46	.57
Letter Series (LS)	9.71	4.94	10.00	3.53	.86
Digit Symbol Substitution Test (DSST)	61.64	16.16	58.57	11.93	.57
Trail Making Test (TB – TA) (sec)	46.59	28.98	45.14	17.34	.87
Shipley Vocabulary Test	36.29	4.68	36.00	3.21	.85

Table 2: Participant Characteristics by Feedback Group

Training Materials and Stimuli

The training sessions involved the completion of a computerized version of the Stroop task. Stroop stimuli were created from seven colours in total (i.e., blue, yellow, green, orange, purple, brown and pink). Two sets of colours were created and counterbalanced across participants, with each set containing two constant colours (i.e., blue and orange in Set 1, and yellow and pink in Set 2). At each session, four colours were used, including the two constant colours and two varying colours selected from the remaining five colours. Importantly, the two varying colours introduced at each session were never the same as those used from the immediate preceding session (e.g., session 1 of Set 1: blue, orange, green, pink; session 2 of Set 1: blue, orange, brown, yellow) (see Table 3). This prevented familiarity and added some variety to the training sessions. Furthermore, the four associated Stimuli-Response (S-R) box response keys were assigned to different colours at different sessions and this assignment was counterbalanced across sessions for several reasons: 1) to add variety to the training program; 2) to reduce effects of stimulus-specific familiarity or colour-key mapping memorization; and 3) to reduce effects of handedness, whereby participants were responding faster on the right vs. left side of the S-R box key panel (or vice versa). Otherwise, if the blue S-R box response button (for response to the ink "blue") was always associated with the index finger on the right hand, the performance improvement could be driven by such confounding variables as memorization or enhanced familiarity of colour-key associations.

Condition	Session 1	Session 2	Session 3	Session 4	Session 5	Session 6
1	blue, orange, green, pink	blue, orange, brown, yellow	blue, orange, green, purple	blue, orange, yellow, pink	blue, orange, purple, brown	blue, orange, yellow, green
2	pink, yellow, blue, green	pink, yellow, orange, brown	pink, yellow, green, purple	pink, yellow, blue, orange	pink, yellow, purple, brown	pink, yellow, orange, green

Table 3: Stroop Colour Counterbalance Sheet

The aforementioned colours were used to create three different types of Stroop trials: congruent (e.g., "GREEN" in green ink, respond green), incongruent (e.g., "GREEN" in blue ink, respond blue), and neutral trials (e.g., "XXXXX" in green, respond green). The number of Xs used in neutral trials matched with the number of letters in their corresponding colour words they represent (e.g. "XXXX" in blue ink, or "XXXXX" in green ink). In the blocks where all three types of trials were presented, the trial types were mixed pseudo-randomly so that no more than three stimuli of the same type (i.e., congruent, incongruent, or neutral) appeared consecutively. In addition, the trials were sequenced with great care to eliminate any possibility of negative priming effects (Little & Hartley, 2000) so that the distracting colour word on the current trial was never the ink colour on the subsequent trial. Similarly, the ink colour on the current trial was never the distracting colour word on the subsequent trial.

In total, there were 424 trials (128 congruent, 128 incongruent and 168 neutral) at each training session. Each colour (e.g., blue) was presented 32 times in congruent trials (e.g., the word "BLUE" printed in blue ink), 32 times in incongruent trials [32 times as the colour words (e.g., the word "BLUE" printed in a different ink colour) and 32 times as the ink colour (e.g., a colour word other than "BLUE" printed in blue ink)], and 42 times in neutral trials (e.g. "XXXX" printed in blue ink). Regarding incongruent trials, for each of the two blocks that were involved in the final data analyses (see *Data Analyses* in the *Results* section for more details), each colour appeared an equal number of times as the ink colour for a different colour word and as the colour word. Specifically, in one block, the colour blue was presented 18 times as the ink colour (six times for each of the other three colours from the set), and 18 times as the colour word. For example, the word "ORANGE" was printed in blue ink six times, the word "GREEN" was printed in blue ink six times, and the word "PINK" was printed in blue six times and the word "BLUE" appeared in orange, green, and pink ink six times each.

Pretest Cognitive Measures

A variety of cognitive measures were administered at the pretest session to compare demographic information and baseline cognitive performance for the two feedback groups (see Table 2). Furthermore, these variables were used to assess potential predictive factors for the training benefits. The cognitive tasks used are described below.

Attention Network Test (ANT; Fan et al., 2002)

The ANT is a computerized task designed to evaluate three functions of attention: alerting, orienting, and executive control. Alerting is "achieving and maintaining an alert state", orienting "is the selection of information from sensory input", and executive control is "resolving conflict among responses" (Fan et al., p.340). This task took approximately 20-30 minutes to complete. The testing stimuli consisted of five arrows presented in a single line on the computer screen. Either all of the arrows would be pointing in the same direction (congruent) or the central arrow would be pointing in one direction, while the other four arrows (two on either side of the central arrow) would be pointing in the opposite direction (incongruent). Furthermore, cues were presented prior to the onset of the arrow display. Some cues were used to alert participants to the upcoming arrow display, while other cues were used to indicate spatial location. Participants were asked to hold the computer mouse in both of their hands and to click the left mouse button with their left thumb, if the central arrow was pointing to the left *or* to click the right mouse button with their right thumb, if the central arrow was pointing to the right. Three attention scores were calculated: alerting, orienting, and executive control. All scores were calculated as mean RT difference scores. Alerting was calculated as the difference between the no cue and the alerting cue conditions. Orienting was calculated as the difference between non-spatial and spatial cue conditions and executive control was calculated as the difference between incongruent and congruent trials (see Fan et al., 2002 for more details).

Go – No Go Task (Donders, 1868/1969)

The Go – No Go task measures the ability to inhibit an automatic response to a stimulus. Participants were exposed to a series of rapidly presented stimuli on a computer screen and asked to press the spacebar on "Go" trials and withhold their response on "No Go" trials. Specifically, participants were asked to press the spacebar when the letter 'O' appeared on the screen (Go trial), and not to press the spacebar when the letter 'X' appeared on the screen (No Go trial). The number of false alarms was used as a measure of inhibition.

Letter Series (LS: Blieszner et al., 1981)

The Thurstone LS Test is a measure of inductive reasoning. In this test, participants viewed a series of letters and were required to decipher the pattern/rule in each series. Based on this pattern/rule, participants were required to pick one letter, from a possible five, that would best continue the pattern (e.g., for the series "z f y e x d __", the correct response would be "w"). Participants were given six minutes to complete up to 20 letter series problems. The number of correct responses was used as a measure of reasoning ability.

Digit Symbol Substitution Test (DSST; Wechsler, 1981)

The DSST is a measure of processing speed. On a single piece of paper, participants were presented with 140 digits in squares (including 7 practice trials), each with a corresponding empty square underneath. Participants were required to draw in the corresponding symbol based on a conversion code presented at the top of the page. Participants were given two minutes to complete as many items as possible. The number of correct response was used as the measure of processing speed.

Trail Making Test (TMT) (Parts A & B) (Reitan Neuropsychology Laboratories, University of Arizona)

The TMT (Reitan Neuropsychology Laboratories, University of Arizona) is part of the Halstead-Reitan Neuropsychological Test Battery and is a measure of executive control. Part A is a measure of visual search speed and part B is a measure of the ability to effectively switch between two task sets (an executive function). In TMT part A (TA) participants were presented with 25 encircled numbers (i.e., 1 to 25) randomly spread across a sheet of paper. Their task was to draw a line with a pencil to connect the numbers in order (i.e., 1 – 2 – 3 – 4 etc.) as fast as possible. In TMT part B (TB), participants were presented with 13 encircled numbers (i.e., 1 to 13) and 12 encircled letters (i.e., A to L). Participants were asked to draw a line to connect the numbers and letters in an alternating order (i.e., 1 – A – 2 – B – 3 – C etc.), starting with number 1 and ending with 13. The time to complete each part was recorded in seconds. Executive control was measured by the difference in time (seconds) to complete TB vs. TA (i.e., TB

– TA), where a larger difference score reflected lower executive control (Yuspeh, Drane, Huthwaite & Klingler, 2000).

Shipley Vocabulary Test (Shipley, 1940)

The Shipley Vocabulary Test is a 40-item, multiple-choice vocabulary test. Participants were required to match the target word (printed in capital letters) with the word that best represents its meaning. Participants were given four choices to select from, and were asked to guess, if they were unsure of the correct answer. The number of correct responses was used to measure vocabulary knowledge.

Procedure

Participants were randomly assigned to the SF or the IAF group. All participants completed a one and a half-hour pretest session. At the end of the pretest session, participants were scheduled in six 30-minute training sessions, three sessions per week for two weeks (details in the *Training Sessions* section). Therefore, the pretest and six training sessions took place over approximately a three-week period. Upon the completion of all the sessions in the study, participants were paid and debriefed.

Pretest Session

The pretest session (approximately 1.5 hours) involved collecting background information (e.g., demographic and health), and assessing baseline performance on various cognitive tasks (see Table 1). Participants first read and signed a consent form. Next, the Dvorine Pseudo-Isochromatic Plates were used to test for colour blindness

(Harcourt, Brace & World, Inc.) and near visual acuity was tested using the Rosenbaum near acuity pocket screener (Merck Sharp & Dohme Canada). The majority of the pretest session involved the completion of a series of cognitive measures (e.g., ANT, Go-No Go, LS, DSST, TMT, and a vocabulary test), and some paper-pencil surveys and questionnaires (e.g., BAI, SBT, Computer Experience Questionnaire and a Background Questionnaire).

Training Sessions

All participants completed six training sessions spread over two consecutive weeks, with each session lasting for approximately 30 minutes. Each session was divided into four blocks: key-colour acquisition (block 1), practice (block 2), training (block 3), and standard (block 4) (see Figure 1). Each block started with instructions that explained the task and upcoming block specifications. All Stroop instructions were presented in white letters against a black background. Participants were instructed to identify the colour of the Stroop stimuli presented on a black screen and respond to each colour by pressing the correspondingly assigned response key on the S-R box. The S-R box was placed right in front of the computer screen so that participants could comfortably place their index and middle finger of their left and right hands on the four (out of five) colour coded S-R box keys (i.e., the two outermost keys on each side). The four S-R box keys were marked with four different coloured stickers. For all blocks, each Stroop trial began with a white fixation-cross (+) presented on a black background for 1000 ms, and then replaced by a Stroop stimulus (i.e., a colour word or a string of letter Xs presented in coloured ink) presented for up to 5000 ms or until a key-press response was made. Blocks

1 and 4 were comparable across the two feedback groups whereas blocks 2 and 3 differed between groups in terms of the type of feedback provided to participants.

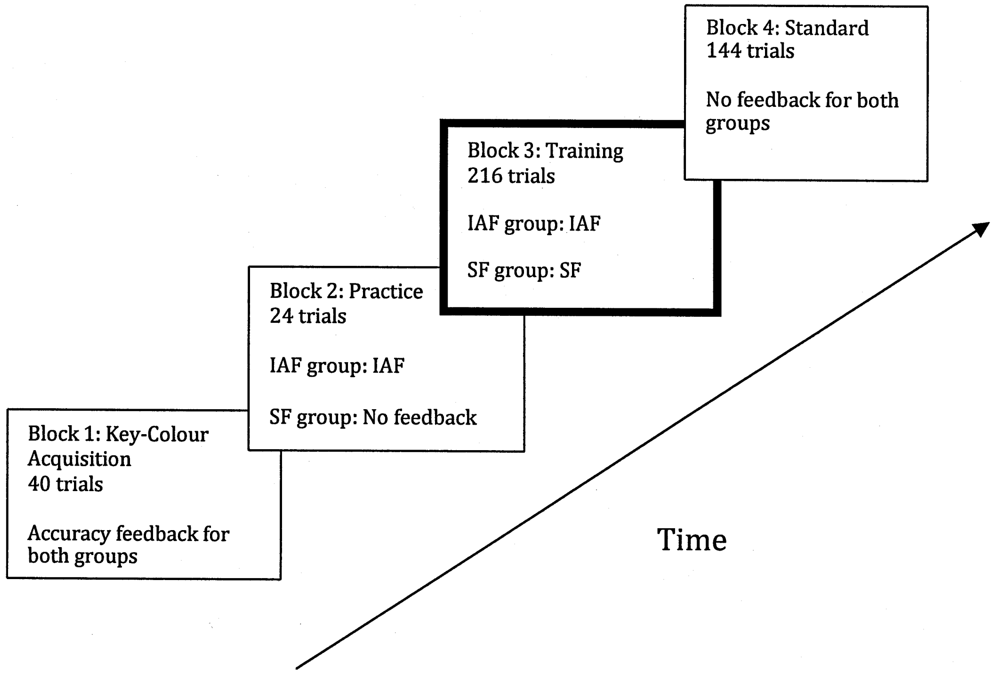

Figure 1: Training Session Procedure

Block 1: Key-Colour Acquisition

The first block (i.e., key-colour acquisition) aimed to help participants learn the specific mapping of the colours to the corresponding keys on the S-R box for a specific training session. This block consisted of 40 neutral trials. The block began with instructions that informed participants that they would be seeing a string of Xs in different ink colours and their task was to respond to the ink colour of the stimuli by pressing the corresponding keys on the S-R box using the index and middle finger of their left and right hand. The participants were told that they would be receiving accuracy feedback (i.e., "Correct!" or "Incorrect") in this block. This was done to ensure that participants were correctly mapping the S-R box keys to the corresponding ink colours. Furthermore, participants were told to keep their fingers on the corresponding keys throughout the block and to make their responses as quickly and accurately as possible. After the spacebar was pressed to begin the block, a fixation cross (+) was presented at the center of the screen for 1000 ms, and then replaced by a Stroop stimulus. The Stroop stimulus was presented for up to 5000 ms or until a key-press response was made. Following each response, a feedback screen (presented for 1500 ms) appeared to indicate whether the response was "Correct!" or "Incorrect". Then the program proceeded to the next trial.

Block 2: Practice

The purpose of the practice block was to familiarize participants with the task requirements and procedure for the upcoming blocks. This block contained 24 trials, eight for each of the three trial types (i.e., congruent, incongruent and neutral). The instructions were similar to those in Block 1 except participants were told that in addition to seeing a series of Xs, they would also be seeing colour words in different ink colours. It was emphasized that the task was still the same (i.e., respond to the ink colour of the stimuli). Furthermore, the IAF group was informed on the specifics of the feedback they would be receiving. The trial procedure paralleled that of block 1, except that a feedback screen was provided following each response for the IAF group whereas no feedback was provided to the SF group (see *Feedback Manipulation* section below for more details on the nature of the feedback provided).

Block 3: Training

The training block consisted of 216 trials, 72 for each of the three trial types: congruent, incongruent and neutral. The instructions and the trial procedure were the same as the previous practice block. At the end of this block both groups received summary feedback (see *Feedback Manipulation* section for more details).

Block 4: Standard

The standard block was designed to provide a fair comparison between the two feedback groups. No feedback of any kind was provided to either the SF or IAF group. This block consisted of 144 trials, 48 for each of the three trial types: congruent, incongruent, and neutral. The instructions were similar to those provided in previous blocks. In addition, the IAF group was told that they would not be receiving feedback of any kind in the upcoming block. The trial procedure followed that of block 1.

At the very end of the entire session, the following screen was displayed to all participants: "Today's training session is now complete. Thank you for participating :)"

Feedback Manipulation

Following a key-press response in blocks 2 and 3, participants in the IAF group were presented with a feedback screen for 2000 ms. This display provided feedback on accuracy (i.e., "Correct!") and RT on the current trial (in ms) and a bar graph. The height of the bar graph was determined by the RT of the current trial relative to the average RT of all previous trials in the block [i.e., (current trial RT) – (average RT of all previous trials)]. For example, if the current RT was much faster or much slower than the average RT of all previous trials, then the bar graph would have been large in size (maximum size was 1¼ inches). Furthermore, the bar graph would turn green if the current RT was faster (i.e., smaller) and turn red if the current RT was slower (i.e., larger) than the average RT of all previous trials. Therefore, if the participant's current RT was much faster than the average RT of all previous trials, the bar graph displayed on the feedback screen would be big and green. Contrastingly, if the participant's current RT was much slower, the bar graph would be big and red. If the difference in RTs was small, the bar graph would be small in size and if there was no difference there would be a flat, straight line (i.e., no bar graph). If an incorrect response was made, a feedback screen displaying "Incorrect" would appear for 1500 ms. Participants in the IAF group were encouraged (in the instructions) to go faster to keep the bar green. For both the SF and IAF group, summary feedback was provided at the end of block 3. The summary feedback consisted of three text screens. The first screen stated: "The following screen will indicate your average response time and your percentage of accurate responses. Please press the spacebar to go to the next screen". The second screen presented feedback on the training block performance: "In the section you just completed, your mean reaction time was ____ ms & your percentage of correct responses was _____%. Press the spacebar to continue". Finally, the third screen presented a reminder to encourage fast and accurate performance: "Remember that your goal is always to try to improve your speed and accuracy throughout each training session."

Results

Data Analyses

All statistical analyses were conducted using SPSS 16.0. All dependent variables were calculated from data collected during the testing block (block 3) and the standard block (block 4). The dependent variables included in the statistical analyses were RTs (the time, measured in ms, between stimulus onset and key-press response), accuracy (proportion of correct responses), interference scores calculated with RT (incongruent RT – neutral RT) and accuracy (neutral accuracy - incongruent accuracy), facilitation scores calculated with RT (neutral RT – congruent RT) and accuracy (congruent accuracy – neutral accuracy). Additionally, in order to determine performance improvement in baseline *SD* units, two training effect size scores were calculated, one for RT interference scores [(RT interference score at session 1 – RT interference score at session 6) / baseline *SD*] and one for accuracy interference scores [(accuracy interference score at session 1 – accuracy interference score at session 6) / baseline *SD*] (Salthouse & Tucker-Drob, 2008; Yang et al., 2009; see Table 4 for a list of the dependent variables – means and *SD*s – at each session).

Session	RT	Accuracy	RT Interference Score	Accuracy Interference Score	RT Facilitation Scores	Accuracy Facilitation Score
1	976.47 (251.84)	.97 (.04)	203.64 (172.67)	.05 (.1)	5.64 (51.23)	.004 (.02)
2	876.18 (197.44)	.97 (.03)	119.16 (70.31)	.02 (.04)	26.95 (48.61)	.01 (.03)
3	864.06 (174.18)	.97 (.02)	138.11 (78.89)	.01 (.04)	-6.9 (39.23)	.01 (.02)
4	825.32 (220.44)	.98 (.02)	113.23 (76.7)	.001 (.02)	11.24 (39.67)	.01 (.02)
5	800.58 (165.04)	.98 (.02)	76.42 (43.73)	.01 (.02)	15.39 (22.38)	-.0004 (.02)
6	794.62 (175.8)	.98 (.02)	113.65 (70.82)	.01 (.03)	6.52 (27.77)	.001 (.03)

Table 4: Means of Dependent Variables, with SDs in parentheses.

Most analyses below were run with the two blocks included as a within-subjects variable in order to determine whether the effects differed across the two blocks. Mean RT and accuracy were calculated separately for each of the three trial types (i.e., incongruent, congruent, or neutral) for each participant and each block at each training session. Only RTs for correct responses were included in the analyses and these RT data were trimmed so that any RTs beyond 2.5 *SD*s from the mean (for each cell condition) were considered outliers and excluded from the final data analysis. As a result, 2.8% of the data were deleted. One subject did not complete the standard block at the first training session due to program problems; therefore, the missing RT and accuracy data were estimated using the linear regression model based on the other five sessions of this participant.

In the following section, first, overall training effects are presented to explore performance improvement in RT and accuracy across the training sessions. To this end, overall 2 (feedback group: SF vs. IAF) × 3 (trial type: congruent vs. incongruent vs.

neutral) × 2 (block: training vs. standard) × 6 (session) mixed model ANOVAs were conducted separately on the RT and accuracy data. To best capture the nature and trajectory of the training benefits, all analyses specified the linear (suggesting incremental improvement) and quadratic contrasts (reflecting saturation effects) for the session effect. Second, the training effects on inhibitory performance were presented by examining the improvement (i.e., reduction) in interference scores across sessions. Facilitation scores were also included in these analyses. Four 2 (feedback group: SF vs. IAF) × 2 (block: training vs. standard) × 6 (session) mixed model ANOVAs were conducted on the interference and facilitation scores (calculated with both RT and accuracy). Here again, the linear and quadratic contrasts for the session effect were specified. Finally, correlation and regression analyses were conducted and reported to assess whether demographic information and/or baseline cognitive performance correlated with and predicted training effect size scores. The training effect size scores calculated for interference scores (RT and accuracy) were first correlated with all demographic information (i.e., age and years of education), and baseline cognitive performance (i.e., reasoning, speed of processing, vocabulary, inhibition, attention, and executive control). The significant correlates were then entered into a regression model to examine whether these variables significantly predicted the training effect size scores.

Overall analyses - RT

An overall mixed model ANOVA, with session, block, and trial type as within-subjects variables and feedback as a between-subjects variable was conducted to evaluate the overall training benefits in RT and accuracy.

The session effect was significant in both linear, $F(1, 26) = 59.59$, $p < .001$, $MSE = 55586.86$, $\eta^2 = .69$, and quadratic trends, $F(1, 26) = 11.17$, $p = .003$, $MSE = 31770.85$, $\eta^2 = .3$. The main effect of trial type was significant, $F(2, 52) = 79.02$, $p < .001$, $MSE = 24899.67$, $\eta^2 = .75$. Post-hoc paired t-tests revealed that RTs for incongruent trials ($M = 943.8$, $SD = 211.91$) were significantly longer than those for congruent trials ($M = 810$, $SD = 173.8$), $t(27) = 9.74$, $p <.001$, and those for neutral trials ($M = 818.15$, $SD = 175.59$), $t(27) = 9.98$, $p < .001$. Furthermore, RTs for neutral trials were marginally longer than those for congruent trials, $t(27) = 1.97$, $p = .06$. The main effect for block was marginally significant, $F(1, 26) = 3.75$, $p = .06$, $MSE = 57359.41$, $\eta^2 = .13$, with a faster overall RT in the standard block ($M = 841.59$, $SD = 206.26$) than in the training block ($M = 870.82$, $SD = 182.48$).

Most importantly, trial type interacted significantly with both the linear, $F(2, 52) = 19.17$, $p < .001$, $MSE = 5163.35$, $\eta^2 = .42$, and quadratic session effect, $F(2, 52) = 8.29$, $p = .001$, $MSE = 3993.66$, $\eta^2 = .24$, suggesting that RT performance improvement differed by the type of trial being evaluated (see Figure 2). A comparison of the slopes revealed that RT improvement was steepest for incongruent trials (slope = -47.1), followed by a similar rate of improvement between congruent (slope = -29.51) and neutral trials (slope = -29.23). Additionally, block interacted with session in both linear, $F(1, 26) = 14.92$, $p = .001$, $MSE = 20512.49$, $\eta^2 = .36$ and quadratic contrasts, $F(1, 26) = 4.20$, $p = .05$, $MSE = 15217.64$, $\eta^2 = .14$. Post-hoc analyses showed that the linear and quadratic session effects were significant for both the training block ($ps < .01$) and the standard block ($ps < .05$). The F-values indicated that the training effect was stronger in linear than in quadratic contrasts, and the linear effect was stronger for the standard block than for the training block. Additionally, there was a significant session x block x feedback interaction, $F(5, 130) = 2.5$, $p = .03$, $MSE = 10867.98$, $\eta^2 = .09$. Contrasts were run separately for the training and standard blocks, and neither linear nor quadratic session effects significantly interacted with feedback, *ps* $\geq .19$, suggesting no session by feedback interaction for either block. The slopes for the IAF training and standard blocks were -37 and -26.67, respectively, while slopes for the SF training and standard block were -50.54 and -20.06, respectively, suggesting the steepest improvement occurred in the training block for the SF group. Importantly, there was no main effect of feedback, $F(1, 26) = .66$, $p = .42$, $MSE = 1325956.95$, $\eta^2 = .03$. All other effects were not significant, *ps* $> .12$.

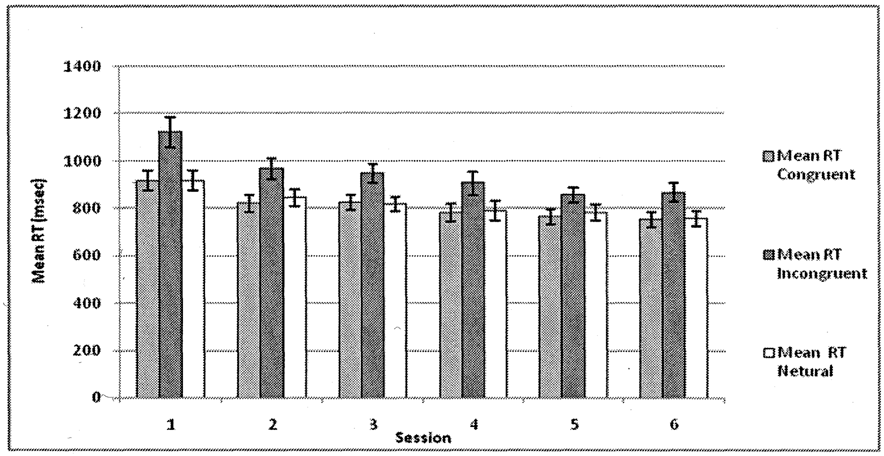

Figure 2: Trial Type by Session (mean RT)
RT improved (i.e., reduced) at a steeper rate for incongruent trials across sessions, compared to neutral and congruent trials.

Overall, these findings indicate that older adults improved RT performance across training sessions following both linear and quadratic patterns. Not surprisingly, overall RTs for incongruent trials were slower than those for both congruent and neutral trials, suggesting the presence of the well-documented Stroop interference effect. Most importantly, the largest RT improvement across sessions occurred for incongruent trials, compared to congruent and neutral trials. This finding implied improved efficiency in inhibiting irrelevant word information with training. This pattern of improved inhibition efficiency across sessions was further explored below in the analyses on Stroop interference scores (see *Interference Scores* section).

Overall analyses - Accuracy

The same mixed ANOVA was conducted on the accuracy data (i.e., proportion of accurate responses). The session effect was not significant in either linear, $F(1, 26) = 2$, $p = .17$, $MSE = .01$, $\eta^2 = .07$ or quadratic trends, $F(1, 26) = 1.27$, $p = .27$, $MSE = .00$, $\eta^2 = .05$, indicating that accuracy did not change significantly across training sessions. However, there was a significant main effect of trial type, $F(2, 52) = 7.6$, $p = .001$, $MSE = .005$, $\eta^2 = .23$. Post-hoc *t*-tests showed that accuracy on congruent trials ($M = .982$, $SD = .015$) was significantly higher than neutral trials ($M = .977$ $SD = .01$), which in turn was higher than incongruent trials ($M = .96$, $SD = .04$), $ps < .04$. Furthermore, there was a significant session by trial type interaction, $F(10, 260) = 3.6$, $p < .001$, $MSE = .001$, $\eta^2 = .12$. Separate contrasts run for each trial type revealed significant session effects only for the incongruent trials, for both linear, $F(1, 27) = 4.21$, $p = .05$, $MSE = .01$, $\eta^2 = .13$ and quadratic trends, $F(1, 27) = 5.6$, $p = .03$, $MSE = .00$, $\eta^2 = .17$. In contrast, none of the session effects were significant for the congruent or neutral trials ($ps > .14$). This indicated that accuracy on incongruent trials improved significantly across sessions. Furthermore, the slope for incongruent trials was larger

(.68) than that for congruent (-.1) and neutral trials (.05). Importantly, there was no main effect of feedback, $F(1, 26) = 2.11$, $p = .16$, $MSE = .02$, $\eta^2 = .08$. All other effects were not significant, *ps* > .15.

Overall, accuracy performance was highest for congruent, followed by neutral and worst for incongruent trials. This finding suggests the presence of the well-documented Stroop interference effect as well as facilitation effects in performance accuracy. Importantly, accuracy was only seen to improve across sessions for incongruent trials. This finding is in support of improved inhibitory abilities across sessions for older adults. Notably, accuracy performance did not differ between the two feedbacks groups across sessions, by trial type or between blocks.

Interference Scores

Although a reduction in interference scores across sessions was expected based on the overall RT and accuracy results, interference scores are the difference in performance between incongruent and neutral trials and are often used in the literature as a measure of inhibition. Therefore, in order to analyze how inhibitory efficiency changed across sessions and to be consistent with the literature, interference scores were calculated at each session and analyzed. The trial type effects in the overall RT and accuracy analyses indicated that performance was slower and less accurate on incongruent trials than on neutral trials. This reflected the well-documented Stroop interference effect. Interestingly, this effect was qualified by a session by trial type interaction that suggested a larger training benefit for incongruent than neutral trials. Therefore, training may have disproportionately reduced interference from the irrelevant and distracting word information of incongruent trials. To test this hypothesis, Stroop interference scores were submitted to two ANOVAs (with session and block as within-subjects factors and feedback as a between-subjects factor), one on RT interference scores and the other on accuracy interference scores.

Interference Scores - RT

The session effect was significant in both linear, $F(1, 26) = 19$, $p < .001$, $MSE = 15313.4$, $\eta^2 = .42$ and quadratic trends, $F(1, 26) = 8.1$, $p = .01$, $MSE = 12238.5$, $\eta^2 = .24$ (see Figure 3), indicating that RT interference scores reduced across sessions. However, there was no main effect of feedback, $F(1, 26) = .26$, $p = .62$, $MSE = 67447.15$, $\eta^2 = .01$. All other effects were not significant, *ps* > .36

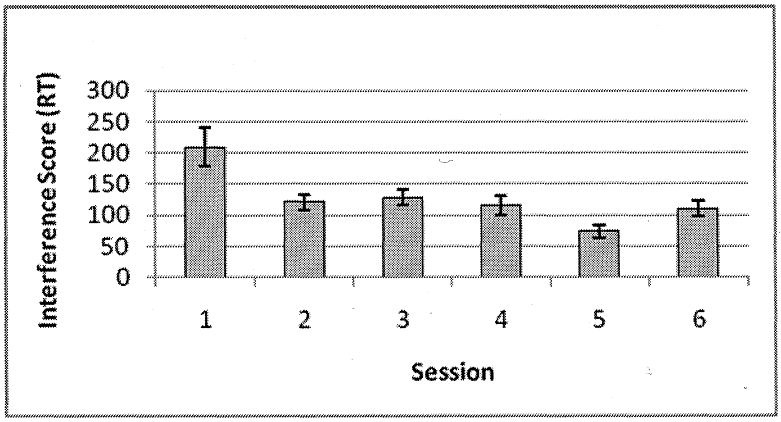

Figure 3: Interference Scores (RT) by Session
RT interference scores reduced across training sessions, indicating improved inhibition efficiency.

Interference Scores – Accuracy

There was a significant quadratic session effect, $F(1, 26) = 6.24$, $p < .05$, $MSE = .00$, $\eta^2 = .19$, indicating that accuracy interference scores decreased across sessions and that this reduction was steeper at earlier sessions and then leveled off (see

Figure 4). This finding suggests improved inhibition efficiency across training sessions. However, there was no main effect of feedback, $F(1, 26) = 1.6$, $p = .22$, $MSE = .01$, $\eta^2 = .06$. All other effects were not significant, $ps > .43$.

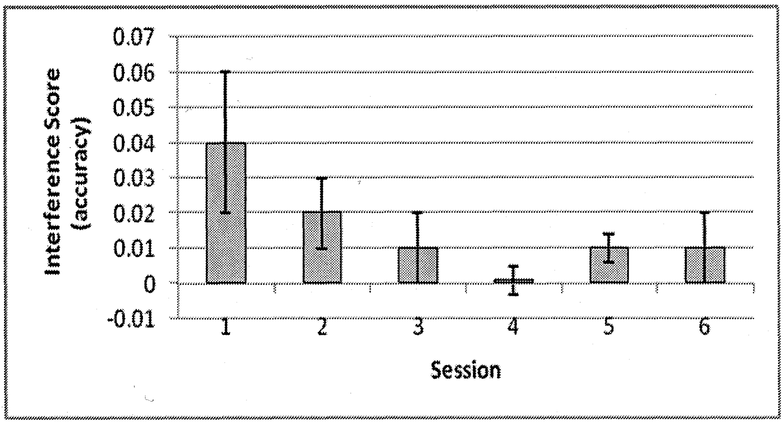

Figure 4: Interference Scores (Accuracy) by Session

Overall, these results indicated that there was a significant reduction in Stroop interference scores (measured with both RT and accuracy) across sessions. This illustrates that performance on incongruent trials was improving relative to neutral trials, indicating that the irrelevant word information was less distracting as the training sessions progressed. This suggested that the ability to inhibit irrelevant word information was improving across sessions.

Facilitation Scores

The trial type effects in the overall RT and accuracy analyses suggested that performance on congruent trials was more accurate and marginally faster than on neutral trials, suggesting the presence of Stroop facilitation effects. To analyze how the facilitation effect changed with training sessions, facilitation scores were submitted to two ANOVAs (with session and block as within-subjects factors and feedback as a between-subjects factor), one on RT facilitation scores and the other on accuracy facilitation scores.

Facilitation Scores - RT

Although the session effect was not significant, there was a significant main effect of block, $F(1, 26) = 7.43$, $p = .01$, $MSE = 975.98$, $\eta^2 = .22$, with a smaller facilitation score in the training block ($M = 5.16$, $SD = 25.74$) than in the standard block ($M = 14.45$, $SD = 22.07$). However, there was no main effect of feedback, $F(1, 26) = .72$, $p = .4$, $MSE = 155162.28$, $\eta^2 = .03$. No other effects were significant, $ps > .07$.

The non-significant session effect indicated that facilitation scores did not change with training, suggesting that the facilitation effects might not be driven by the same mechanism as interference scores (i.e., conflict of irrelevant word information). Moreover, there was a smaller facilitation effect during the training block than the standard block. Although the real mechanism driving this block effect cannot be determined by the current study, I offered two speculative interpretations in the *Discussion* section.

Facilitation Scores – Accuracy

No significant effects were found (all $ps > .23$), suggesting that accuracy facilitation scores did not differ across sessions, between blocks or by feedback group.

The lack of consistent reductions in facilitation scores across sessions suggests that facilitation and interference scores are probably being driven by different mechanisms.

Correlations and Regression

The goal of this section was to evaluate whether the training effects were related to or further predicted by demographic variables and baseline cognitive performance assessed at the pretest session. All analyses were conducted using 2-tailed Pearson's r correlations. The variables that correlated significantly with the training effect size scores were entered simultaneously into a linear regression analysis. Only significant results are reported below.

The training effect size scores were calculated only for interference scores (RT and accuracy), because facilitation scores did not produce any significant linear or quadratic session effects and thus may not well reflect the same inhibition processes as the interference scores. Furthermore, considering that no significant effects were revealed for block when running the interference score analyses, the data were collapsed across the two blocks (i.e., testing and standard) in the calculation of training effect size scores.

Correlations

There was a significant relationship between the accuracy interference training effect size score and DSST performance, $r = -.58$, $p = .001$, suggesting that slow speed of processing was related to large inhibition training gains. Furthermore, there was a significant relationship between this training effect size score and the TMT score (i.e., TB – TA), r = .54, p = .003, indicating that low executive control (as indexed by a high TMT difference score) was related to large inhibition training gains. Taken together, these correlations suggest that individuals with lower speed of processing and/or low executive control showed large inhibition training gains specifically in terms of a reduction in performance accuracy interference effects.

Regression

Lastly, the pretest and demographic variables that produced significant correlations (i.e., DSST and TMT) were entered as predictors in the follow-up linear regression model in which the accuracy interference training effect size score were set as the dependent/outcome variable. Scatterplots were examined to ensure that the variables shared a linear relationship. The regression model was significant, p = .001, R^2 = .44.

Taken together the correlations and regression analyses suggested that lower speed of processing and lower executive control predicted larger training benefits in reducing accuracy interference scores across sessions.

In summary, the results from the current study suggested that inhibition improved with training as demonstrated by decreased interference scores (RT and accuracy) across sessions. However, facilitation scores (RT and accuracy) did not change significantly across sessions. Importantly, the type of feedback received during training did not impact the magnitude of the training gains. Furthermore, low speed of processing and low executive control predicted inhibition training gains in terms of a reduction in accuracy interference scores.

Discussion

The current study addressed three specific research questions: (1) Do older adults show plasticity in inhibition, indexed by a training-induced reduction in Stroop interference scores? (2) Do the two feedback groups (i.e., SF and IAF) show differential training benefits in inhibitory processing? (3) Does demographic information and/or baseline cognitive performance predict training gains and, if so, which ones?

To address the primary question, whether older adults could improve the efficiency of inhibiting irrelevant information, 28 older adults were trained in a six session training protocol using a Stroop task. Overall performance was assessed by the improvement in RT and accuracy. Specifically and most importantly, training benefits in inhibitory efficiency were assessed by the reduction in Stroop interference scores across training sessions. In the literature, Stroop interference, but not facilitation, scores have typically been used as a measure of inhibition (e.g., Dulaney & Rogers, 1994; Little & Hartley, 2000; Verhaeghen & De Meersman, 1998; West & Alain, 2000). In fact, it has been suggested that different mechanisms are underlying Stroop interference and facilitation effects altogether (Davidson et al., 2003; MacLeod, 1998; MacLeod & MacDonald, 2000). However, the change in facilitation scores across multiple sessions had yet to be examined in an older population and may have provided further insights into whether different mechanisms were underlying these two effects. As such, the change in facilitation scores across sessions was also examined in the current study.

To address the second question, training effects were examined between the two feedback groups. For those in the SF group, summary feedback indicating average RT and percent of accurate responses was provided at the end of the training block. For those in the IAF group, in addition to receiving summary feedback at the end of the training block, trial-by-trial feedback was provided on response latency and accuracy as well as how current RT differed (faster or slower) from the average RT of all previous trials.

Lastly, to address the third research question, analyses were conducted to evaluate whether demographic information and/or baseline cognitive measures correlated with and furthermore, predicted training effect size scores. The training effect size scores were calculated as the training induced improvement in reducing interference scores from the initial to the final training session in the units of baseline *SD*s. The effect size scores were only calculated for interference scores collapsed across the two blocks (testing and standard).

Plasticity of Inhibition in Older Adults

To address the first question, I examined the change in overall performance and then specifically in the interference scores across sessions. The results showed substantial improvements, not only in the overall performance, but importantly, in the reduction of Stroop interference scores across training sessions, suggesting plasticity of inhibition among older adults.

Overall RT and accuracy analyses revealed significant session effects, suggesting performance improvement (i.e., decrease in RT and increase in accuracy) across sessions. Overall performance was slower and less accurate for incongruent trials (e.g., the word "RED" in blue ink, respond blue) compared to neutral trials (e.g., "XXX" in red ink, respond red), which was marginally slower and less accurate than congruent trials (e.g., the word "RED" in red ink, respond red). This suggests the well-documented Stroop interference and, less-documented, facilitation effects. However, there was little evidence of a speed-accuracy trade-off, since participants were the slowest but also the most inaccurate at session 1. Importantly, performance on incongruent trials improved at a steeper rate than that of neutral trials, resulting in a reduction in the difference between performance on incongruent and neutral trial across sessions. This suggested that older adults were experiencing less interference from the irrelevant word information, implying a reduced interference effect with training. This effect was later examined with Stroop interference scores (see *Stroop Interference Scores* section below). These results parallel earlier findings of Davidson et al. (2003), which found reduced RT on incongruent trials across blocks within a single session in older adults; however, in the current study this was demonstrated in a multiple-session training program. The current findings solidify the well-documented cognitive plasticity of older adults (e.g., Ball et al., 2002; Baltes et al., 1989; Baltes & Lindenberger, 1984; Bherer et al., 2005; Dahlin et al., 2008; Edwards et al., 2005; Kramer et al., 1999; Yang et al., 2006; Yang et al., 2009).

The current study's findings suggest that inhibition was improving as a result of training effects as opposed to simple practice effects. Several reasons for this assertion are presented here. First, with general practice effects improvement would have been equivalent among the three trial types. However, performance improvements in the current study (RT and accuracy) were found to be steeper (as indexed by slope for the RT data) and consistent across sessions (as indexed by the significant session effects) for incongruent trials as compared to neutral and congruent trials. This disproportionate performance improvement for incongruent trials suggested training as opposed to practice effect and, furthermore, the reduction of the well-documented Stroop interference score across training sessions (which was later confirmed and is discussed in detail below), reflecting enhanced inhibitory performance across sessions.

Furthermore, practice effects primarily driven by task familiarity and reduced task novelty should not persist after participants become fully familiar with the task. Given the simplicity of the Stroop task and the extensive practice provided at each session, it should take more than two sessions for participants to become fully familiar the task. However, in the current study performance continued to improve (indexed by a significant reduction in interference scores) throughout the six sessions, further indicating the existence of training effects.

With training effects, corresponding changes in brain and neural activation would have been expected (Greenwood, 2007; Jones et al., 2006). Based on previous neuroimaging studies (e.g., Dahlin, Stigsdotter Neely, Larsson, Bäckman & Nyberg, 2008), changes in neural activation from session 1 to session 6 would have been expected as a result of the improved ability to inhibit irrelevant information. Given that the frontal lobe is involved in executive function performance (e.g., Rabbitt et al., 2001; Raz, 2000) and older adults displayed decreased activation in the DLPFC during incongruent trials (Milham et al., 2002), it is expected that after training (i.e., at session 6 relative to session 1), older adults will demonstrate increased activation in the DLPFC during incongruent trials. However, the current study was not able to address the question of underlying neural mechanisms responsible for the training effect, because it did not collect brain-imaging data. As such, this speculative expectation will have to be examined in future research.

In light of the overall RT and accuracy results, Stroop interference scores were specifically analyzed to evaluate the effects of training on inhibitory performance. Furthermore, although Stroop facilitation scores were not expected to decrease across sessions, the pattern of change in facilitation effects across multiple sessions was of interest to explore the assumption that different mechanisms were underlying interference and facilitation effects (MacLeod, 1998; MacLeod & MacDonald, 2000) in an older population.

Stroop Interference Scores

The current data showed that Stroop interference scores (calculated with both RT and accuracy) decreased significantly across training sessions. These findings followed the same pattern of results found in Davidson et al. (2003) and Dulaney and Rogers (1994), except that the present study demonstrated the reduction over multiple sessions, instead of across blocks within a single session, for older adults. Furthermore, the findings demonstrated that older, like younger adults (MacLeod, 1998), showed a reduction in Stroop interference across sessions. Following the view that Stroop interference arises from deficits in efficiently inhibiting irrelevant word information (Milham et al., 2000; West & Alain, 2000), the reduction in Stroop interference suggests improvement in inhibitory efficiency (specifically, the ability to inhibit irrelevant word information). Therefore, the current study provides clear and solid support for the hypothesis that older adults improved inhibition efficiency with training, suggesting cognitive plasticity of inhibition in older adults.

Stroop Facilitation Scores

The current data showed that facilitation scores did not decrease significantly across training sessions. This finding suggests that different mechanisms may be underlying interference and facilitation scores. Therefore, facilitation might not reflect the influence of irrelevant word information (as does interference) and thus, may be the result of inadvertent word reading (MacLeod & MacDonald, 2000). It is important to note that, in the literature, Stroop facilitations scores have not typically been used as a measure of inhibition (e.g., Dulaney & Rogers, 1994; Little & Hartley, 2000; Verhaeghen & De Meersman, 1998; West & Alain, 2000).

Interestingly, the current study found significantly smaller facilitation scores in the training block (block 3) than in the standard block (block 4). Although the real mechanism driving this block effect cannot be determined here, two speculative interpretations are offered. First, due to the build-up of fatigue effects within each session, participants may have been less willing to exert cognitive control over which dimension was driving responding (i.e., word or colour) on congruent trials in the final block (i.e., standard) relative to the training block; therefore, would default to the automatic reading response. Since both reading the word and naming the colour would yield the same correct response on congruent trials, exerting less cognitive energy and simply reading the word would never result in an incorrect response and thus would not have been internalized negatively. Second, older adults may have developed a strategy, whereby they learned that reading words can be helpful (i.e., decrease RT) on some trials (i.e., congruent trials) and, thus implemented this strategy during the standard block.

Given that interference scores changed across sessions, but facilitation scores did not, we can very speculatively assume that the type of inhibition that was trained in the current study was the ability to inhibit irrelevant word information (i.e., the mechanism underlying interference), whereas the ability to inhibit an automatic, inadvertent reading response (i.e., the mechanism underlying facilitation; MacLeod & MacDonald, 2000) did not improve with training. Therefore, the current study found that older adults improved in the ability to inhibit irrelevant word information (not an automatic reading response), indicating plasticity of the ability to inhibit irrelevant word information. The difference in the pattern of training effects on interference and facilitation scores suggests that different mechanisms are underlying these Stroop scores and offers partial support for MacLeod and MacDonald's (2000) assertion that inadvertent word reading is driving facilitation scores.

The Role of Feedback in Inhibition Training

To address the second research question, feedback was manipulated and compared between groups: SF and IAF. The two feedback groups did not differ on a variety of demographic characteristics and baseline cognitive performance. The SF group was given summary feedback at the end of the training block whereas the IAF group was also provided with trial-by-trial, individualized and adaptive feedback during the training block.

The current study did not reveal any main effects of feedback in the analyses on both overall performance and specifically the interference (or facilitation) scores. Together, these findings suggest that the two feedback groups demonstrated comparable training gains (i.e., the type of feedback received during training did not impact overall performance in RT and accuracy, and did not affect the training-related improvement in inhibition across sessions). Even though the findings from Bherer et al. (2005) revealed that individualized and adaptive feedback led to greater training gains in older relative to younger adults in terms of accuracy, our study failed to show that this feedback was related to larger training benefits when compared to another, less intensive, form of feedback (i.e., summary feedback). Although it could be argued that feedback effects are ability-specific in that what benefits one executive function (i.e., dual-task performance) may not benefit another (i.e., inhibitory performance), no research to date has directly compared the effects of different types of feedback on executive function training effects. Thus, this study provided the first empirical evidence that older adults do not require elaborate, trial-by-trial, individualized and adaptive feedback to maximize the inhibition training effects.

Several speculative reasons for the lack of feedback effects found in the current study are discussed next. For one, perhaps the individualized and adaptive feedback screens, presented for 2000 ms following each response in the training block for the IAF group, had too much information presented for too little time. As such, older participants did not have enough time to fully absorb and/or utilize the feedback in a meaningful way. This possibility could be further tested in future studies with either simplified feedback (e.g., only including the relative speed bar graph) or increasing the presentation duration of the IAF screen. Furthermore, older participants may have found the elaborate IAF display to be distracting and given that the current study was training inhibition, the IAF screens may have been ignored. Additionally, the bar graph included in the IAF compared current RT to the average RT of *all* previous trials. Perhaps this bar graph would have been more informative and meaningful, if it had compared current RT to the average RT of the same trial type. Keeping track of relative RT performance for incongruent trials would have been more meaningful and may have resulted in a faster reduction of Stroop interference scores for the IAF group. Nevertheless, no feedback effects were revealed in the current study, suggesting that older adults did not need the elaborate IAF to motivate and guide their performance.

The lack of feedback effects is in line with earlier findings that older adults who participated in self-guided training (i.e., without any external strategies or feedback provided) demonstrated similar performance gains to those who were exposed to tutor-guided training (Baltes et al., 1989). Subsequent research has successfully demonstrated that even the oldest old (i.e., adults in their 80s) maintained the ability to improve performance in a self-guided training program (Yang et al., 2006). Therefore, past research has consistently demonstrated that older adults can improve their performance in the trained ability without any externally provided performance monitoring, effective strategies, or feedback (Baltes et al., 1989; Yang et al., 2006; Yang et al., 2009). In support for this line of research findings, the current study demonstrated that older adults do not need trial-by-trial, individualized and adaptive feedback to guide and motivate their performance. Older adults are self-motivated to optimize and monitor their performance. For example, participants in the SF group did not receive any trial-by-trial accuracy feedback; however, their accuracy performance did not differ from that of the IAF group who received trial-by-trial accuracy feedback (during the training block). Therefore, suggesting that older adults are self-monitoring their accuracy performance. In summary, the training-induced reduction in interference scores (RT and accuracy) across training sessions did not differ by feedback group, suggesting that older adults' improvement in inhibition efficiency was not impacted by the type of feedback provided during training.

Predictive Variables of Inhibitory Training Effects

The third research question was whether demographic and/or baseline cognitive variables related to and predicted inhibition training gains. The correlation and regression analyses suggested that lower speed of processing and lower executive control predicted larger inhibition training gains. Speed of processing plays an important role in a variety of cognitive abilities, including attention and memory (Kliegl et al., 1990). Attention has been closely linked to inhibition in that efficient attention requires not only the activation of the relevant information, but also, importantly, inhibition of the irrelevant information (Houghton & Tipper, 1994; Jonides et al., 2002; Kok, 1999; Smith & Jonides, 1999; Stoltzfus et al., 1993). Furthermore, according to Smith and Jonides (1999), executive control is composed of a variety of abilities, including attention and inhibition. Since Stroop task performance requires both attention to the relevant (colour) information, and suppression of the irrelevant (word) information, the Stroop task is tapping several cognitive abilities including executive control, attention, and speed of processing. Therefore, the individuals who displayed poor baseline performances in abilities that were essential to the Stroop task (i.e., speed of processing and executive control) were the ones who benefited the most from the training.

Although the current study found some significant correlations between baseline cognitive performance and training effect size scores, there were some cognitive variables that were expected to provide significant correlations; however, did not. Given that the Stroop task is a measure of inhibition, of most notable was the lack of significant correlations between measures of inhibition (Go – No Go), attention (ANT), and training effect size scores, and I offer two speculative explanations. For one, even though the inhibition task (Go – No Go) is the nearest task - in terms of measured cognitive abilities - to the Stroop task (they both test inhibition), the Go – No Go task is measuring response inhibition (i.e., withholding a motor response to a stimuli (Langenecker & Nielson, 2003), which may not be comparable to the inhibition of irrelevant information tapped by the Stroop task. Interestingly, Langenecker and Nielson (2003) used fMRI to examine areas of brain activation during completion of the Go – No Go task in older and younger adults. They asserted that increased activation in the right medial frontal gyrus and the right supramarginal gyrus were associated with good inhibitory performance in the Go – No Go task. However, there was no mention of the DLPFC that Milham et al. (2002) pointed out as crucial for effective Stroop performance. This observation suggests that different brain areas are involved in response inhibition and suppression of irrelevant information and offers some explanation as to why inhibition (as measured by the Go – No Go task) did not predict inhibition training gains in Stroop task performance. Furthermore, although the ANT task measures attention, it is mainly focused on measuring attention to task-relevant information (Fan et al., 2002) and not suppression of task-irrelevant information. Alternatively, given the small number of participants included in the present study (n = 28), it is also very possible that the lack of significant correlations may have been the result of a power issue due to the small sample size.

However, with regards to the significant correlations and predictive variables that were found in the current study, declines in processing speed and executive control are typically found in older adults (e.g., Levine et al., 2007; Raz, 2000; Salthouse, 2006; Thompson & Foth, 2005) and, furthermore, these deficits are linked to decreased abilities in performing activities of daily living (Johnson et al., 2007; van Iersel et al., 2008). The current findings are meaningful in that they suggest that the inhibition training is most beneficial to a large portion of the older population, and particularly to those who show compromised processing speed and/or executive control.

Limitations

There are several limitations of the current study. First, the small sample size in each group ($n = 14$) may have impacted the power and reliability of the results. However, it should be noted that the effects that were found were very robust and consistent. The effect size scores were also consistently high (η^2s ranged from .13 to .75). Second, all of the participants involved in the current study were well educated and very active in the community (e.g., many of the participants were members of the continuing education program offered at Ryerson University); therefore, the current findings may not reflect patterns that would typically be seen in the general older population. Third, the current study does not address whether underlying neural mechanisms change as a result of the training or, importantly, whether older adults need any feedback at all to enhance inhibition efficiency across sessions.

Implications & Future Research

The current study makes novel contributions to the cognitive aging literature by demonstrating plasticity of inhibition among older adults in a multiple session training program. This finding adds to a growing body of literature demonstrating training-induced plasticity in executive functions, including updating (Dahlin et al., 2008), task-switching (Kramer et al., 1999), and dual-task processing (Bherer et al., 2005) in older adults. The current findings suggest that older adults do not need elaborate, trial-by-trial feedback to guide and direct performance. Furthermore, it was demonstrated that individuals with low speed of processing and low executive control benefited the most from the inhibition training program. These findings will be extremely useful in creating effective executive function training programs for older adults in the future. Executive functions are extremely important to overall cognition, and particularly, to age-related declines in cognition. Executive functions in older adults have been demonstrated to modulate normal age-related declines in cognition and impact performance in activities of daily living. Furthermore, life-long practice with executive functions has been demonstrated to delay the onset of symptoms of dementia (Bialystok et al., 2004 Bialystok et al., 2007; Hasher et al., 2007; Hasher & Zacks, 1988; Johnson et al., 2007; van Iersel et al., 2008). Therefore, creating training programs that aim to optimize executive functions is of particular importance to older populations. But specifically, inhibition has been shown to play a critical role in age-related declines in memory and speed of processing (e.g., Gazzaley et al., 2005; Lustig et al., 2006). As such, the maintenance of effective inhibitory processing into old age holds powerful implications for slowing down age-related declines in cognition. Maintaining the executive function inhibition will aid in sustaining a healthy and active quality of life, thus prolonging independent living into old age.

The current findings not only make strong contributions to the cognitive aging literature, but also evoke further research questions that need to be addressed. First, the current study cannot address the underlying neural mechanisms for the training effects. As such, future research may want to investigate the change in neural activation at session 6 compared to session 1 to evaluate the neural mechanisms associated with improved inhibitory performance in older adults. This information would provide further insights into the underlying neural mechanisms for inhibition and its plasticity in the aging brain. Second, a no-feedback control group needs to be included to examine whether providing any feedback at all is necessary to elicit training benefits in inhibition. This no-feedback control group is currently being tested to address this question. Third, near and far transfer effects of inhibition training gains needs to be explored. Posttest data (overlaps with pretest) have already been collected from all of the participants tested to date; therefore, a no-contact control group will need to be added to fully address this issue. However, some preliminary analyses on the pre-post improvement in the training groups will need to be done first to validate this design.

In summary, three main conclusions can be drawn from the current study. First, older adults show improved ability to efficiently inhibit irrelevant, distracting information across training sessions. This is based on the main finding of a reduced Stroop interference score across sessions. Second, the type of feedback provided did not impact the training effect. Older adults presented with either summary feedback or individualized and adaptive feedback during training showed equal improvement in inhibition efficiency across sessions. This suggests that older adults do not need frequent or elaborate feedback to guide and motivate their performance. Third, individuals with low speed of processing and low executive control benefited the most from inhibition training, indicated by an increased training effect size score in accuracy interference effects.

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Appendices

Appendix 1: Computer Experience Questionnaire

1. Do you ever use a computer?
   - ☐ Yes
   - ☐ No

   If yes, how often do you use a computer?

   - ☐ About every day
   - ☐ Every 2-3 days
   - ☐ About once or twice a week
   - ☐ About once or twice a month
   - ☐ Less than once a month
   - ☐ Rarely to Never

2. On a 5-point scale, please indicate how much you agree with the following statement:

   I feel confident about using a computer in this study.

Strongly Agree   Somewhat Agree   Agree   Somewhat Disagree   Strongly Disagree

(4) BL-51-89