CUMULATIVE DISADVANTAGE IN COGNITIVE CONTROL DUE TO DEPRESSION AND AGING: A DOUBLE JEOPARDY HYPOTHESIS

By

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To my wonderful parents, who taught me the value of education and loved and believed in me throughout my educational journey, and to my amazing husband, for teaching me to love and believe in myself

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Depressive symptoms are prevalent in older adults, and both aging and depression are independently associated with cognitive deficits, particularly in executive control—high-level cognitive control processes that are supported by the frontal lobes and are believed to mediate other aspects of cognition. This pattern of cognitive difficulties suggests older depressed adults may be at "double jeopardy" for executive dysfunction due to the combined effects of aging and depression. Using event-related potentials (ERPs) acquired in the context of a trial-by-trial task-switching version of the Stroop task, we temporally dissociated regulative components of cognitive control, which support the activation and implementation of control, and include such functions as context encoding and maintenance, and conflict resolution.

As predicted, older adults showed clear behavioral evidence of impaired cognitive control, reflected in a disproportionate increase in error rates and slowing of reaction time on the incongruent color-naming, or interference, task condition. Depressive

symptomatology was associated with greater impairment in older, but not younger adults. ERP findings showed that older adults were impaired in context encoding and maintenance, and conflict resolution. Depressive symptomatology was associated with inefficient recruitment of neural resources in older but not younger adults.

Overall, the current findings suggest that impairments in context encoding, context maintenance, and conflict resolution contribute to cognitive control dysfunction in older adults, and that aging and depression have a synergistic effect on cognitive control (i.e., the combined effect is greater than the sum of the individual effects). These findings further our understanding of the relationship between aging, depression, and cognition and suggest older depressed adults are particularly vulnerable to cognitive decline. This line of research may aid in the development of assessment and intervention strategies for older depressed adults.

CHAPTER 1
INTRODUCTION

Depressive symptoms are prevalent in older adults, and both aging and depression are independently associated with cognitive deficits, particularly in executive functioning –high-level cognitive control processes supported by the frontal lobes that are believed to mediate other aspects of cognition (Bryan & Luszcz, 2000; Hartlage, Alloy, Vazquez, & Dykman, 1993). Executive dysfunction is associated with difficulties performing activities of daily living (Mehta, Yaffe, & Covinsky, 2002), thus leading to functional decline in older adults and depressed individuals. This suggests older depressed adults may be at "double jeopardy" for executive dysfunction and functional decline due to the combined effects of aging and depression.

While the unique effect of aging and depression on cognition is often studied, less research has looked at the combined effect of aging *and* depression on cognitive performance in the same individual. This question can be addressed by comparing the cognitive performance of individuals that vary in age and depressive symptoms. Using scalp-recorded brain event-related potentials (ERP), both behavioral and neural changes associated with aging and depressive symptoms can be measured and component processes associated with cognitive performance can be temporally dissociated. The current studies addressed these issues and focused on the following specific aims: 1) to determine if aging and depressive symptoms are associated with declines in cognitive control as assessed by a "cued-Stroop" task; 2) to use ERPs to temporally and, to a lesser extent, anatomically dissociate component processes associated with cognitive control

and determine if aging and depression differentially affect these processes; and 3) to determine if the combined effect of aging and depression on cognitive control is additive or multiplicative.

We hypothesized that both increasing age and depressive symptoms would contribute to declines in cued-Stroop performance and would be reflected in altered neural activity associated with cognitive control functioning, and that the combined effect of aging and depression would be multiplicative.

Cognitive Control in Healthy Aging

Neuropsychological studies have long demonstrated age-related impairments in performing specific cognitive tasks. While there is no uniform pattern of age-related changes across intellectual abilities, both cross-sectional and longitudinal studies suggest older adults show decreased abilities on controlled, effortful tasks that place heavy demands on attention and concentration, such as those which highly depend on executive functions, while verbal skills and other automatic processes (i.e., tasks that are performed with minimal attentional demands) are relatively spared (e.g., Hartlage et al., 1993; Schaie, 1994; Singer, Verhaeghen, Ghisletta, Lindenberger, & Baltes, 2003). Though debate continues regarding the precise nature of executive control functions (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Stuss & Alexander, 2000), there is universal agreement that they are critically involved in the adaptive and flexible guidance, regulation, and control of behavior (Miller & Cohen, 2001; Norman & Shallice, 1986; Stuss & Alexander, 2000), and include such functions as response inhibition, working memory, error monitoring, and task switching (Logan, 2003; Miller & Cohen, 2001; Norman & Shallice, 1986; Stuss & Alexander, 2000).

Older adults show performance deficits on a number of traditional neuropsychological tests purported to measure executive functioning. A large body of literature suggests that there are age-related deficits on tests of inhibition, including the Stroop test (Dulaney & Rogers, 1994; West, 2003; West & Alain, 1999; West & Alain, 2000a), variations on the Stroop test (e.g., Graf, Uttl, & Tuokko, 1995; Shilling, Chetwynd, & Rabbitt, 2002), the Simon test (Van der Lubbe & Verleger, 2002), Go/No-Go (Kaiser et al., 2003), and the Continuous Performance Test (Lockwood, Alexopoulos, & van Gorp, 2002). The Stroop task, which is of particular interest to the current research, requires subjects to either read words or name the color in which they are written. To perform this task, subjects must selectively attend to one stimulus attribute. This is especially so when naming the color of a conflict, or incongruent, stimulus (e.g., the word RED displayed in green) because there is a strong prepotent tendency to read the word ("red") which competes with the response to the color ("green"). Increased error rates and slower reaction times (RT) in the conflict condition of the Stroop test have been found for older adults compared to younger adults (e.g., Bryan & Luszcz, 2000; Dulaney & Rogers, 1994; Graf et al., 1995; Wecker, Kramer, Wisniewski, Delis, & Kaplan, 2000; West & Alain, 2000a), suggestive of an age-related impairment in inhibition of prepotent response tendencies.

A decline in working memory, the temporary storage and concurrent manipulation of information (Baddeley, 1986; Goldman-Rakic & Brown, 1981), is associated with aging (e.g., Braver et al., 2001; MacPherson, Phillips, & Della Sala, 2002). Older adults demonstrate poorer performance relative to younger adults on span tasks that require either the simultaneous manipulation of information, active rehearsal while responding to

further material, or active maintenance and monitoring of previous responses (Craik, Morris, & Glick, 1990; Daigneault & Braun, 1993). On the other hand, minimal age effects are observed on tasks that involve relatively passive storage of small amounts of information and retrieval in the same form (e.g., Craik et al., 1990; Salthouse, 1991). Furthermore, older adults frequently show increased perseverative responses on the Wisconsin Card Sort Task (WCST; Parkin & Walter, 1992); that is, they continue to sort according to the previous rule, even in the presence of feedback to the contrary, reflecting difficulties in monitoring task behavior and adjusting strategies appropriately.

A number of studies have found that, compared to younger adults, older adults show greater deficits associated with task switching—the dynamic and adaptive switching between multiple functions, rather than statically accomplishing preset tasks (e.g., Hsieh & Liu, 2005; Kramer, Hahn, & Gopher, 1999; Lorist et al., 2000). In task-switching paradigms, subjects perform two relatively simple tasks such as judging whether a letter is a vowel or a consonant, or judging the number of items in a display. On repetition trials, subjects perform the same task consecutively, while on switching trials, subjects alternate between performing two tasks. Task-switching paradigms typically measure mixing costs or switching costs. Mixing cost refers to performance differences between single-task blocks and mixed blocks, in which the task alternates, thus evoking a switching component (i.e., global switching effect). Switching cost is defined as performance differences between switch and repeat *trials* within a mixed block (i.e., local switching effects). Older adults tend to show increases in RT and/or errors due to both local switching and global switching. These age-related differences are presumably due to the increased requirement of executive control processes on switching

trials, such as behavioral maintenance (i.e., maintaining task set), and flexibly switching attention in response to contextual demands, such as a changing task instruction. However, there is some evidence that age differences in switch costs decrease with practice on the task. For example, Kramer et al. (1999) reported that switch costs for older and younger adults became equivalent after as few as 220 trials as older adults improved their performance.

These cognitive deficits are not surprising given the evidence of age-related frontal lobe pathology and disruption of frontal-subcortical circuits (Fuster, 1989; Liu, Erikson, & Brun, 1996; Raz, 2000; Raz, Gunning-Dixon, Head, Dupuis, & Acker, 1998; Raz et al., 1997). Recently, Braver et al. (2001) postulated that executive dysfunction in older adults occurs due to a breakdown in the cognitive control system secondary to dysfunction in the dopamine system in the dorsolateral prefrontal cortex (dlPFC). They tested their model by comparing the performance of younger and older adults on the AX-CPT task, in which sequences of letters are presented one at a time, and subjects are required to respond to the probe (an X) only when it follows a cue (an A). As hypothesized, older adults performed significantly worse on AX-CPT conditions that placed the heaviest demands on context representations. The authors interpreted their results as evidence of age-related impairments in context representation, which serves to bias processing and response to subsequent events. Their results are consistent with evidence of prefrontal cortex (PFC) and dopaminergic changes in old age (Goldman-Rakic & Brown, 1981; Raz et al., 1997). Supporting the hypothesis that cognitive control dysfunction in older adults involves impaired PFC functioning, several neuroimaging studies have demonstrated altered PFC activity in older adults while performing tasks

heavily dependent upon cognitive control processes (Cabeza, 2002; DiGirolamo et al., 2001; Nielson, Langenecker, & Garavan, 2002). Moreover, ERP studies have shown altered function of PFC-mediated cognitive processes (Pelosi & Blumhardt, 1999; West & Bell, 1997), including on working memory tasks which are heavily dependent upon cognitive control processes.

Cognitive Control in Depression

Depressed adults of any age show cognitive deficits that are similar to those of older adults, though the magnitude of the deficits is typically lower. Specifically, depression, like aging, is associated with impaired performance on tasks that require executive control processes while automatic processes are relatively intact (Hartlage et al., 1993). Depression, like aging, is associated with inhibitory deficits. Poor Stroop performance, reflected by increased error rates and slower RTs in the conflict condition, have been found for depressed patients compared to non-depressed controls (e.g., Moritz et al., 2002; Schatzberg et al., 2000; Trichard, Martinot, Alagille, & Masure, 1995; however, see Cohen, Barch, Carter, & Servan-Schreiber, 1999). Depression-related deficits have been reported for other tests of inhibition, including the Hayling test (Channon & Green, 1999), Go/No-Go (Kaiser et al., 2003), and variations of the Stroop test, such as the emotional Stroop (Dozois & Dobson, 2001). Depression is also associated with declines in working memory performance (e.g., Elliott, Sahakian, McKay, & Herrod, 1996; Landro, Stiles, & Sletvold, 2001; Murphy, Michael, Robbins, & Sahakian, 2003; Pelosi, Slade, Blumhardt, & Sharma, 2000). For example, Landro et al. (2001) found that depressed patients were impaired relative to healthy controls on a variant of the Paced Auditory Serial Addition Test (PASAT), and Pelosi et al. (2000) found that depressed adults had slower RTs and more errors compared to non-depressed

adults on a memory scanning paradigm, particularly with increasing set size. Moreover, Moritz et al. (2002) found that, similar to older adults, depressed adults made more perseverative errors on the WCST than controls.

Similar to aging, these depression-related cognitive impairments may be mediated by frontal lobe changes, especially in the PFC (Davidson, Pizzagalli, Nitschke, & Putnam, 2002) and anterior cingulate cortex (ACC; Drevets et al., 1997; Mayberg, Lewis, Regenold, & Wagner, 1994). For example, in an fMRI study by Okada, Okamoto, Morinobu, Yamawaki, & Yokota (2003), depressed patients and controls were compared during performance of a verbal fluency test, a putative measure of frontal lobe functioning (Henry & Crawford, 2004). While controls showed increased PFC and ACC activity, depressed patients showed attenuated activation in the left PFC and did not show significant activation in the ACC. ERP studies of depression have also revealed alterations in neural activity associated with cognitive control (e.g., Pelosi et al., 2000). However, it is unclear whether these PFC and ACC abnormalities in depressed individuals precede the onset of depression, co-occur with the onset of the disorder, or follow the expression of the disorder (Davidson et al., 2002).

Aging and Depression: Double Jeopardy?

Depression is associated with cognitive deficits beyond those caused by aging alone. Geriatric depression studies suggest that older depressed adults perform more poorly than elderly controls across various neuropsychological domains, including attention, visuospatial abilities, memory processing, and overall cognitive functioning (de Asis et al., 2001; Kramer-Ginsberg et al., 1999; Nebes et al., 2001). However, few studies have examined the interaction between aging and depression. One notable exception is a study by Lockwood et al. (2002), in which depressed and non-depressed older and

younger adults were compared on measures of executive functioning and attention, such as category fluency, digit span, Stroop, Trail Making, and WCST. Depressed individuals and older adults performed more poorly than controls in the selective attention, sustained attention, inhibitory control, and focused effort domains. More importantly, an interaction was found, such that compared to younger depressed adults and elderly controls, elderly depressed adults had disproportionately low scores on measures of set shifting, perseverative responses, initiation, and processing speed. The observed declines were greater than would be expected by simply combining the effects of aging and depression, suggesting a possible multiplicative effect of aging and depression on some cognitive functions.

This study has not been replicated, and the literature is lacking in imaging and ERP studies that compare both the behavior and neural correlates of cognitive performance in the same groups. Thus, we addressed these issues in the current study by examining the combined effect of aging and depression on cognitive control using an ERP paradigm. Determining whether aging and depression have an additive or multiplicative effect is important as it may indicate that depression is a greater risk factor for cognitive difficulties in older adults than in younger adults, which would suggest that older depressed adults are particularly vulnerable to cognitive and functional decline. Evaluating the neural correlates of cognitive performance may have implications for treatment of geriatric depression.

Component Processes of Cognitive Control

Recent theory proposes that cognitive control comprises at least two dissociable but functionally linked components. For example, several researchers (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver et al., 2001; Kerns et al., 2004; MacDonald,

Cohen, Stenger, & Carter, 2000) have described both evaluative and regulative components of control. The evaluative component of cognitive control is responsible for detecting conflict and signaling the need for adjustments in control required for adaptation to constantly changing task demands, and includes functions such as conflict detection and error monitoring (e.g., Botvinick et al., 2001; Kerns et al., 2004). The regulative component of control is involved in the actual implementation of top-down support for task-relevant processes, allowing them to compete effectively against inappropriate ones, particularly in the face of conflict. Regulative control involves such processes as the allocation of attention to task-relevant demands, negotiating response conflict, and preparation to override potential prepotent but contextually-inappropriate response tendencies. An important element of the implementation of regulative control is the active maintenance and utilization of context representations in working memory to guide task-appropriate behavior and the resolution of conflict. In this sense, context can be viewed as a subset of representations within working memory that govern how other representations are used (e.g., a set of task instructions or a specific prior stimulus; (Cohen & Servan-Schreiber, 1992).

Regulative control is necessary for task switching. Task switching requires executive control processes for behavioral maintenance (i.e., maintaining task set), and flexibly switching attention in response to contextual demands, such as a task instruction (Sohn, Ursu, Anderson, Stenger, & Carter, 2000). Global switching (i.e., mixed versus single-task blocks) necessitates sustained implementation of cognitive control, by virtue of the requirement to maintain multiple task sets at a relatively high level of activation. Local switching (i.e., repetition versus switching trials), on the other hand, requires rapid,

transient adjustments in cognitive control during task switching as the contextual demands of the task change from trial to trial (Braver, Reynolds, & Donaldson, 2003).

A number of studies have implicated a neural network in these cognitive control functions that includes areas of the frontal lobes, such as a region of the ACC (evaluative functions; Gehring, Goss, Coles, & Meyer, 1993; Kerns et al., 2004; Miltner, Braun, & Coles, 1997; van Veen & Carter, 2002a, 2002b) the dlPFC (regulative functions; MacDonald et al., 2000; regulative functions; Perlstein, Dixit, Carter, Noll, & Cohen, 2003), and more posterior brain regions (Barcelo, 2003; Barcelo, Perianez, & Knight, 2002; Braver et al., 2003; Kimberg, Aguirre, & D'Esposito, 2000). Recent models of attention suggest that anterior regions of the brain work together with parietal areas in an interdependent fashion (Banich, Milham, Atchley, Cohen, Webb, Wszalek, Kramer, Liang, Wright et al., 2000; Banich, Milham, Atchley, Cohen, Webb, Wszalek, Kramer, Liang, Barad et al., 2000; MacDonald et al., 2000; Miller & Cohen, 2001; Posner & Petersen, 1990; Sohn et al., 2000). Consistent with this postulation, both structural and functional connectivity of the frontal and parietal cortices have been observed (Cabeza, McIntosh, Tulving, Nyberg, & Grady, 1997; Cavada & Goldman-Rakic, 1989; Morecraft, Geula, & Mesulam, 1993).

Cued-Stroop Task

The components of cognitive control can be measured using a trial-by-trial cued version of the Stroop Color Word Test (cued-Stroop), originally devised by Cohen et al. (1999). In this variation of the traditional Stroop task, participants are given a task instruction before each trial indicating whether to read the word or name the color. After a brief delay, the Stroop stimulus is presented and subjects respond. Thus, the task temporally separates regulative processes associated with the task instruction (i.e.,

representing and maintaining the attentional demands of the task) from evaluative processes associated with the participant's response (i.e., conflict detection, error monitoring). Using event-related fMRI and the cued-Stroop paradigm, MacDonald et al. (2000) revealed a double dissociation in which *dlPFC activity increased following the more attentionally-demanding color-naming instruction*, interpreted as being consistent with the increased requirement for exerting top-down control and with the dlPFC's role in representing and maintaining the task demands needed for such control (i.e., regulative processes). *ACC activity,* on the other hand, *increased following the conflict or incongruent condition of the color-naming stimulus*, taken to reflect the ACC's role in the evaluative process of conflict monitoring or detection.

Scalp-Recorded Brain Event-Related Potentials

ERPs provide a powerful methodology for examining cognitive processes such as executive control. ERP methodologies are based on the assumption that the distribution of electrical activity across the scalp reflects the activity of neural structures supporting specific cognitive states and processes (Kutas & Dale, 1997). ERPs represent ongoing electroencephalographic (EEG) activity in the brain that has been time-locked to a specific event and averaged over multiple samples in response to repeated events. EEG is the record of the volume-conducted electrical activity of the brain. This activity can be measured non-invasively across the scalp using electrodes. Initially, the event-related signal associated with the presentation of a stimulus is embedded in the noise of the background EEG activity. Extracting the signal associated with a specific cognitive activity from the "noise" (background activity and measurement error) is accomplished by averaging multiple samples of the EEG that are time-locked to repeated occurrences of the event (i.e., stimulus or response) of interest. The logic of averaging is that the

event-related signal is relatively invariant to repeated occurrences of the same event, while the noise is random, thus, the signal is enhanced by a factor proportional to the square-root of the number of trials, while the noise is reduced essentially to zero (Fabiani, Gratton, & Coles, 2000). The resulting ERP waveforms typically consist of a series of discrete deflections (i.e., peaks and troughs), often followed by slow-wave potentials, which reflect temporally extended changes in the ERP waveform, rather than distinct or punctate deflections.

Characteristics of ERP waveforms usually include descriptors of polarity (positive or negative) and latency (in milliseconds). For example, "P300" refers to an ERP with a positive peak that has an approximate latency of 300 milliseconds. Another similar labeling system involves a descriptor of polarity followed by a number representing the ordinal latency of the component. Using these labeling criteria, "P3" refers to the third positive peak in the ERP waveform. Other descriptors, such as the scalp location at which the component is maximal (e.g., frontal P3), are also used.

Due to the direct measure of electrical brain activity associated with specific cognitive events, ERPs are currently considered the "gold standard" in terms of temporal resolution among noninvasive imaging methods (Fabiani et al., 2000). Under the appropriate task conditions ERPs can be used to temporally dissociate component processes associated with cognition, such as cognitive control, by enabling inferences to be made regarding the timing, level of processing and, roughly, the anatomical location of neural mechanisms supporting these processes. Thus, the present research exploited the temporal sensitivity of scalp-recorded brain ERPs acquired in the context of the cued-Stroop task in order to temporally dissociate the components of cognitive control. The

ERP components of relevance to the current studies, and their associated components of cognitive control, are described below (Table 1-1).

Table 1-1. Summary of ERP components of relevance to the current study.

ERP Component	Cognitive Process	Area of Activity
P3a	Attentional mechanisms	Frontal areas
P3b	Context encoding	Parietal areas
Cue-related slow wave	Context maintenance	Frontal and parietal areas
N450 and NSW	Conflict detection and resolution	Frontal areas

Note: NSW = negative slow wave.

Context Encoding and Maintenance

The encoding and maintenance of context are reflected in three primary ERP waveforms. P3a is a positive ERP component usually observed over frontocentral regions 250-400ms after a novel stimulus is presented. This modulation is presumed to reflect the engagement of frontal lobe attentional mechanisms (e.g., Friedman, Cycowicz, & Gaeta, 2001). P3b is a related but distinct component that is usually focused over centroparietal areas between 300-600ms post stimulus (Debener, Makeig, Delorme, & Engel, 2005) which reflects context encoding, or working memory updating (Donchin & Coles, 1988; West, 2004). Confirming previous ERP studies using a combined ERP and fMRI paradigm, Bledowski et al. (2004) localized the source of P3a to frontal areas and the insula, while P3b was mainly produced by parietal and inferior temporal areas. The allocation of attentional resources under challenging task conditions and the active maintenance of goal/task-representations have been shown to be reflected in ERP slow-wave associated with stimulus cues that portend the need to respond to a shortly-following stimulus. This slow wave is associated with the implementation of cognitive control to bias processing in favor of the more attentionally-demanding aspect of the task (West, 2003). In contrast to the findings of West (2003), who observed a negativity over

posterior regions and positivity over frontal regions, we previously observed a slow negativity over more fronto-lateral regions of the scalp (Perlstein, Larson, Dotson, & Kelly, 2006). Thus, P3a, P3b, and the cue-related slow wave appear to represent an interactive network of frontal and parietal regions of the brain that operate in concert to support the encoding and maintenance of context and the implementation of cognitive control.

Conflict Detection and Resolution

Cognitive tasks that require the detection of processing conflicts between simultaneous but incompatible competing alternative responses (e.g., Stroop or Eriksen flanker tasks) evoke a late fronto-central ERP signature referred to as the N450 or N2 component (Bartholow et al., 2005; van Veen & Carter, 2002a; West, 2003; West & Alain, 1999; West & Alain, 2000a). This ERP deflection is largest under conditions in which response conflict is high, such as the incongruent condition of the Stroop color-naming task (Liotti, Woldorff, Perez, & Mayberg, 2000; Rebai, Bernard, & Lannou, 1997; West, 2003; West & Alain, 1999; West & Alain, 2000a). A number of studies have localized the N450 component to a region of the ACC (van Veen & Carter, 2002a, 2002b; West, 2003). Thus, the N450 appears to be a neurobiological index of the detection of processing conflicts.

Finally, the conflict slow potential (conflict SP; McNeely, West, Christensen, & Alain, 2003; West & Alain, 2000b) or negative slow wave (NSW; Curtin & Fairchild, 2003; West & Alain, 1999) has also been observed over frontal regions of the scalp. The NSW occurs following stimulus presentation but prior to response in paradigms that require the negotiation or resolution of response conflict, such as the Stroop task. For example, West and colleagues (West, 2003; West & Alain, 1999) showed that the NSW,

which begins approximately 600ms after stimulus presentation, is more negative-going following incongruent than neutral or congruent trials of the Stroop task, is modulated by the proportion of congruent and incongruent trials, and is greater in amplitude for correct than incorrect responses. On the basis of these and other findings, West and colleagues (West & Alain, 1999; West & Alain, 2000b) have suggested that the NSW reflects the implementation of regulative control in the service of resolving response conflict and supporting selection of the appropriate stimulus dimension. Findings by West and Alain (2000c) suggest that the source of the NSW is located within the dlPFC.

Task Switching

ERP studies have shown that the shifting of attention required for task-switching evokes both frontal and parietal P3 components (Barcelo, 2003; Barcelo et al., 2002; Hsieh & Liu, 2005; West, 2004). These components are greater in mixed compared to single-task blocks (global switching) and in switching compared to repetition trials (local switching). In addition, West (2004) found a greater cue-related slow wave over anterior regions for mixed blocks. There is evidence that ERP differences between switching and repetition trials become smaller with increasing time on task (Lorist et al., 2000). fMRI studies provide support for the contention that a network of frontal and parietal areas are involved in task-switching (Kimberg et al., 2000).

West (2004) examined age-related differences in cognitive control using a cued-Stroop paradigm and found differences in the timing of ERP modulations associated with cognitive control, including P3b, cue-related slow wave, N450, and NSW. These results were interpreted as indicative of impaired efficiency of encoding or representing context (P3b), context maintenance (slow-wave), and conflict detection and resolution (N450 and NSW, respectively) in older adults. Aging effects were found to be greater on more

demanding tasks, suggesting that the effect of aging interacts with task context. In addition, the ERP modulations were greater for mixed blocks than for single-task blocks, which suggests that additional cognitive resources were recruited to perform the more difficult task-switching blocks. However, this global measure of task-switching did not allow for the examination of brain potentials that were evoked *while* the task was being switched, i.e., in the time period after the cue to switch tasks is given and the participant must flexibly adopt a new rule for the task at hand. Therefore, in the current studies we examined local task-switching effects by comparing switching and non-switching trials, in addition to comparing blocks of trials.

In a cued-Stroop study by Cohen et al. (1999), depressed participants were used as a patient control group in a comparison of healthy adults versus participants with schizophrenia. In this study, the depressed groups showed similar behavioral and ERP results compared to the healthy control group. However, other studies have shown that depression is associated with decreased P3b, but not P3a amplitude (Kayser, Bruder, Tenke, Stewart, & Quitkin, 2000; Pierson et al., 1996). This would suggest that in depression, recruitment of frontal lobe attentional mechanisms (P3a) is intact; however, context encoding (P3b) may be impaired.

Current Studies

The current studies were designed to evaluate cognitive control dysfunction related to aging and depression using ERPs and the cued-Stroop paradigm. In the first study, we examined age-related differences in cognitive control, including context maintenance, conflict resolution, and task-switching. The second study compared the cognitive control performance of older and younger adults who varied in depressive symptoms to evaluate the combined effect of aging *and* depression on executive control.

CHAPTER 2
EXPERIMENT 1: AGING AND COGNITIVE CONTROL DYSFUNCTION—ERPS AND THE CUED-STROOP TASK

Experiment 1 compared behavioral and event-related potential (ERP) correlates of cognitive control processes of younger and older adults using the cued-Stroop task designed to facilitate the temporal separation of component cognitive control processes. This research replicates aspects of West's (2004) previous cued-Stroop study of aging. Furthermore, it expands the scope of previous research by investigating local *and* global task-switching effects. This allows for examination of momentary, trial-to-trial adaptations in cognitive control, providing a more sensitive measure of the implementation of control on a constantly changing basis. Behaviorally, we predicted that increasing age would be associated with impairments in cognitive control, reflected in greater Stroop reaction times (RT) and error rate interference effects, greater context maintenance effects (i.e., selective and disproportionate increases in RTs and error rates to the incongruent condition of the color-naming task compared to other task conditions), as well as greater task-switching effects in older adults. We also examined the relationship between cued-Stroop performance and scores on traditional measures of attention and working memory, which we anticipated would be associated with incongruent color-naming error rates.

Age-related differences in behavioral performance could be due to a breakdown in various components of cognitive control engaged by the cued-Stroop task, thus ERPs were used to *temporally dissociate* neural activity associated with these components and

to determine if aging differentially affected these processes. We examined the following hypotheses: 1) Age-related impairments on the cued-Stroop task result in part from deficits in encoding and maintaining context. This would be reflected in reduced amplitude cue-related P3a and/or P3b components to the more attentionally-demanding color-naming task compared to word-reading task, or to mixed blocks compared to single-task blocks in older adults. 2) Impairment in older adults is partly due to inadequate implementation of cognitive control, which is associated with impaired preparation to override the prepotent response tendency. This finding would be reflected in a reduced-amplitude slow wave associated with the task instructional cue to color-naming task compared to the word-reading task, or to mixed blocks compared to single-task blocks in older adults. 3) Impairment is due, in part, to impaired anterior cingulate cortex-mediated detection and resolution of the conflict information inherent in the incongruent color-naming condition. This finding would be reflected in a decreased N450 deflection and negative slow wave (NSW), respectively, in the incongruent vs. congruent color-naming condition. 4) Aging is associated with impaired local task switching, which would be reflected in reduced-amplitude cue-related slow wave associated with switching compared to repetition trials.

Methods

Participants

Nineteen older adults (ages 62–84) and 20 younger adults (ages 18–35) participated in the study. Participant recruitment methods included 1) advertisement through the university and local community college, 2) describing the study in a brief article for a regional senior magazine, and 3) attending monthly meetings of local senior organizations (e.g., AARP) and church groups. All participants were right-handed native-

English speakers. The sample consisted of 90% White, 5% African-American, 2.5% Hispanic, and 2.5% Asian participants. Potential participants were excluded from the study for the following reasons: 1) Major Axis I psychopathology; 2) dementia or other neurological disease; 3) severe or acute medical illness; 4) current use of antiepileptics or other medication known to affect cognitive functioning (Appendix A); 5) color blindness; 6) visual acuity difficulties that would interfere with task performance; 7) motor deficits that would interfere with the use of the dominant hand for performance of button press associated with the cued-Stroop task; and 8) a score of less than 30 on the Telephone Interview for Cognitive Status (TICS; Brandt, Spencer, & Folstein, 1988). All participants provided written informed consent according to procedures established by the University of Florida Health Science Center Institutional Review Board. Participants were either given course credit or compensated $40 for their time.

Table 2-1. Mean (+standard deviation) demographic and neuropsychological test data for younger and older adults.

	Younger Adults (n=20)	Older Adults (n=19)
No. of males/no. of females	6/14	3/16
Age (years)	23.60 (5.16)	75.37 (6.35)
Education (years)	15.13 (1.96)	14.84 (2.24)
TICS (raw score)	36.80 (1.96)*	34.26 (2.23)*
GDS (raw score)	5.95 (6.24)	3.21 (4.08)
BDI (raw score)	5.85 (6.50)	5.95 (5.31)
STAI-S (raw score)	31.40 (11.36)*	62.47 (2.09)*
STAI-T (raw score)	33.55 (12.18)	29.47 (6.77)
FSIQ (standard score)	109.86 (7.48)	113.19 (8.69)
Trails-A (seconds)	25.75 (10.10)*	39.21 (12.57)*
Trails-B (seconds)	49.40 (14.75)*	98.74 (42.24)*
Mean ACT errors	1.11 (.57)*	2.24 (.74)*

Note: TICS = Telephone Interview for Cognitive Status; GDS = Geriatric Depression Scale; BDI-II = Beck Depression Inventory; STAI-S = State Trait Anxiety Inventory state score; STAI-T = State Trait Anxiety Inventory trait score; FSIQ = Full-scale IQ; Trails = Trailmaking Test; ACT = Auditory Consonant Trigrams.
*Groups significantly different at $p < .001$.

Demographic characteristics of study participants are provided in Table 2-1. Age groups were well matched for education, $t(37) = .42$, $p > .60$, and Full Scale IQ as estimated by the North American Adult Reading Test (NAART; Blair & Spreen, 1989; Nelson, 1982), $t(37) = -1.28$, $p > .20$. Older and younger adults reported similar levels of depressive symptoms on both the Beck Depression Inventory, 2nd Edition (BDI-II; Beck, 1996), $t(37) = -.05$, $p > .90$, and Geriatric Depression Scale (GDS; Yesavage et al., 1983), $t(37) = 1.61$, $p > .10$. Older adults reported more state, $t(37) = -11.73$, $p < .001$, but similar trait anxiety, $t(37) = 1.28$, $p > .20$, compared to younger adults.

Procedure

Participants attended two testing sessions within a one-week period. Prior to the first session, participants were administered the TICS (Brandt et al., 1988) as an initial screen for cognitive impairment. Potential participants with TICS scores of less than 30 were excluded from the study. Using this cutoff score, the TICS has a sensitively of 94% and a specificity of 100% for distinguishing demented individuals from cognitively intact individuals (Brandt et al., 1988). Thus, the TICS provided a means to exclude demented individuals from the study.

Session 1

The first testing session lasted approximately 1½ hours. All participants received a screening of relevant psychiatric and medical history. Participants underwent a structured clinical interview using the mood, psychotic disorders, substance abuse, and anxiety modules of the Structured Clinical Interview for DSM-IV-TR Axis I Disorders, Research Version (SCID-IV; First, Gibbon, Spitzer, & Williams, 2001) to determine the presence of major psychiatric disorder that might be an exclusionary criterion. The SCID-IV was administered by a psychology graduate student or trained research assistant.

Interviews were tape recorded, and 25% of interviews were randomly selected for recoding by another member of the research team. Interrater reliability for the presence or absence of psychiatric diagnoses was high (r = .96). Participants were also screened for neurological insult that might be an exclusionary criterion. They were asked whether they had difficulty reading the newspaper to determine visual acuity problems that might interfere with performing the computer task. The Ishihara Test for Color Blindness (Clark, 1924) was administered to ensure that participants could discriminate the colors (red, green, blue) used in the cued-Stroop task.

The presence and severity of depressive symptoms were assessed via the BDI-II and the GDS. The BDI-II was chosen because it is brief, easily administered and scored, and has good reliability and validity; however, it was not normed on older adults, and the emphasis on somatic symptoms of depression may lead to inflated scores in the elderly (Spreen & Strauss, 1998). In addition, the multiple-choice format may be confusing for older adults (Scogin, 1994). The GDS, in contrast, was normed on an elderly population and was designed to avoid somatic symptoms that complicate diagnosing when comorbid medical conditions are present (Blazer, 2002). The GDS has good reliability and validity and uses a yes/no format that may be easier to administer in older adults (La Rue, 1992). The State-Trait Anxiety Inventory (STAI; Speilberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983) was used to assess anxiety symptoms, which might contribute to difficulties performing the task.

Participants completed a short battery of neuropsychological tests to assess cognitive functioning. The NAART (Blair & Spreen, 1989; Nelson, 1982) was used to estimate overall cognitive functioning. Participants were administered the Trail Making

Test A & B (Trails; Reitan & Wolfson, 1995) and the Auditory Consonant Trigrams test (ACT; Peterson & Peterson, 1959) to assess attention and working memory. These tasks were used to examine the potential role of working memory capacity and attention as mediators of the different components of cognitive control, as at least one study has shown a significant relationship between working memory capacity and regulative aspects of cognitive control (Perlstein et al., 2006).

Session 2

The second testing session lasted approximately 2 hours. During this time, ERP data were acquired while participants performed the cued-Stroop task described in detail below. All subjects were pre-practiced on the button press procedure in order to ensure adequate learning of the color-key mapping. During this procedure, individual strings of X's (i.e., XXXX) were presented in red, green, and blue in the middle of the computer monitor over a black background. Participants pressed one of three keys on a computer keyboard (v, b, n) with their index, middle, and ring finger in response to the color. Color-to-key mapping was randomized across subjects. One hundred trials were presented in this color-key mapping practice. Once the color-key mapping was established to an accuracy of at least 80%, participants practiced 40 trials of the cued-Stroop task. If accuracy was less than 60%, the practice block was repeated. Practice blocks allowed the participants to become familiar with the button press procedure, insured that subjects understood task instructions, and reduced the influence of strategy development on ERP-related measurement of task performance. Participants then performed the cued-Stroop task during electroencephalography (EEG) acquisition, and were debriefed at the end of the testing session. During this time, participants completed a post-task questionnaire regarding subjective experience associated with performing the

task (Appendix B) using a modification of the questionnaire employed by Luu, Colllins, & Tucker (2000). In this questionnaire, participants used a 5-point Likert scale to rate their subjective experience regarding their performance (e.g., how well they performed, their response to errors), the task (e.g., whether the task was interesting or stressful), and the experiment.

Cued-Stroop task. The cued-Stroop task was run on a Dell Dimension computer using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002) for control of stimulus presentation and timing, and recording of accuracy and RT.

At the beginning of each trial, participants were presented with an instructional cue (the word "color" or "word" presented visually by computer) for 750ms, followed after a one-second delay by the probe, i.e., the Stroop stimulus. The Stroop stimulus was presented for a maximum duration of 2500ms or until the participant responded. Participants were instructed to respond manually to the stimulus, as designated by the cue, as quickly and accurately as possible. They responded by pressing one of the three color-coded response keys (v, b, n) using the index, middle, and ring fingers of their right hand. Color-to-key mapping was randomized across subjects. Participants performed two tasks, as specified by the instructional cue: Word reading and color naming. In the word-reading task, subjects simply read the probe word; in the color-naming task, subjects named the printed color of the probe. On color-naming trials, the context provided by the task instruction (i.e., color) must be used to override the influence of the stronger dimension (i.e., word). Three colors and words were used (red, green, blue) presented in each of two congruency conditions (congruent, incongruent). Congruent stimuli consisted of one of the three color names presented in its own color. Incongruent stimuli consisted

of a color name presented in one of the two remaining colors. To increase the degree of conflict and error rates, 60% of trials were congruent and 40% incongruent. All stimuli were presented over a black background.

The task was presented in 8 blocks of 90 trials each, for a total of 720 trials distributed equally across tasks (color-naming, word-reading). Two color-naming and two word-reading blocks were presented (single-task blocks), in which the task for each trial was to either name the color or read the word, respectively. Four mixed blocks were presented, in which the tasks of color-naming and word-reading were randomly presented in each block, thus introducing a task-switching component. Color-naming and word-reading tasks were distributed equally in each mixed block. The task instruction cue was also presented in single-task blocks in order to make the blocks equivalent in terms of timing and perceptual characteristics; however, the instruction was practically irrelevant for the participant in these blocks. Prior to the start of the block, participants were informed of whether they should always respond based on the color or the word, or if the color-naming and word-reading tasks would vary within the block. Block order was pseudorandomized, with the constraint that blocks of the same type (i.e., single-task color, single-task word, or mixed) did not occur consecutively. Participants were randomly assigned one of eight possible randomization sequences.

EEG Recording and Reduction

EEG was obtained from 64 scalp electrodes mounted in a Geodesic Sensor Net (Tucker, 1993) and amplified at 20K using an Electrogeodesics, Inc. (EGI; Eugene, Oregon) amplifier system (nominal bandpass .10-100Hz). The 64-channel montage and corresponding International 10-20 System (Jasper, 1958) equivalent are depicted in Figure 2-1. Electrode placements also enabled recording of vertical and horizontal eye

movements reflected in electro-oculographic (EOG) activity. During recording, EEG was referenced to Cz and digitized continuously at 250Hz with a 16-bit analog-to-digital converter. A right posterior electrode served as common ground. Electrode impedance was maintained below 50 kΩ.

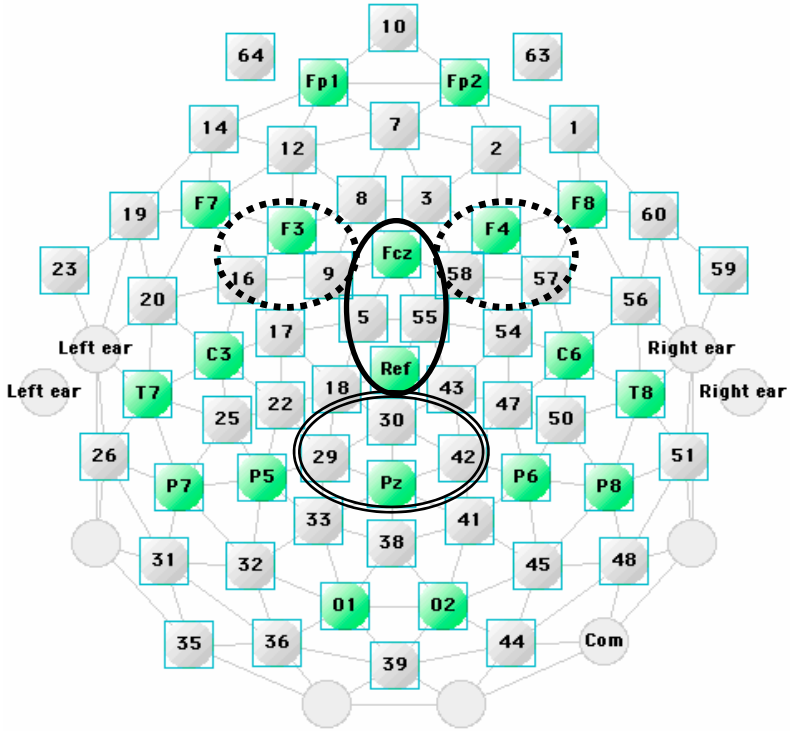

Figure 2-1. Sensor layout and international 10–20 equivalents of 64-channel geodesic sensor net (EGI; Eugene, Oregon). Solid-line circle indicates frontocentral recording sites averaged for P3a and frontal cue-related slow wave; double-line circle indicates parietal recording sites averaged for P3b and parietal cue-related slow wave; dashed-line circle indicates left and right frontal sites averaged for measurement of stimulus-related negative slow wave. Note that the reference electrode (REF) was positioned at Cz, and transformed to an active recording site during preprocessing through average re-referencing (see text).

EEG data were prepared for analysis using Brain Electric Source Analysis software (BESA version 5.1, MEGIS software, Munich, Germany; Berg & Scherg, 1994). Eye movement and blink artifacts were corrected using a spatial filtering method (Berg & Scherg, 1994; Ille, Berg, & Scherg, 1997, 2002). EEG was segmented and thresholds for discarding single trial epochs were determined individually for each subject. Averaged

across subjects, voltages that exceeded 92.47 μV or transitional (sample-to-sample) thresholds of 56.62 μV were discarded. EEG was re-referenced to an average reference (Bertrand, Perrin, & Pernier, 1985; Dien, 1998) and digitally low-pass filtered at 30 Hz.

Individual-subject averages were calculated for task instruction- and stimulus-related activity relative to a prestimulus baseline. Task instruction-locked averages were derived separately for mixed-block and single-task block color-naming and word-reading trials, spanning 100ms before and 800ms after instruction presentation. Stimulus-locked averages were derived separately for mixed block congruent and incongruent color-naming and word-reading trials, spanning 100ms before and 1000ms following stimulus onset. Individual-subject instruction- and stimulus-locked averages were baseline corrected using a 100ms window prior to event onset.

Data Analysis

Cued-Stroop behavioral data

For analyses involving error rates, data were arcsine transformed (Neter, Wasserman, & Kutner, 1985) prior to all analyses. This transformation is used to normalize the distribution of reaction time data, which is often skewed because the data points are proportions or percentages. For analyses involving RT, we employed median RTs (Ratcliff, 1993) for correct responses. Measures of effect size utilized Cohen's d (Cohen, 1988) with the pooled standard deviation used for between-group comparisons (Rosnow & Rosenthal, 1996). A set of repeated measures analyses of variance (ANOVAs) were performed on error and RT data to address the following aims: (a) verification of the Stroop interference effect, by comparing RTs and error rates in the incongruent vs. congruent conditions in each group; (b) verification of the context maintenance effect, by examining errors and RT in the incongruent color-naming

conditions compared to other conditions; (c) examination of global and local switching costs, by comparing RTs and error rates for both single-task versus mixed blocks, and switching versus repetition trials, respectively; and (d) examination of age-related differences in cognitive control, by comparing age differences in interference, context maintenance, and task-switching. We predicted that older adults would show greater Stroop interference, selective and disproportionate increases in error rates and/or slower RT on the incongruent condition of the color-naming task, and greater task-switching interference effects relative to younger adults.

Neuropsychological test data

To evaluate age differences in attention and task switching, we performed a 2-age group x 2-card (Trails A vs. Trails B) ANOVA. In addition, we evaluated age differences in errors related to working memory load by performing a 2-age group x 4-working memory load (0, 3, 9, and 18" ACT errors) trend analysis. For Trails, analyses were performed on time to completion (in seconds), and for ACT, analyses were performed on the mean number of errors.

EEG data

Analysis of ERP waveforms focused on instruction- and stimulus-locked ERP activity from selected electrode sites based on previous findings indicating that the ERP modulations of interest are relatively focal over frontal and parietal sites (Liotti et al., 2000; Perlstein et al., 2006; West, 2003; West, 2004; West & Alain, 2000a, 2000b, 2000c), as well as the scalp-distribution maps of the present data which indicated that the ERP deflections of interest were greatest in amplitude over these regions. All EEG analyses were performed on mean voltages.

The ERP modulations of interest in the *instruction-related* ERPs were the slow wave, P3a, and P3b. ERP amplitudes for the instruction-related components were measured at frontocentral (electrodes 4 [Fcz], 5, 55, and Cz) and centroparietal (electrodes 29, 30, 34 [Pz], and 42) sites (Figure 2-1). P3a (frontocentral) and P3b (centroparietal) amplitudes were measured as the mean voltage between 250–350ms and 400–500ms, respectively. Slow-wave amplitude was measured as the mean voltage between 600 and 752ms at frontocentral and centroparietal sites. Mean cue-related ERP were subjected to 2-age group (young, old) x 2-task (color-naming, word-reading) x 2-block type (mixed, single-task) ANOVAs. Separate ANOVAs were performed for each component of interest. To evaluate the effect of practice on local task-switching effects, slow wave amplitudes for switching and repetition trials were separately averaged for each of the four mixed blocks between 600–752ms. Mean voltages were subjected to 2-age group x 2-switching group (repetition trials, switching trials) x 4-time point (mixed block 1, 2, 3, and 4) ANOVAs. Congruency effects were not examined for task switching due to the relatively poor signal-to-noise ratio that would result from having too few trials per condition for the ERP averages.

For *stimulus-locked* activity, an N450 component was not apparent upon examination of the ERP waveforms, thus, analyses were focused on the NSW. The NSW was measured at left (electrodes 9, 13 [F3], and 16) and right (electrodes 57, 58, and 62[F4]) frontal sites as the mean voltage between 600 and 700ms. We also measured sustained negative slow-wave activity at the same sites during the 704–804ms epoch. NSW and sustained slow-wave activity were analyzed separately using 2-age group

(young, old) x 2-task (color-naming, word-reading) x 2-congruency (congruent, incongruent) x laterality ANOVAs.

We predicted that younger adults would show greater P3a, P3b, and cue-related slow wave to color-naming compared to word-reading cues, and to mixed compared to single-task blocks. We also predicted that younger adults would exhibit greater NSW to incongruent compared to congruent color-naming trials. In contrast, we expected that older adults would fail to show these effects, which would be reflective of age-related impairments in regulative components of cognitive control.

Correlations with attention and working memory scores. We conducted a series of Pearson product-moment correlations to test specific predictions regarding the relationship between ACT errors, Trails switching scores (i.e., Trails B – Trials A scores), Stroop task performance, and ERP data. We predicted that older adults would perform more poorly on working memory and attention measures than younger adults, and that scores would be correlated with cued-Stroop task performance as well as regulative components of cognitive control (i.e., P3a, P3b, and/or cue-related slow wave).

Results

A summary of the results obtained for each of our behavioral and ERP hypotheses is presented in Appendix C.

Behavioral Data

Cued-Stroop task behavioral performance

RTs and error rates for the cued-Stroop task were positively and significantly correlated for younger adults, $r(18) = .61$, $p < .01$. For older participants, RTs and error rates were also positively correlated, however the correlation was not significant, $r(17) =$

.40, $p > .09$. These results suggest that a speed/accuracy trade-off was not a significant factor in task performance for either group.

Verification of Stroop interference

Young, $F(1, 19) = 121.82$, $p < .001$, $\eta 2 = .87$, and older adults, $F(1, 18) = 139.71$, $p < .001$, $\eta 2 = .89$, showed robust Stroop RT interference, with longer RTs to the incongruent than congruent condition (Figure 2-2). Stroop error interference was also observed for both young, $F(1, 19) = 259.14$, $p < .001$, $\eta 2 = .93$, and older adults, $F(1, 18) = 157.98$, $p < .001$, $\eta 2 = .89$, with more errors committed in the incongruent than congruent condition (Figure 2-3). An age group x congruency interaction was observed for errors, $F(1, 37) = 19.20$, $p < .001$, $\eta 2 = .34$, reflecting a greater interference effect in older adults.

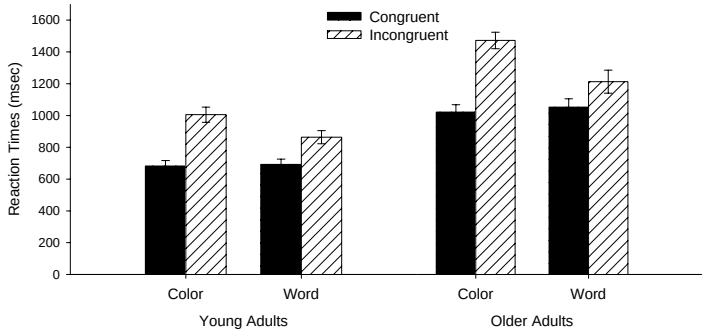

Figure 2-2. Cued-Stroop task reaction times for younger and older adults in Experiment 1.

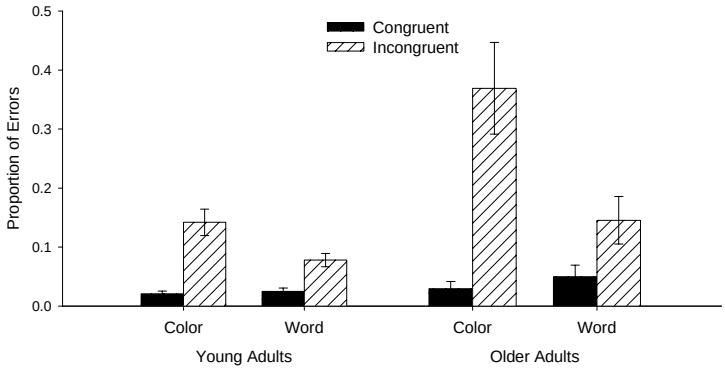

Figure 2-3. Cued-Stroop task error rates for younger and older adults in Experiment 1.

Verification of the context maintenance effect

For RTs, a 2-congruency (congruent, incongruent) x 2-cue (color naming, word reading) x 2-age group (young, old) ANOVA yielded significant effects of age group, $F(1, 37) = 6.29$, $p < .05$, $\eta^2 = .15$, cue, $F(1, 37) = 37.63$, $p < .001$, $\eta^2 = .50$, and congruency, $F(1, 37) = 370.32$, $p < .001$, $\eta^2 = .91$, reflecting generalized slowing in the older adult group, slower responses to the more attentionally-demanding color-naming task, and RT interference in the incongruent compared to congruent conditions, respectively. For error rates, a main effect was found for cue, $F(1, 37) = 10.75$, $p < .01$, $\eta^2 = .21$, and congruency, $F(1, 37) = 350.44$, $p < .001$, $\eta^2 = .91$. A cue x age group x congruency interaction was found for RT (Figure 2-2), $F(1, 37) = 7.61$, $p < .01$, $\eta^2 = .17$, and errors (Figure 2-3), $F(1, 37) = 4.48$, $p < .05$, $\eta^2 = .11$. We decomposed the three-way interactions by performing separate analyses for color-naming and word-reading tasks. For RT, an effect of congruency was found for both color naming, $F(1, 37) = 311.68$, $p < .001$, $\eta^2 = .89$, and word reading, $F(1, 37) = 139.03$, $p < .001$, $\eta^2 = .79$; however, a congruency x age effect, reflecting a greater congruency effect in younger adults, was found for word reading, $F(1, 37) = 6.27$, $p < .05$, $\eta^2 = .15$, but not color naming, $F(1, 37) = 1.92$, $p > .10$. For errors, a congruency effect was found for both color naming, $F(1, 37) = 172.03$, $p < .001$, $\eta^2 = .82$, and word reading, $F(1, 37) = 64.78$, $p < .001$, $\eta^2 = .64$; however, older adults showed a disproportionate increase in errors on incongruent trials for the color-naming task, $F(1, 37) = 13.51$, $p < .001$, $\eta^2 = .27$, but not the word-reading task, $F(1, 37) = .71$, $p > .40$.

Task-switching effects

Both global (i.e., block-by-block) and local (i.e., trial-by-trial) task-switching effects were evaluated. Single-task (collapsed across color naming and word reading) and

mixed blocks were compared with ANOVAs on errors and RT in each group. Both younger and older adults showed significant block effects for errors, younger adult $F(1, 19) = 11.76$, $p < .001$, $\eta^2 = .38$, older adult $F(1, 18) = 11.80$, $p < .01$, $\eta^2 = .40$, and RT, younger adult $F(1, 19) = 52.84$, $p < .001$, $\eta^2 = .74$, older adult $F(1, 18) = 68.94$, $p < .001$, $\eta^2 = .79$, reflecting an increase in errors and slower RTs in the mixed (switching) blocks compared to single-task blocks. For both young, $F(1, 19) \geq 4.77$, $p < .05$, $\eta^2 \geq .20$, and older adults, $F(1, 18) \geq 5.80$, $p < .05$, $\eta^2 \geq .24$, block effects for errors were greater on incongruent compared congruent trials, while block effects for RT were greater on incongruent compared to congruent and color-naming compared to word-reading trials. The age group x block type interaction was not significant.

Trial-by-trial task-switching effects were analyzed by comparing RTs and errors for switching and non-switching (i.e., repetition) trials. Both younger adults, $F(1, 19) = 25.87$, $p < .001$, $\eta^2 = .58$, and older adults, $F(1, 18) = 42.12$, $p < .001$, $\eta^2 = .70$, showed a switching effect for RT. Similarly, a switching effect for errors was found in both young, $F(1, 19) = 13.17$, $p < .01$, $\eta^2 = .41$, and older adults, $F(1, 18) = 7.24$, $p < .05$, $\eta^2 = .29$. The age group x switching group interaction was not significant.

To analyze the effect of practice on task switching, we calculated errors and RT for switching and non-switching trials, averaged separately for each of the four mixed blocks. An age group x switching group x time (mixed blocks 1, 2, 3, and 4) ANOVA on errors yielded a significant age group x time interaction, $F(3, 111) = 6.23$, $p < .001$, $\eta^2 = .14$ (Figure 2-4). Older adults made significantly more errors during the first mixed block, $t(37) = -3.25$, $p < .01$, $d = 1.04$, but age differences decreased with each successive block, and group differences were not significant during any other block, $t(37) \leq -1.64$, $p > .10$,

$d \leq .52$. As can be seen in the figure, younger adults performed similarly across time, while older adults made successively fewer errors with practice.

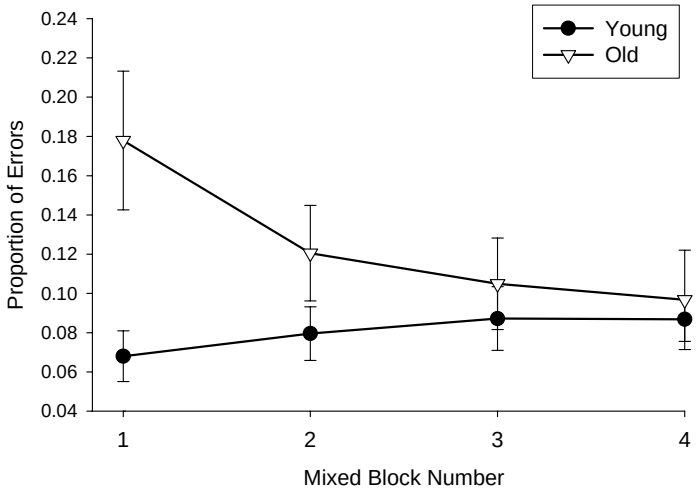

Figure 2-4. Proportion of errors in mixed blocks for younger and older adults.

Attention and working memory performance

Neuropsychological test scores are presented in Table 2-2. Older adults performed more poorly than younger adults on measures of attention, $F(1, 37) = 24.13$, $p < .001$, $\eta 2 = .40$, and working memory, $F(1, 37) = 28.50$, $p < .001$, $\eta 2 = .44$. Older adults performed disproportionately slower on Trails B compared to Trails A, $F(1, 37) = 20.05$, $p < .001$, $\eta 2 = .35$, suggesting age differences in task switching above those caused by generalized slowing in the older group. On the ACT, between-group tests of polynomial trends over load revealed a significant group x linear trend over load interaction, $F(1,37) = 9.63$, $p < .001$, reflecting an increase in errors with increasing load. In addition, a group x quadratic trend over load interaction was observed, $F(1, 37) = 7.05$, $p < .05$, $\eta 2 = .16$. Older and younger adults performed similarly at the 0" delay, $t(37) = -.63$, $p > .50$, $d = .20$, but older adults performed worse than younger adults at all other delays $t(37) \geq -3.75$, $p < .001$, $d \geq 1.14$.

Post-task questionnaire data

Post-task questionnaire data were missing for one younger adult participant. Certainty of correct performance (question 10) was significantly correlated with total errors for young, $r(19) = -.51$, $p < .05$, but not older adults, $r(19) = .06$, $p > .80$. Younger adults who felt more certain about their correct performance made fewer errors on the task. Older adults reported feeling more confident in their performance before beginning the task compared to younger adults (question 13), $t(36) = -2.63$, $p < .05$, $d = .85$. Older adults, more than younger adults, felt they performed better than they initially expected (question 14), $t(36) = -3.08$, $p < .01$, $d = 1.0$.

ERP Data

A total of 34.80% of trials were excluded from averages due to performance errors and EEG artifacts. Younger and older adult groups had an equivalent number of trials retained for both stimulus- and task-instruction-locked ERPs, $t(31) \leq -.07$, $p > .90$, $d \leq .02$. Per participant, stimulus-related waveforms contained an average of 124 trials for younger adults (min/max = 71/166) and 121 trials for older adults (75/175); task-instruction-related waveforms contained an average of 116 trials for younger adults (65/173) and 118 trials for older adults (57/169) in the cue analysis, and 29 trials for younger adults (15/42) and 26 trials for older adults (10/39) in the switching analysis. EEG data for two younger adults and three older adults were discarded due to excessive eye movement artifact, which prevented us from computing reliable ERPs. In addition, EEG data for two older adults were lost due to equipment malfunction. Thus, EEG analyses were performed on 18 younger and 15 older adults.

Context encoding and maintenance

Figure 2-5 illustrates the grand average ERP waveforms for cue-related P3a, P3b, and slow wave activity in younger and older adults. For both younger and older adults, cue-related ERPs were more positive-going for mixed blocks than single-task blocks, and were marked by both frontal and parietal P3 components as well as slow wave activity, which began at approximately 600ms and continued throughout the epoch. As can be seen in the figure, ERP waveform deflections differed in younger and older adults, consistent with other ERP aging studies (e.g., West, 2004). Due to these morphological differences, inferences regarding age differences could not be made based on between-group comparisons. Rather, we separately analyzed the effect of cue (color naming, word reading) and block type (single-task, mixed) on the ERP components of interest in each age group.

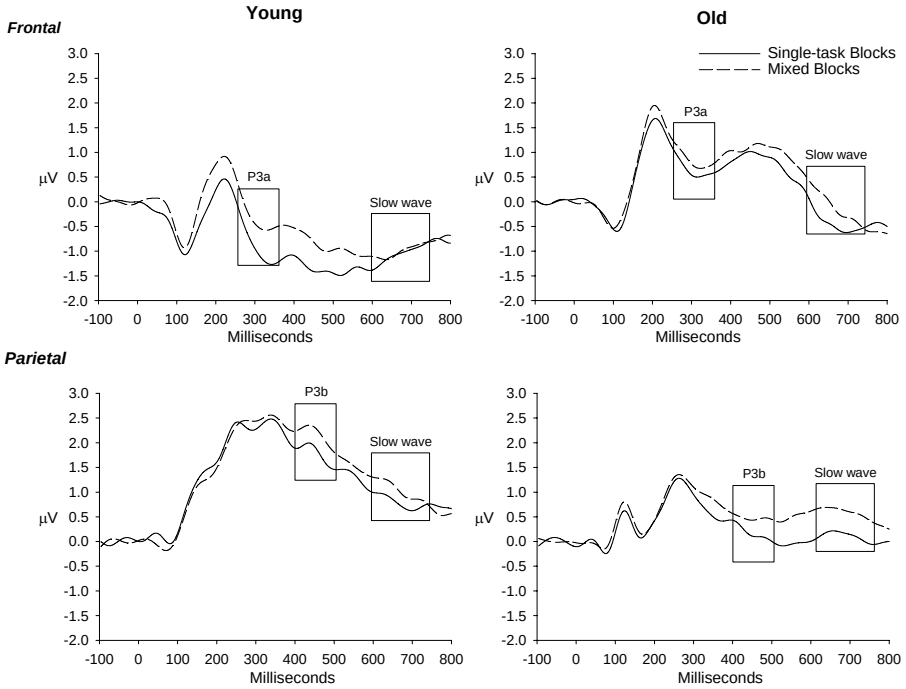

Figure 2-5. Grand average instruction-related ERP waveforms showing the P3a, P3b, and slow wave components as a function of block type (single-task, mixed) and group in Experiment 1. Waveforms were averaged over frontocentral and centroparietal sites (Figure 2-1) and low-pass filtered at 30 Hz.

Younger adults showed greater P3a and P3b amplitudes to mixed blocks compared to single-task blocks $F(1, 17) \geq 9.35$, $p < .01$, $\eta^2 \geq .36$. The P3a effect was absent in older adults, $F(1, 14) = 2.87$, $p > .10$, $\eta^2 = .17$; however, older adults did show an effect of block type on P3b, $F(1, 14) = 7.81$, $p < .05$, $\eta^2 = .36$. No P3a differences in color-naming versus word-reading were observed in either group. P3b activity was greater in color-naming compared to word-reading cues in older, but not young, adults, $F(1, 31) = 9.69$, $p < .01$, $\eta^2 = .24$.

The cue-related slow wave was measured from 600–752ms. Older adults showed a greater *negative* slow wave in frontal regions for color-naming compared to word-reading in mixed blocks, while the slow wave was more *positive-going* for color-naming than word-reading in single-task blocks, $F(1, 14) = 5.77$, $p < .05$, $\eta^2 = .29$. Both young, $F(1, 17) = 4.74$, $p < .05$, $\eta^2 = .22$, and older adults, $F(1, 14) = 9.83$, $p < .01$, $\eta^2 = .41$, showed a more positive slow wave in parietal areas for mixed blocks compared to single-task blocks (Figure 2-5).

Thus, age differences in global task-switching effects were observed. Older adults failed to effectively recruit frontal attentional mechanisms in mixed blocks, while parietal mechanisms necessary for context encoding and maintenance appeared intact.

Mean amplitude cue-related activity related to switching and repetition trials (i.e., local switching effects) are presented in Figures 2-6 (younger adults) and 2-7 (older adults). The cue-related slow-wave was more positive-going for switching compared to repetition trials over parietal areas for young, $F(1, 17) = 6.75$, $p < .05$, $\eta^2 = .28$, but not older, $F(1, 14) = 1.08$, $p > .30$, $\eta^2 = .07$, adults. In younger adults, a main effect of time was found for the parietal slow wave, $F(3, 51) = 3.41$, $p < .05$, $\eta^2 = .17$, such that ERPs

became more positive-going over time, reaching a plateau at blocks three and four. Thus, older adults failed to show increased slow wave activity to switching trials, suggestive of a local switching effect on the implementation of cognitive control.

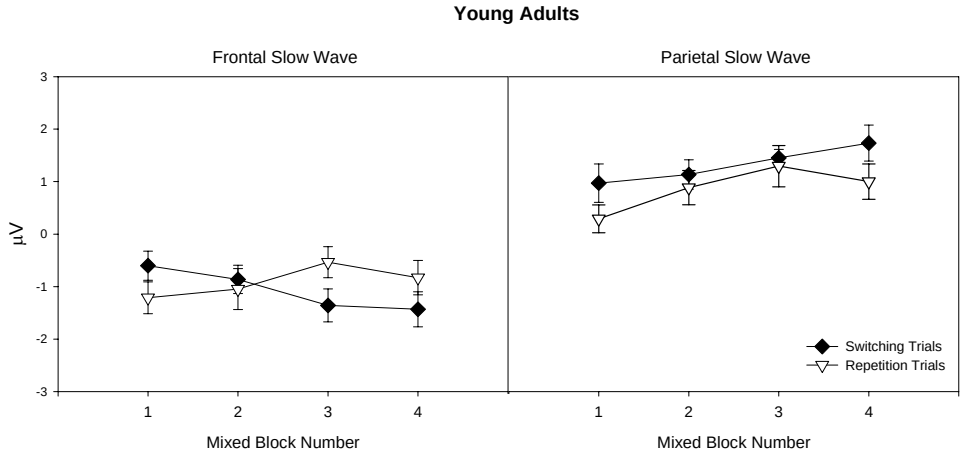

Figure 2-6. Cue-related slow wave amplitudes, averaged over frontocentral and centroparietal sites (Figure 2-1), for switching and repetition trials in younger adults.

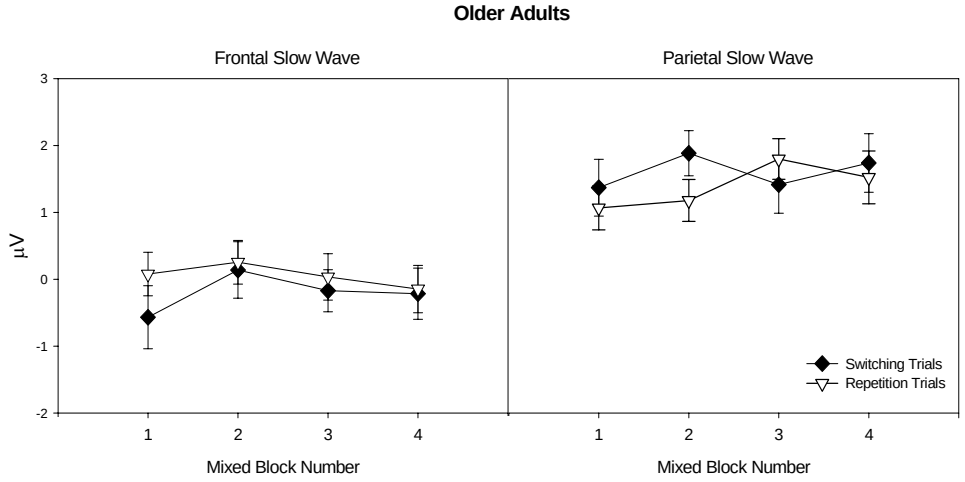

Figure 2-7. Cue-related slow wave amplitudes, averaged over frontocentral and centroparietal sites (see Figure 2-1), for switching and repetition trials in older adults.

Conflict detection and resolution

Stimulus-locked grand average ERPs waveforms reflecting slow wave activity for mixed-block congruent and incongruent color-naming trials are shown in Figure 2-8. Unexpectedly, an N450 was not apparent upon examination of the waveforms (*General Discussion*), as can be seen in the figure. Slow wave activity was observed which began

at 600ms, continued through the end of the epoch, and was more negative for incongruent, compared to congruent, color-naming trials for young, but not older adults at left frontal sites. Similar to cue-related ERP activity, age differences in the morphology of stimulus-locked waveforms were observed, therefore, the components of interest were analyzed separately within each age group.

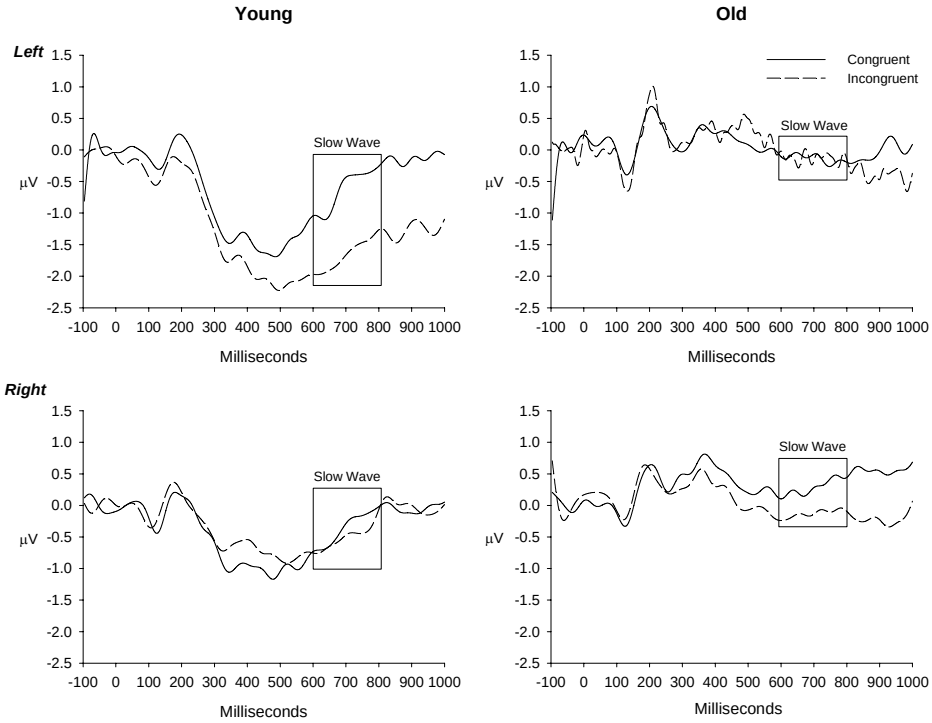

Figure 2-8. Grand average stimulus-related ERP waveforms showing the NSW as a function of color-naming task condition (congruent, incongruent) and group for the mixed-block trials in Experiment 1. Waveforms were averaged over left and right frontal sites (see Figure 2-1) and low-pass filtered at 30 Hz.

Examination of the frontal NSW revealed a significant effect of congruency in younger adults that was absent in older adults, $F(1, 31) = 4.55$, $p < .05$, $\eta 2 = .13$. The congruency effect in younger adults reflected greater negativity to the incongruent than congruent condition. A laterality x congruency x age group interaction reflected a left-lateralized increase in negativity for incongruent compared to congruent conditions in younger adults, which was absent for older adults, $F(1, 31) = 6.07$, $p < .05$, $\eta 2 = .16$. Age

differences in the effect of congruency continued from 704–804ms, $F(1, 31) = 5.39$, $p < .05$, $\eta 2 = .15$. During this epoch, greater left-sided negative-going slow wave was observed in older, $F(1, 14) = 6.26$, $p < .05$, $\eta 2 = .31$, as well as younger adults, $F(1, 17) = 8.68$, $p < .01$, $\eta 2 = .34$. However, older adults continued to lack the left-lateralized increase in negative slow wave to incongruent compared to congruent conditions that was observed in younger adults, $F(1, 31) = 6.93$, $p < .05$, .18.

Correlations with attention and working memory scores

Incongruent color-naming errors were significantly correlated with the Trails switching score, $r(39) = .59$, $p < .01$ and mean ACT errors, $r(39) = .34$, $p < .05$. Moreover, mean ACT errors were significantly correlated with the instruction-related color-naming vs. word-reading P3b difference, $r(33) = .44$, $p < .01$, suggesting that greater working memory capacity is associated with greater P3b amplitude following the color-naming than word-reading task instruction.

Discussion

Overall, the current behavioral and ERP findings suggest that aging is associated with impaired regulative components of cognitive control, reflected in 1) greater Stroop interference effects, 2) greater context maintenance effects, 3) greater task-switching effects, and 3) modulations in ERP reflections of context encoding, context maintenance, and conflict resolution. These results are consistent with previous research that has demonstrated age-related differences in the active maintenance of context information in working memory, implementation of control, and allocation of attentional resources to more attentionally-demanding tasks (Braver et al., 2001; MacDonald et al., 2000; West, 2003; West, 2004). In addition, task performance was correlated with traditional neuropsychological measures of attention and working memory, and working memory

capacity was correlated with ERP measures of regulative aspects of cognitive control, consistent with previous work in our laboratory (Perlstein et al., in press). In Experiment 2, we examined the effect of depressive symptomatology on this relationship between aging and cognitive control dysfunction.

CHAPTER 3
EXPERIMENT 2: DOUBLE JEOPARDY—COGNITIVE CONTROL DYSFUNCTION IN DEPRESSION AND AGING

In Experiment 1, we demonstrated behavioral and event-related potential (ERP) evidence of cognitive control dysfunction in older adults. Depressive symptoms are prevalent in older adults, and both aging and depression are independently associated with deficits in cognitive control (Bryan & Luszcz, 2000; Hartlage et al., 1993). This suggests older depressed adults may be at "double jeopardy" for executive dysfunction due to the combined effects of aging and depression. Thus, the primary aim of Experiment 2 was to examine the combined effect of aging and depression on cognitive control functioning to determine if the effect is additive or multiplicative. An additive effect would be reflected in performance deficits in older adults that are approximately equal to the summed performance of depressed younger adults and healthy older adults. For example, older depressed adults may show an error rate of 10% on a task, while younger depressed adults and healthy older adults showed error rates of 3% and 7%, respectively. A multiplicative effect, on the other hand, would be indicated if the error rate of the depressed older adults was 15%. The results of Lockwood et al. (2002) suggest that the combined effect of aging and depression is in fact multiplicative.

Behaviorally, we predicted that both increasing age and depressive symptoms would contribute to deficits in cognitive control, reflected by greater Stroop interference and context maintenance effects compared to controls. More importantly, we hypothesized that older depressed adults would exhibit significantly greater deficits in

cognitive control than older non-depressed adults or younger depressed adults. We predicted that the combined effect of aging and depression would be multiplicative.

Importantly, age- and/or depression-related impairments in behavioral performance could be due to a breakdown in various components of cognitive control engaged by the cued-Stroop task. Thus, ERPs were used to *temporally dissociate* neural activity associated with these component processes in order to determine if aging and/or depression differentially affected these processes. We examined the following hypotheses: 1) Impairments on the cued-Stroop task result in part from deficits in encoding and maintaining context. This would be reflected in reduced amplitude cue-related P3a and/or P3b components to the more attentionally-demanding color-naming task compared to word-reading task, or to mixed blocks compared to single-task blocks. 2) Impairment is partly due to inadequate implementation of cognitive control, which is associated with preparation to override the prepotent response tendency. This finding would be reflected in a reduced-amplitude slow wave associated with the task instructional cue to the color-naming task compared to the word-reading task, or in mixed blocks compared to single-task blocks. 3) Impairment is due, in part, to impaired anterior cingulate cortex-mediated detection and processing of the conflict information inherent in the incongruent color-naming condition. This finding would be reflected in a decreased N450 deflection and negative slow wave (NSW) in the incongruent vs. congruent color-naming condition.

We hypothesized that older adults would show ERP evidence of cognitive control dysfunction compared to younger adults, reflected in reduced amplitude ERP signatures of context encoding and maintenance (P3a, P3b, and cue-related slow wave) and conflict

resolutoin (NSW). We expected depressive symptomatology to be associated with reduced P3b amplitude, while P3a and NSW would be unaffected by depression. We further predicted an age x depression interaction for P3b, such that the effect of depressive symptomatology on P3b amplitude would be greater in older than younger adults.

Methods

Participants

Twenty older adults (ages 62–84) and 24 younger adults (ages 18–35) participated in the study. This sample consisted of the 39 participants from Experiment 1, with the addition of five participants who were excluded from the first study due to a diagnosis of Major Depression. The sample consisted of 91% White, 5% African-American, 2% Hispanic, and 2% Asian participants. Inclusion and exclusion criteria were identical to Experiment 1, with the exception that participants with Major Depression were allowed in Experiment 2 since we were interested in the effect of depression in this study.

Demographic characteristics of study participants are provided in Table 3-1. Age groups were well matched for education, $t(42) = 1.44$, $p > .10$, and Full Scale IQ as estimated by the North American Adult Reading Test (NAART; Blair & Spreen, 1989; Nelson, 1982), $t(42) = -.90$, $p > .30$. Older adults reported more state, $t(42) = -11.02$, $p < .001$, but similar levels of trait anxiety, $t(42) = 1.44$, $p > .10$.

Participants varied in their level of depressive symptoms, as measured by the Beck Depression Inventory, 2nd edition (BDI-II) and the Geriatric Depression Scale (GDS; Appendix D). Rather than categorizing participants into depressed and non-depressed groups, depression was used as a random variable in all analyses. The depression scores used in the statistical analyses were a composite of each participant's BDI-II and GDS

scores, obtained by calculating z-scores for the BDI-II and GDS separately and averaging them. For the purposes of this study, the term "depression" refers to this composite score, which represents the degree of depressive symptomatology in each participant. Older and younger adult groups reported similar levels of depressive symptoms on both the BDI-II, $t(42) = .11$, $p > .90$, and GDS, $t(42) = 1.33$, $p > .10$.

Table 3-1. Mean (+standard deviation) demographic and neuropsychological test data for younger and older adults.

	Younger Adults (n=24)	Older Adults (n=20)
No. of males/no. of females	7/17	3/17
Age (years)	24.00 (5.07)	75.65 (6.31)
No. with Major Depression	4	1
No. with Minor Depression	5	8
Education (years)	15.73 (2.44)	14.70 (2.27)
TICS (raw score)	36.58 (1.89)*	34.20 (2.19)*
GDS (raw score)	6.46 (6.04)	4.10 (5.62)
BDI (raw score)	7.08 (7.16)	6.85 (6.56)
STAI-S (raw score)	32.25 (12.12)*	62.25 (2.04)*
STAI-T (raw score)	35.42 (13.42)	30.50 (8.02)
FSIQ (standard score)	109.99 (7.47)	112.28 (9.38)
Trails-A (seconds)	25.04 (9.44)*	40.40 (13.34)*
Trails-B (seconds)	50.67 (15.84)*	99.35 (41.20)*
Mean ACT errors	1.06 (.57)*	2.33 (.82)*

Note: TICS = Telephone Interview for Cognitive Status; GDS = Geriatric Depression Scale; BDI-II = Beck Depression Inventory; STAI-S = State Trait Anxiety Inventory state score; STAI-T = State Trait Anxiety Inventory trait score; FSIQ = Full-scale IQ; Trails = Trailmaking Test; ACT = Auditory Consonant Trigrams.
*Groups significantly different at $p < .001$.

Procedure

The experimental procedure was identical to Experimental 1 in regards to the testing sessions, experimental task, and electroencephalography (EEG) recording and reduction.

Data Analysis

Cued-Stroop behavioral data

As in Experiment 1, error rates were arcsine transformed (Neter et al., 1985) prior to all analyses, and we employed median reaction times (RTs; Ratcliff, 1993) for correct responses for all RT analyses. Measures of effect size utilized Cohen's *d* (Cohen, 1988) with the pooled standard deviation used for between-group comparisons (Rosnow & Rosenthal, 1996). A set of repeated measures analyses of variance (ANOVAs) were performed on error and RT data to address the following aims: (a) verification of the Stroop interference effect, by comparing RTs and error rates in the incongruent vs. congruent conditions in each group; (b) verification of the context maintenance effect, by examining errors and RT in the incongruent color-naming conditions compared to other conditions; (c) examination of age-related differences in cognitive control, by comparing interference and context maintenance effects in younger and older adults; and (d) evaluation of the combined effect of aging and depression, by examining the interaction between age and depressive symptomatology. We predicted that older adults would show greater Stroop interference, as well as selective and disproportionate increases in error rates and/or slower RT on the incongruent condition of the color-naming task. We expected depressed adults to show some cognitive control deficits, but that these would be smaller in magnitude than the age-related impairments. Most importantly, we predicted an age x depression interaction, reflecting a multiplicative effect of age and depression on cued-Stroop performance.

Neuropsychological test data

2-age group x depression ANOVAs were performed on Trails B and Auditory Consonant Trigrams (ACT) scores to examine the effect of age and depression on

attention and working memory span, respectively. For Trails B, analyses were performed on time to completion (in seconds), and for ACT, analyses were performed on the mean number of errors. To evaluate age and depression-related differences in task switching, we performed a 2-age group x depression x 2-card (Trails A vs. Trails B) ANOVA. Finally, we evaluated differences in errors related to working memory load due to age and depression by performing a 2-age group x depression x 4-working memory load (0, 3, 9, and 18" ACT errors) ANOVA. We predicted that older adults and depressed participants would perform more poorly on working memory and attention measures than controls, and that the age x depression interaction would be significant.

EEG data

ERP activity was quantified in a manner identical to Experiment 1. For *instruction-locked* activity, mean cue-related ERPs were subjected to 2-age group (young, old) x depression x 2-task (color-naming, word-reading) x 2-block type (mixed, single-task) ANOVAs. Separate ANOVAs were performed for each component of interest (P3a, P3b, and cue-related slow wave). For *stimulus-locked* activity, an N450 component was not apparent upon examination of the ERP waveforms, thus, analyses were focused on the NSW and sustained negative slow-wave (704–804ms). NSW and sustained slow-wave activity were analyzed separately using 2-age group x depression x 2-congruency (congruent, incongruent) x laterality ANOVAs.

Results

Behavioral Data

RTs and error rates for the cued-Stroop task were positively and significantly correlated for both young, $r(22) = .60$, $p < .01$, and older participants, $r(18) = .50$, $p < .05$,

suggesting that a speed/accuracy trade-off was not a significant factor in task performance for either group.

Verification of Stroop interference

As in Experiment 1, both young, $F(1, 22) \geq 135.30$, $p < .001$, $\eta^2 \geq .86$, and older adults, $F(1, 18) \geq 136.24$, $p < .001$, $\eta^2 \geq .88$, showed Stroop RT (Figure 3-1) and error interference (Figure 3-2). For errors, an age group x congruency interaction was observed, $F(1, 40) = 31.05$, $p < .001$, $\eta^2 = .44$, reflecting a greater interference effect in older participants. Young, $F(1, 22) \geq 22.38$, $p < .001$, $\eta^2 \geq .50$, and older adults, $F(1, 18) \geq 18.60$, $p < .001$, $\eta^2 \geq .51$, showed greater error and RT interference in mixed blocks compared to single-task blocks, reflecting a task-switching effect on Stroop interference.

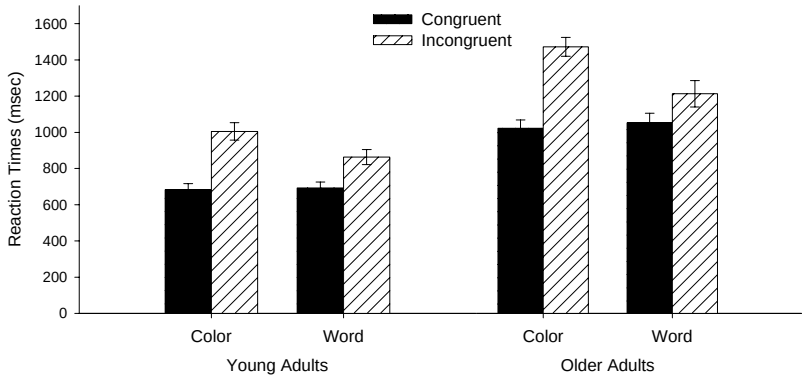

Figure 3-1. Cued-Stroop task reaction times for younger and older adults in Experiment 2.

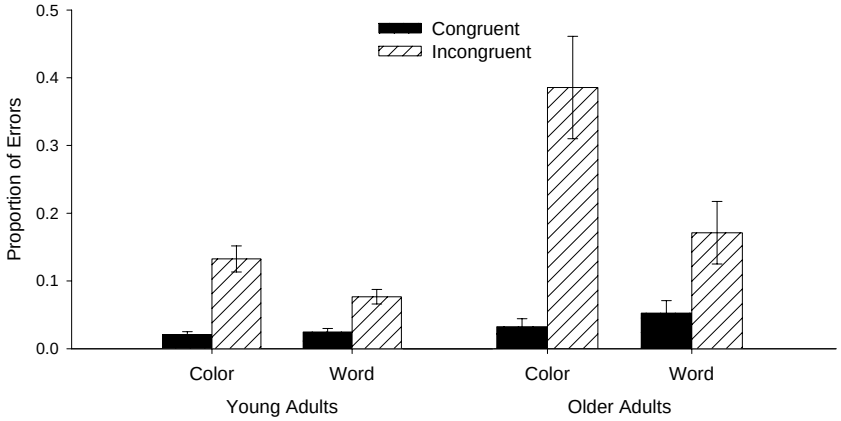

Figure 3-2. Cued-Stroop task error rates for younger and older adults in Experiment 2.

An age x depression x congruency interaction was observed for errors, $F(1, 40) = 5.12$, $p < .05$, $\eta^2 = .11$, such that the interference effect became greater with increasing depressive symptoms for older, but not younger adults (Figure 3-3). Thus, age was associated with greater Stroop interference, and depression was associated with greater interference effects only in older adults.

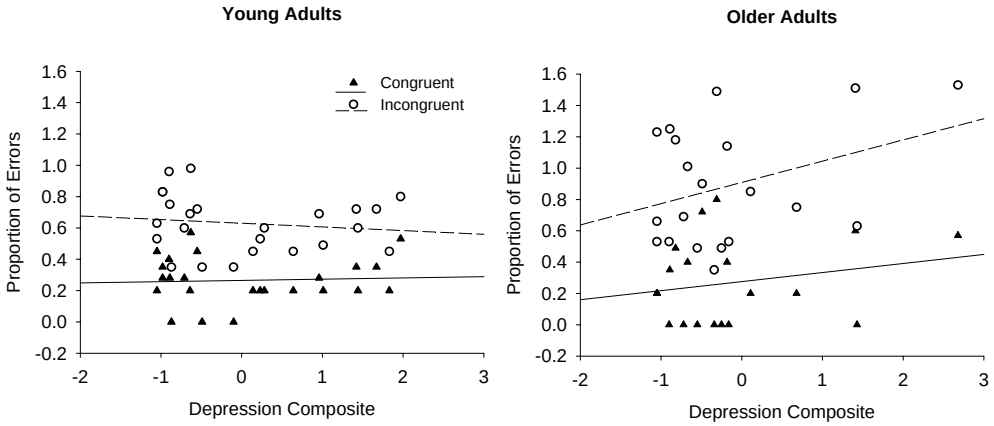

Figure 3-3. Proportion of congruent and incongruent errors in younger and older adults as a function of depression.

Verification of the context maintenance effect

Replicating results from Experiment 1, significant effects were found for age group, $F(1, 40) \geq 4.19$, $p < .05$, $\eta^2 \geq .10$, cue, $F(1, 40) \geq 10.91$, $p < .01$, $\eta^2 \geq .21$, and congruency, $F(1, 40) \geq 379.14$, $p < .001$, $\eta^2 \geq .91$, for both RT (Figure 3-1) and errors (Figure 3-2), reflecting an increase in RT and errors in the older adult group, slower RT and greater errors to the more attentionally-demanding color-naming task, and Stroop RT and error interference effects, respectively. A congruency x cue interaction was found in both age groups for errors and RT, $F(1, 40) \geq 27.67$, $p < .05$, $\eta^2 = .41$, reflecting greater error rates for color-naming compared to word-reading trials in the incongruent condition, with similar rates in congruent conditions. Again, older adults showed a disproportionate increase in errors on incongruent color-naming trials, reflected in a cue x

age group x congruency interaction, $F(1, 40) = 5.35$, $p < .05$, $\eta^2 = .12$ (Figure 3-2). These results are suggestive of age-related deficits in context maintenance.

A congruency x cue x depression interaction was found in older, $F(1, 18) = 11.24$, $p < .01$, $\eta^2 = .38$, but not younger adults, $F(1, 22) = .09$, $p > .70$, $\eta^2 = .00$ (Figure 3-4). Follow-up analyses revealed that color-naming and word-reading RTs were similar across the range of depressive symptoms in the congruent conditions, $F(1, 18) = .01$, $p > .90$, $\eta^2 = .00$; however, in incongruent trials, color-naming RTs were generally slower than word-reading RTs, but became faster than word reading as depressive symptoms increased, $F(1, 18) = 8.39$, $p < .01$, $\eta^2 = .32$. This suggests that depressed older adults may not have allocated sufficient time to complete incongruent color-naming trials.

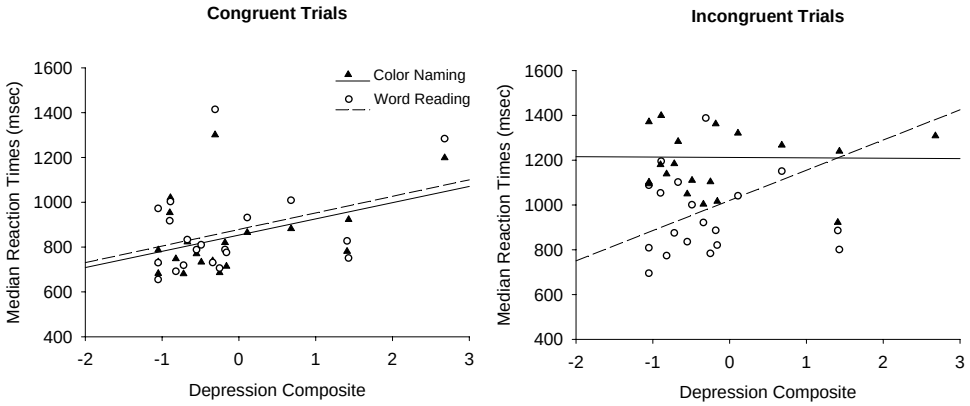

Figure 3-4. Congruent and incongruent RTs in older adults as a function of depression.

Attention and working memory performance

Neuropsychological test scores are presented in Table 3-1.As in Experiment 1, older adults performed more poorly than younger adults on measures of attention, $F(1, 40) = 28.90$, $p < .001$, $\eta^2 = .42$, and working memory, $F(1, 40) = 38.55$, $p < .001$, $\eta^2 = .49$. Older adults performed disproportionately slower on Trails B compared to Trails A, $F(1, 40) = 18.58$, $p < .001$, $\eta^2 = .32$, again suggesting age differences in task switching above those caused by generalized slowing in the older group. Similar to Experiment 1,

younger and older adults performed similarly at the 0" delay, $t(42) = -.75$, $p > .40$, $d = .23$, but older adults performed worse than younger adults at all other delays $t(42) \geq 4.25$, $p < .001$, $d = \geq 1.29$. As in Experiment 1, incongruent color-naming errors were significantly correlated with the Trails switching score, $r(44) = .56$, $p < .01$ and mean ACT errors, $r(44) = .44$, $p < .01$. Contrary to our hypothesis, no depression-related differences in neuropsychological test scores were observed.

Overall, the behavioral data were consistent with our prediction that older adults would show impaired cognitive control functioning. Depressive symptomatology was associated with poorer performance only in older adults. This suggests that age and depression have a synergistic effect, i.e., the interaction of age and depression led to an enhanced combined effect that was greater than the sum of the individual effects despite the lack of an effect in depression alone.

ERP Data

A total of 33.98% of trials were excluded from averages due to performance errors and EEG artifacts. Younger and older adult groups had an equivalent number of trials retained for both stimulus- and task-instruction-locked ERPs, $t(36) \leq .17$, $p > .80$, $d \leq .05$. Per participant, stimulus-related waveforms contained an average of 124 trials for younger adults (min/max = 71/166) and 121 trials for older adults (75/175); task-instruction-related waveforms contained an average of 116 trials for younger adults (65/173) and 118 trials for older adults (57/169). EEG data for two younger adults and two older adults were discarded due to excessive eye movement artifact, which prevented us from computing reliable ERPs. In addition, EEG data for two older adults were lost due to equipment malfunction. Thus, EEG analyses were performed on 22 younger and 16 older adults.

Context encoding and maintenance

Figure 3-5 illustrates the grand average ERP waveforms for cue-related P3a, P3b, and slow wave activity in younger and older adults. As in Experiment 1, cue-related ERPs were more positive-going for mixed blocks than single-task blocks, and were marked by both frontal and parietal P3 components and slow wave activity, which began at approximately 600ms and continued throughout the epoch.

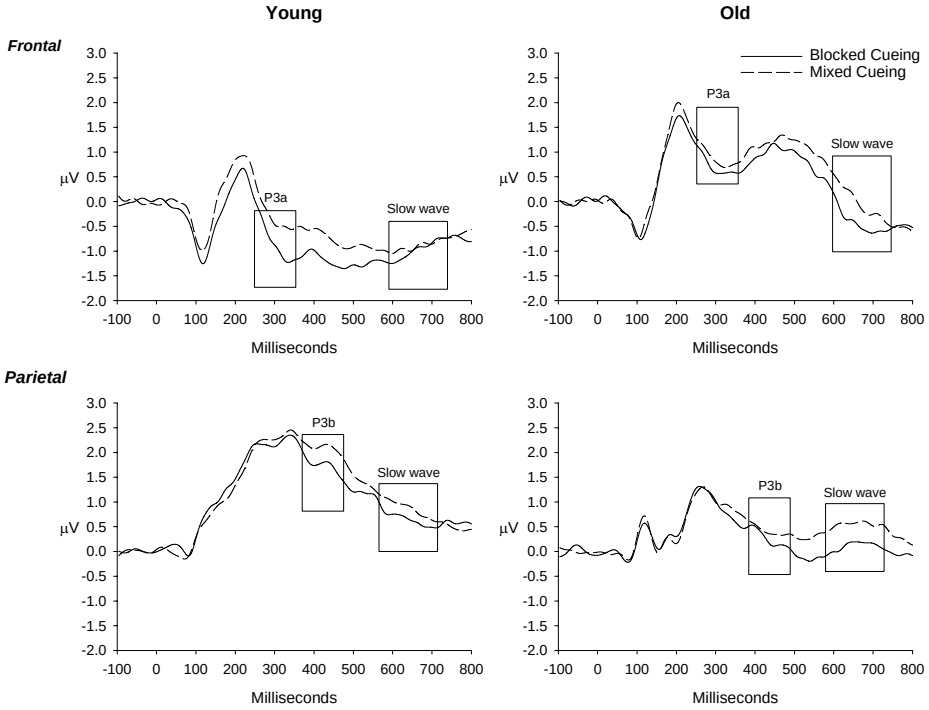

Figure 3-5. Grand average instruction-related ERP waveforms showing the P3a, P3b, and slow wave components as a function of block type (single-task, mixed) and group in Experiment 2. Waveforms were averaged over frontocentral and centroparietal sites (see Figure 2-1) and low-pass filtered at 30 Hz.

Age group differences were consistent with the results of Experiment 1: Younger adults showed greater P3a and P3b amplitudes to mixed blocks compared to single-task blocks $F(1, 20) \geq 10.57$, $p < .01$, $\eta^2 \geq .35$, while the P3a effect was absent in older adults, $F(1, 14) = 2.16$, $p > .10$, $\eta^2 = .13$. Older adults did show an effect of block type on P3b, $F(1, 14) = 5.88$, $p < .05$, $\eta^2 = .30$, though the P3b block effect was greater in younger

adults, $F(1, 34) = 5.37$, $p < .05$, $\eta^2 = .14$. These results suggest age-related impairments in frontal attentional mechanisms necessary for context encoding.

No P3a differences in color-naming versus word-reading were observed in either group. P3b activity was greater in color-naming compared to word-reading cues in older, but not young, adults, $F(1, 34) = 11.46$, $p < .01$, $\eta^2 = .25$. The poorer behavioral performance of the older adult group compared to younger adults suggests that this increased P3b activity to color-naming trials was ineffective, possibly due to impaired frontal attentional mechanisms that work in concert with parietal areas. In younger adults, a cue x depression interaction was observed, $F(1, 20) = 5.37$, $p < .05$, $\eta^2 = .21$, such that P3b amplitudes were greater for word-reading compared to color-naming cues for participants with fewer depressive symptomatology, while color-naming amplitudes became greater than word-reading as depressive symptomatology increased (Figure 3-6). In younger adults, performance increased somewhat as depressive symptoms increased, thus, this finding may represent successful recruitment of neural resources for context encoding.

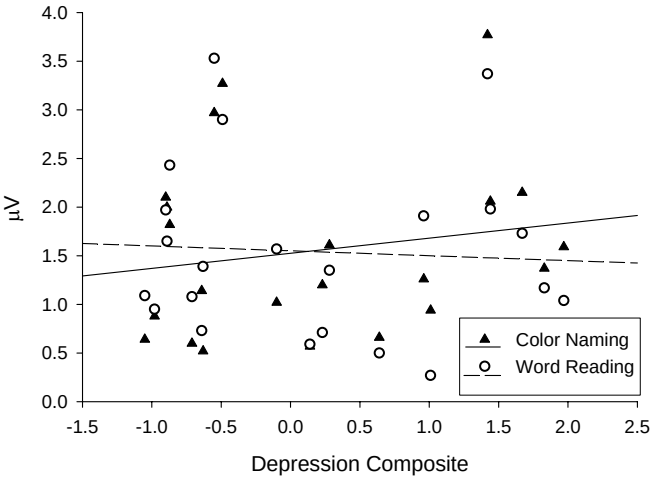

Figure 3-6. Younger adult color-naming and word-reading P3b amplitudes as a function of depression.

The cue-related slow was measured from 600–752ms. Older adults showed a greater *negative* slow wave in frontal regions for color-naming compared to word-reading in mixed blocks, while the slow wave was more *positive* for color-naming than word-reading in single-task blocks, $F(1, 14) = 5.73$, $p < .05$, $\eta^2 = .29$, suggesting that the frontal cue-related slow wave was reduced in older adults in the more difficult switching blocks. Older adults showed a more positive parietal slow wave for color-naming compared to word-reading trials, $F(1, 14) = 5.85$, $p < .05$, $\eta^2 = .30$, particularly as depressive symptoms increased, $F(1, 14) = 6.16$, $p < .05$, $\eta^2 = .31$. Both young, $F(1, 20) = 4.88$, $p < .05$, $\eta^2 = .20$, and older adults, $F(1, 14) = 10.21$, $p < .01$, $\eta^2 = .42$, showed a more positive slow wave in parietal areas for mixed blocks compared to single-task blocks. These results provide further evidence for age-related impairments in context maintenance.

Conflict detection and resolution

Stimulus-locked grand average ERPs reflecting slow wave activity for mixed-block congruent and incongruent color-naming trials are shown in Figure 3-7. Again, slow wave activity beginning at 600ms until the end of the epoch was observed, but an N450 was not apparent upon examination of the waveforms (*General Discussion*). Slow wave activity was more negative for incongruent, compared to congruent, color-naming trials for young, but not older adults at left frontal sites. The stimulus-related components of interest were analyzed separately within each age group.

Examination of the frontal NSW revealed a significant effect of laterality in young, $F(1, 20) = 21.83$, $p < .001$, $\eta^2 = .52$, and older adults, $F(1, 14) = 5.29$, $p < .05$, $\eta^2 = .27$. The laterality effect reflected greater left-hemisphere compared to right-hemisphere activity. Similar to Experiment 1, a laterality x congruency x age group interaction

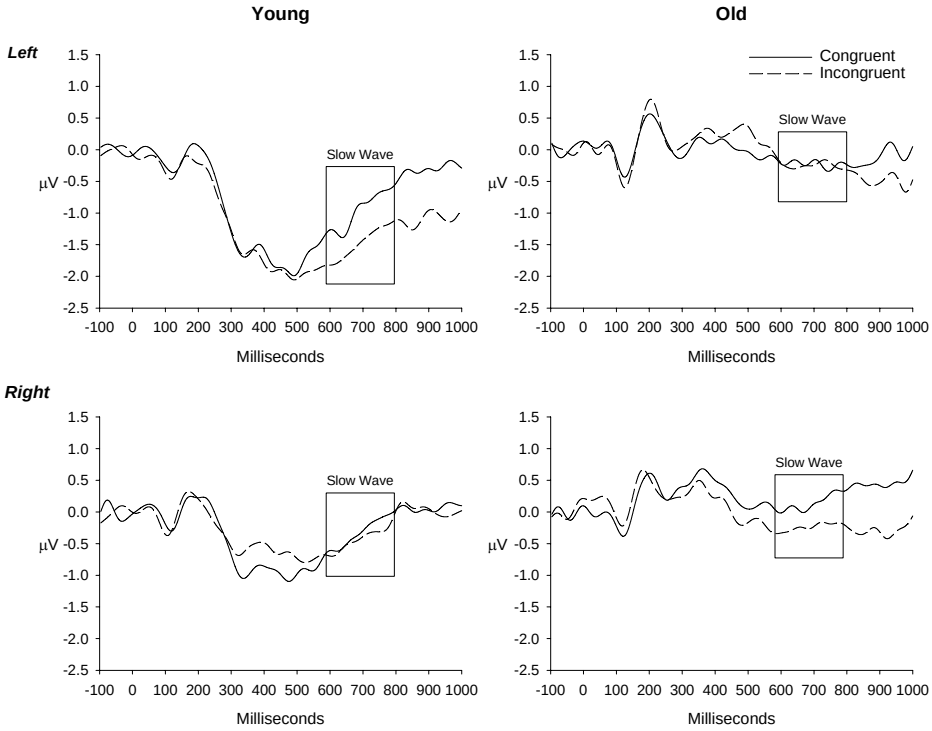

Figure 3-7. Grand average stimulus-related ERP waveforms showing the NSW as a function of color-naming task condition (congruent, incongruent) and group for the mixed-block trials in Experiment 2. Waveforms were averaged over left and right frontal sites (see Figure 2-1) and low-pass filtered at 30 Hz.

reflected a left-lateralized increase in negativity for incongruent compared to congruent conditions in younger adults, which was absent in older adults, $F(1, 34) = 6.01$, $p < .05$, $\eta^2 = .15$. A laterality x congruency x depression interaction was observed in younger adults, $F(1, 20) = 6.09$, $p < .05$, $\eta^2 = .23$ (Figure 3-8). This effect consisted of an increased NSW for incongruent compared to congruent trials at left frontal sites that decreased as depressive symptoms increased. In contrast, there were no depression-related congruency differences at right frontal sites. For the most part, these effects continued from 704–804ms: Both young, $F(1, 20) = 13.35$, $p < .01$, $\eta^2 = .40$, and older adults, $F(1, 14) = 7.30$, $p < .05$, $\eta^2 = .34$, showed a laterality effect, and a similar laterality x congruency x age group interaction $F(1, 34) = 8.01$, $p < .01$, $\eta^2 = .19$, was observed. These effects are consistent with age-related impairments in conflict resolution.

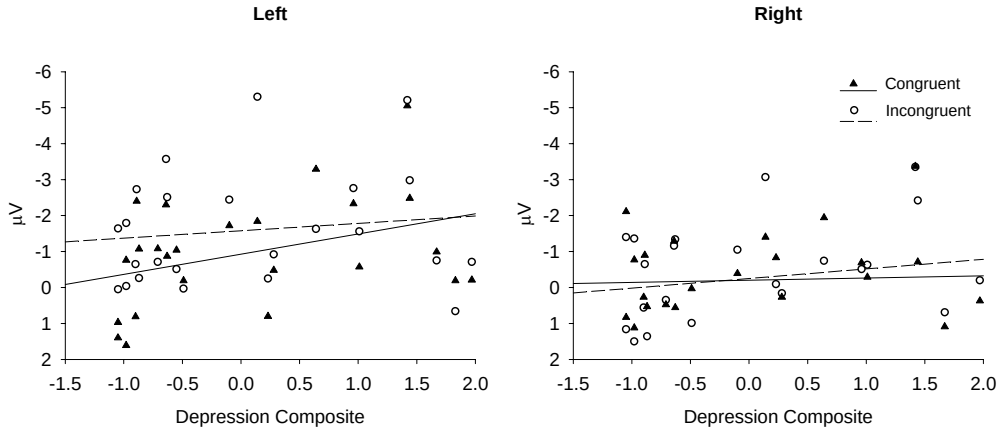

Figure 3-8. Mean NSW amplitudes for younger adults as a function of congruency (congruent, incongruent) and depression.

Discussion

As in Experiment 1, older adults showed clear behavioral evidence of impaired cognitive control, reflected in greater Stroop interference and context maintenance effects. More importantly, depressive symptomatology was associated with greater impairment in older, but not younger adults. ERP results paralleled the behavioral results and replicated the findings in Experiment 1, which showed that older adults were impaired in context encoding, context maintenance. and conflict resolution. Depressive symptomatology was associated with inefficient recruitment of neural resources in older, but not younger adults. The results of this study were consistent with the prediction that older adults, particularly older depressed adults, have disproportionate difficulties in performing cognitive control tasks that require the active maintenance of stimulus context and overriding prepotent response tendencies.

CHAPTER 4
GENERAL DISCUSSION

The current studies were designed to 1) determine if aging and depressive symptoms are associated with declines in cognitive control as assessed by the cued-Stroop task; 2) use event-related potentials (ERPs) to temporally and anatomically dissociate component processes associated with cognitive control and determine if aging and depressive symptoms differentially affect these processes; and 3) determine if the combined effect of aging and depressive symptoms on cognitive control is additive or multiplicative. The results of this study were consistent with the prediction that older adults, particularly older depressed adults, have disproportionate difficulties in performing cognitive control tasks that require the active maintenance of stimulus context and overriding prepotent response tendencies. Both the behavioral and ERP results support this contention, as elaborated below.

Behavioral Results

As predicted, older adults showed clear behavioral evidence of impaired cognitive control, reflected in greater Stroop interference effects, greater context maintenance effects (i.e., a disproportionate increase in error rates and slowing of reaction times (RT) on the incongruent color-naming task condition), and greater local task-switching effects. These results are consistent with the results of West's (2004) study of the cued-Stroop task in older adults and with evidence that age differences in task-switching costs exist, but may decrease after practice on the task (Hsieh & Liu, 2005; Kramer et al., 1999; Lorist et al., 2000). Older depressed adults showed greater error interference than older

adults with low depressive symptoms. In contrast, in younger adults, interference effects were similar across all levels of depression. Similarly, depression led to slower RTs to color-naming compared to word-reading cues in older, but not younger participants.

These results suggest that depression contributes to cognitive deficits in older, but not younger adults. Similar to a previous study in which depressed younger adults performed the cued-Stroop task (Cohen et al., 1999), we found no depression-related differences in task performance in our younger adults. Given the lack of depression-related impairments in younger adults, neither an additive nor a multiplicative effect is indicated by our results. Rather, the combined effect of aging and depression was synergistic, as the interaction led to an enhanced effect that was greater than the sum of the individual effects *despite* the lack of an effect in depression alone.

ERP Results

ERPs, which were used to temporally dissociate components of cognitive control in the context of the cued-Stroop task, yielded findings which were largely consistent with our predictions. Regarding context encoding and maintenance of the instructional cue information, younger adults increased engagement of frontal lobe attentional mechanisms, reflected in the P3a component, during mixed blocks compared to single-task blocks, while older adults failed to show this effect. Both age groups, however, showed increased parietal activity (P3b and parietal cue-related slow wave) during the mixed blocks. This suggests that older adults are specifically impaired in the recruitment of frontal lobe attentional mechanisms necessary for context encoding, consistent with the large body of literature that suggests that aging is associated with selective vulnerability of frontal lobe structures and frontal-subcortical circuits (Fuster, 1989; Liu et al., 1996; Raz, 2000; Raz et al., 1998; Raz et al., 1997), and consequently, older adults

are disproportionately impaired on cognitive tasks that are putative measures of frontal lobe functioning (Braver et al., 2001; MacDonald et al., 2000; Raz, 2000; West, 2003; West, 2004). The finding of increased P3b amplitude to mixed blocks in both younger and older adults is consistent with the results of West (2004), who interpreted this similarity as an indication that both groups used the instructional cue to update a representation of the relevant dimension. The fact that older adults showed less of an increase than younger adults is suggestive of age-related difficulties in updating representations of relevant dimensions.

Older adults did not show a cue-related increase in the frontal P3a; however, they showed greater P3b and parietal slow wave amplitudes to the more attentionally-demanding color-naming instruction, particularly with increasing depressive symptomatology. Despite this additional recruitment of neural resources, older adults showed a disproportionate increase in errors on the color-naming task. Context encoding mechanisms, reflected in P3b, may have been ineffective given the lack of increased engagement of frontal attention mechanisms (P3a). Thus, the behavioral evidence of impaired context maintenance may be largely due to impaired frontal attentional mechanisms in older adults.

In younger adults, low levels of depressive symptoms were associated with greater P3b amplitudes for word-reading compared to color-naming, while color-naming P3b amplitudes became greater than word-reading as depressive symptoms increased. In this sample, analyses performed on a median split of the depression composite (Appendices E and F) revealed that depressed younger adults made *fewer* errors than nondepressed younger adults. Thus, the finding that increased P3b amplitudes to the more attentionally-

demanding color-naming task was apparent only at high depression levels is consistent with the idea that P3b reflects the recruitment of neural resources that underlie context encoding, which are necessary for successful completion of the color-naming task.

While both age groups showed a global switching effect for the parietal cue-related slow wave, only younger adults showed a local switching effect on this component. This suggests that older adults inefficiently allocate neural resources to successfully complete cognitive tasks. The finding that older adults had a greater cue-related frontal slow wave in color-naming versus word-reading single-task blocks, while showing increased activity for *word-reading* in the mixed blocks supports this contention. Perhaps the more difficult context in the mixed blocks does evoke more activity in the older adults, but they fail to modulate this recruitment during the appropriate trials.

Younger adults showed an effect of time on slow-wave activity in mixed blocks. This effect consisted of increasing positivity of ERP waveforms with each successive block, and was present for both switching and nonswitching trials. These results are consistent with the findings of Lorist et al. (2000), who also found that parietal activity increased with time on task for both switching and repetition trials. In the context of the current data, in which a positive slow wave is associated with more difficult cognitive requirements (e.g., mixed blocks compared to single-task blocks) and younger adults performed similarly across time on switching blocks, it is likely that this finding indicates that younger adults successfully recruited additional neural resources as they became fatigued in order to maintain their level of performance on the task. Older adults did not show this effect of time on ERP amplitudes, though their performance on mixed blocks improved over time. However, older adults exhibited more positive waveforms than

younger adults across early and late epochs. It may be that rather than increasing recruitment of resources, older adults more efficiently allocated resources to switching trials, and thus performed better with time.

We predicted that younger adults would show congruency-related differences in the negative slow wave (NSW), an ERP deflection thought to reflect regulative aspects of conflict processing, perhaps involving processes devoted toward the resolution of response conflict (West & Alain, 1999). Indeed, younger adults showed an increase in the NSW over left frontal sites for incongruent compared to congruent color-naming conditions, which continued over the later, 704–804 epoch. In contrast, although older participants did show an increased left-sided negativity, they failed to show differentiated ERP activity to the incongruent versus congruent color-naming conditions. Considered in the context of previous studies (Perlstein et al., 2006; West, 2004) this pattern of findings suggests that older adults did not implement regulative control to adaptively resolve the conflict inherent in the incongruent color-naming condition. These modulations in ERP signatures of conflict resolution in older adults is consistent with behavioral evidence of impaired performance in conflict conditions (i.e., Stroop interference).

In younger adults, the increased NSW for incongruent compared to congruent trials at left frontal sites decreased as depressive symptoms increased, while no depression-related congruency differences were found at right frontal sites. Thus, it would appear that the younger depressed adults in our sample, who performed better than nondepressed younger participants, experienced less conflict in the incongruent condition.

The pattern of correlations among behavioral, neuropsychological, and ERP measures is consistent with the hypothesis that working memory-dependent context

processing is, indeed, associated with modulation of the task instruction-related slow wave and, furthermore, that a larger working memory capacity is associated with a larger increase in P3b amplitude to the more attentionally demanding color-naming than word-reading instruction. However, the absence of relationships between the stimulus-related NSW and Auditory Consonant Trigrams or Trails performance suggests that the actual processing of conflict information may be independent of participants' attention and working memory capacity. Perhaps an individual-difference variable – working memory capacity – is an important moderator of the influence of aging on context maintenance processes.

Overall, behavioral and ERP data provided converging evidence for age-related cognitive control impairments. In contrast, while the synergistic effect of depression and aging was apparent in the behavioral data, ERPs did not show a similar effect. It is possible that ERPs are not sufficiently sensitive to detect this effect, or that we simply did not have enough power to detect the effect in our sample.

Study Limitations and Future Directions

Several limitations of the current study must be kept in mind. First, our depression analysis was not based on comparing participants with and without Major Depressive Disorder; that is, depressive symptoms were quantified on a continuous basis based on questionnaire data rather than a binary diagnostic cutoff. It is possible that our lack of depression-related differences in younger adults is due to the paucity of diagnosed depressed participants in the sample. However, it seems that our findings are even more compelling because older adults exhibited disproportionate deficits at high levels of depressive symptoms even without a clinical diagnosis of depression. Perhaps younger adults only show depression-related impairments at high severity levels, while older

adults, who are already vulnerable to cognitive decline due to age-related changes in the brain, are more susceptible to even moderate levels of depression. Second, ERPs allow for only coarse spatial localization compared to neuroimaging methods such as functional magnetic resonance imaging (fMRI), thus our ability to make inferences regarding age- and depression-related differences in specific neural structures supporting cognitive control performance is limited. It is possible, for example, that the disproportionate declines observed in older depressed adults is due to the cumulative effects of age-related prefrontal cortex (PFC) damage and depression-related anterior cingulate cortex (ACC) alterations. However, our goal for the current studies was to examine *component processes* associated with cognitive control, rather than neural structures, and, based on the current task design, ERPs were more appropriate for this goal given their temporal sensitivity (Fabiani et al., 2000). Third, older adults in our sample reported more state anxiety than younger adults, thus, anxiety, rather than depression, may have contributed to the poor performance of older adults. However, the State Trait Anxiety Inventory (STAI) was administered during the first testing session, when the experimental environment was likely less familiar, and thus more anxiety-provoking, for older participants. Cued-Stroop and EEG data were acquired during the second testing session, when older participants presumably were more comfortable with the testing environment and thus may have had lower state anxiety. In addition, state anxiety was not significantly correlated with error or RT performance in either group ($r \leq |.26|$, $p \geq .28$), suggesting that age differences in cognitive performance were not likely due to anxiety. Further, the effect of depression remained in when state anxiety was used as a covariate in our analyses (Appendix G); thus, differences in state anxiety between younger and older

adults do not appear to explain the depression-related effects observed in the current study. Fourth, the high education level of participants in our sample could limit our ability to generalize our results. However, a number of studies suggest that higher educational attainment has a protective effect on cognitive aging (e.g., Albert et al., 1995; Christensen, 2001), thus, age-related differences in cognitive performance should be smaller in highly educated samples. It is likely that we would have similar findings, in even greater magnitude, in a less-educated sample. Finally, we did not observe an N450 component in response to the incongruent color-naming task condition in any of the study groups. The reasons for this are unclear, and are unlikely to be due to the EEG acquisition parameters, since we have successfully obtained the N450 in previous studies using similar recording parameters (Perlstein et al., 2006), or to the modality of response (i.e., vocal, manual), as N450 has been obtained using both response modalities (e.g., Liotti et al., 2000). Thus, the absence of an observable N450 response limits our ability to make firm conclusions regarding the integrity of conflict detection processes, as this component has most reliably been thought to reflect conflict detection.

Future studies will address some of the limitations of the current study. We will use fMRI to examine cognitive differences between younger and older adults who either do or do not meet criteria for a *diagnosis* of Major Depressive Disorder. This will enable us to determine, with a greater degree of confidence, some of the neural structures that may mediate the observed cognitive control impairments. Recognizing the heterogeneity in the population of depressed adults, we will examine executive functioning in various subsets of depression, such as late-onset versus early-onset depression in older adults. In addition, future studies will examine the relationship between experimental measures of

cognitive control and "ecologically valid" measures of executive dysfunction as measured, for example, using the Behavioral Assessment of the Dysexecutive Syndrome (Wilson, Evans, Emslie, Alderman, & Burgess, 1998).

Concluding Remarks

Overall, the current findings suggest that aging is associated with impairments in regulative components of cognitive control, consistent with previous research that has demonstrated age-related differences in the active maintenance of context information in working memory, implementation of control, and allocation of attentional resources to more attentionally-demanding tasks (Braver et al., 2001; MacDonald et al., 2000; West, 2003; West, 2004). Importantly, depressive symptomatology led to greater cognitive difficulties only in older adults. This suggests that depression constitutes a significant risk factor for further cognitive decline in older adults. To our knowledge, this is the first study to examine the interactive effect of aging and depression on executive control using both behavioral and cognitive neuroscience techniques.

In our study, only one older adult met criteria for Major Depressive Disorder. Thus, our finding of depression-related impairments even in individuals without a diagnosable depressive disorder supports the idea that subsyndromal depressive symptoms are associated with negative outcomes. Research suggests that older adults with depressive symptoms are more likely to develop a major depressive episode, and depressive symptoms are associated with similar outcomes as major depression, including health problems, malnutrition, disability, functional and cognitive impairment, and increased mortality rates (Gatz, 2000; Karel, Ogland-Hand, Gatz, & Unuetzer, 2002). In addition, the presence of depression and/or executive dysfunction in older adults is associated with impairment in performing instrumental activities of daily living (Kiosses, Klimstra,

Murphy, & Alexopoulos, 2001). While estimates of the *syndrome* of Major Depression in older adults tend to be as low as 1–2% (Henderson, Jorm, Mackinnon, & Christensen, 1993), an estimated 10–15% of community-dwelling older adults and 25–30% of the elderly residing in medical or long-term care settings present with clinically significant depressive *symptoms* (Blazer, 1994). Thus, as the number and proportion of elderly individuals in the population increases, it is likely that a significant number of these older adults will suffer from depressive symptoms and/or cognitive difficulties, including executive dysfunction. Thus, the current findings may help to identify older depressed adults as a group that is particularly vulnerable to functional and cognitive decline and may aid in the development of assessment and intervention strategies for older depressed adults.

APPENDIX A
LIST OF MEDICATIONS USED BY YOUNGER AND OLDER ADULT PARTIPANTS

Table A-1. Medications used by study participants.

Antidepressant Medication	
Bupropion[YO]	Escitalopram[Y]
Sertraline[O]	
Arthritis and Osteoporosis Medication	
Alendronate[O]	Raloxifene[O]
Chondroitin sulfate[O]	Risedronate[O]
Glucosamine[O]	Valdecoxib[O]
Prednisone[O]	
Asthma and Allergy Medication	
Albuterol[YO]	Fluticasone[O]
Azelastine[O]	Loratadine[O]
Azmacort[Y]	Mometasone[O]
Cetirizine[O]	Vanceril[Y]
Fexofenadine[YO]	
Contraceptives and Estrogen Replacement	
Alesse[Y]	Orthotricyclen[Y]
Estradiol[O]	Premarin[O]
Diabetes, Hypercholesterolemia, and Hypertension Medication	
Atenolol[O]	Lisinopril[O]
Atorvastatin[O]	Niaspan[O]
Colesevelam[O]	Ramipril[O]
Coumadin[O]	Rosiglitazone[O]
Diltiazem[O]	Simvastatin[O]
Fosinopril[O]	Timolol[O]
Glyburide[O]	Valsartan[O]
Hydrochlorothiazide[O]	
Vitamin Supplements	
Biotin[O]	Feosol[O]
Caltrate[O]	Oscal[O]
Others	
Baclofen[Y]	Levothyroxine[O]
KlorCon[O]	Terazosin[O]
Lasix[O]	Tolterodine[O]

[Y] Medication taken by at least one young adult.
[O] Medication taken by at least one older adult.

APPENDIX B
POST-TASK QUESTIONNAIRE

- How well do you think you did on the task?

1	2	3	4	5
very well	*okay*	*average*	*poor*	*very poor*

- How satisfied are you with your performance?

1	2	3	4	5
very satisfied	*satisfied*	*neutral*	*not satisfied*	*very unsatisfied*

- During the experiment, how concerned were you about the feedback that you were going to receive about your overall performance?

1	2	3	4	5
not at all concerned	*moderately unconcerned*	*neutral*	*concerned*	*very concerned*

- How stressful was the task?

1	2	3	4	5
very stressful	*moderately stressful*	*neutral*	*moderately unstressful*	*not at all stressful*

- How interesting was the task?

1	2	3	4	5
very boring	*moderately boring*	*neutral*	*interesting*	*very interesting*

- How did you feel when you made a mistake?

1	2	3	4	5
very good	*good*	*neutral*	*bad*	*very bad*

- How did you feel when you were correct?

1	2	3	4	5
very good	*good*	*neutral*	*bad*	*very bad*

- How did you feel when you were late in your response?

1	2	3	4	5
very good	*good*	*neutral*	*bad*	*very bad*

- When your response was incorrect, how aware were you that your response was incorrect?

1	2	3	4	5
I was certain that my response was correct		*uncertain whether my response was correct or incorrect*		*very certain that my response was incorrect*

- When your response was correct, how aware were you that your response was correct?

1	2	3	4	5
I was certain that my response was correct and on time		*uncertain whether my response was correct and on time or correct and too late*		*very certain that my response was correct but too late*

- Compared to the beginning of the experiment, as the experiment went on I became

1	2	3	4	5
very interested	*interested*	*did not change*	*uninterested*	*very uninterested*

- Compared to the beginning of the experiment, as the experiment went on my incorrect responses

1	2	3	4	5
did not bother me at all	*bothered me less*	*did not change*	*bothered me more*	*bothered me very much*

- Relative to my initial expectations, my performance was

1	2	3	4	5
very bad	*bad*	*as I expected*	*good*	*very good*

- At the beginning of the experiment I expected to do

1	2	3	4	5
very well	*well*	*unsure of how I would do*	*bad*	*very bad*

- What do you think of the experiment in general?

_____
_____
_____
_____
_____

APPENDIX C
SUMMARY OF STUDY RESULTS FOR EACH OF THE HYPOTHESES

Hypothesis 1: Aging and depression would be associated with greater Stroop interference, context maintenance, and task-switching effects

- *Stroop interference:* Error interference greater in older adults, $p < .001$; no main effect of depression on interference, $p > .10$
- *Context maintenance:* Context maintenance for errors greater in older adults, $p < .05$; no effect of depression on context maintenance, $p > .1$
- *Task switching:* Greater task-switching effects in older adults only during the first mixed block, $p < .01$; no effect of depression on task switching, $p > .06$

Hypothesis 2: Older adults would show reduced amplitude ERP signatures of context encoding and maintenance (P3a, P3b, and cue-related slow wave) and conflict resolution (NSW). Depression would be associated with reduced P3b amplitude.

- *P3a:* Young adults showed an effect of block type, $p < .01$, but older adults did not, $p > .10$
- *P3b:* Both young, $p < .01$, and older adults, $p < .05$ showed an effect of block type; no effect of depression on P3b, $p > .09$
- *Cue-related slow wave:* Both young, $p < .05$ and older adults, $p < .01$, showed an effect of block type
- *NSW:* A left-lateralized increase in incongruent compared to congruent conditions found in young, but not older adults, $p < .05$.

Hypothesis 3: Aging and depression would have a multiplicative effect on cued-Stroop performance and P3b amplitude.

- *Behavioral results:* Error interference greater with increasing depressive symptoms for older, but not young adults, $p < .05$ (i.e. a synergistic effect was observed)

  EEG results: No interaction of aging and depression was observed

APPENDIX D
DISTRIBUTION OF BECK DEPRESSION INVENTORY AND GERIATRIC DEPRESSION SCALE SCORES IN YOUNGER AND OLDER ADULTS

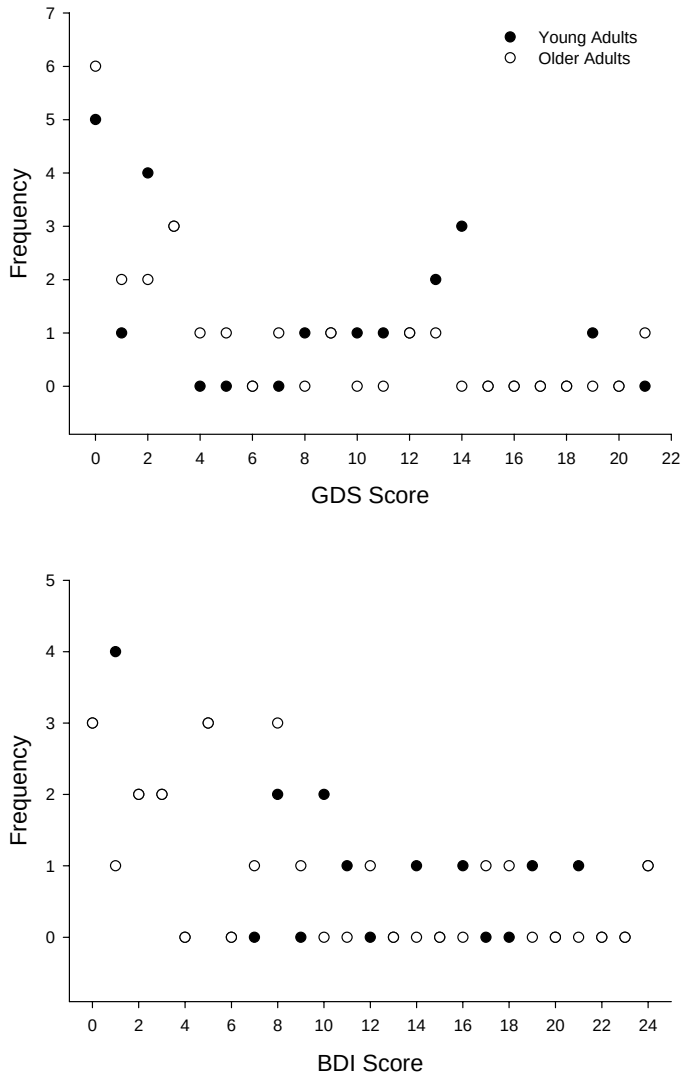

Figure A-1. Distribution of Beck Depression Inventory (BDI) and Geriatric Depression Scale (GDS) scores in study participants.

APPENDIX E
MEAN BEHAVIORAL PERFORMANCE IN EXPERIMENT 2 WHEN A MEDIAN SPLIT OF THE DEPRESSON COMPOSITE IS USED

Table A-2. Mean behavioral performance in Experiment 2 when a median split of the depression composite is used.

	Young Adults		Older Adults	
	Non-depressed	Depressed	Non-depressed	Depressed
Reaction time (msec)				
Color naming				
Congruent	708.0 (207.4)	657.5 (118.2)	793.1 (112.09)	890.8 (205.1)
Single-task block	672.8 (168.5)	646.3 (131.3)	780.6 (119.0)	877.3 (186.9)
Mixed block	737.1 (244.5)	680.5 (119.9)	818.7 (122.9)	926.5 (258.7)
Incongruent	1032.9 (290.3)	977.5 (171.9)	1191.1 (120.8)	1233.9 (249.9)
Single-task block	983.7 (295.0)	902.9 (178.8)	1137.9 (160.7)	1168.9 (299.1)
Mixed block	1159.9 (340.4)	1076.2 (205.9)	1280.0 (110.0)	1380.6 (226.8)
Word reading				
Congruent	720.7 (196.4)	663.6 (121.4)	812.0 (119.6)	921.9 (245.1)
Single-task block	664.9 (140.7)	630.1 (115.2)	762.6 (123.3)	864.(230.7)
Mixed block	774.0 (244.4)	710.3 (119.8)	858.5(128.4)	981.0 (259.2)
Incongruent	885.0 (212.8)	841.9 (197.6)	942.9 (166.6)	1055.4 (342.7)
Single-task block	801.8 (176.9)	755.6 (179.9)	858.6 (158.6)	984.3 (353.9)
Mixed block	1011.1 (231.1)	999.1 (217.8)	1107.3 (251.8)	1229.7 (360.5)
Error rates (%)				
Color naming				
Congruent	.03 (.02)	.02 (.02)	.02 (.02)	.04 (.05)
Single-task block	.03 (.03)	.01 (.01)	.01 (.01)	.03 (.05)
Mixed block	.02 (.02)	.03 (.03)	.03 (.04)	.05 (.06)
Incongruent	.17 (.11)	.09 (.05)	.25 (.22)	.36 (.32)
Single-task block	.13 (.14)	.06 (.03)	.21 (.22)	.29 (.34)
Mixed block	.22 (.14)	.14 (.08)	.30 (.24)	.44 (.30)
Word reading				
Congruent	.03 (.03)	.02 (.02)	.04 (.08)	.04 (.06)
Single-task block	.03 (.03)	.02 (.01)	.07 (.16)	.04 (.06)
Mixed block	.03 (.03)	.02 (.03)	.02 (.03)	.05 (.07)
Incongruent	.08 (.06)	.07 (.05)	.14 (.17)	.14 (.16)
Single-task block	.07 (.06)	.05 (.04)	.11 (.17)	.10 (.17)
Mixed block	.09 (.06)	.10 (.06)	.17 (.25)	.17 (.19)

APPENDIX F
STATISTICAL RESULTS FOR EXPERIMENT 2 WHEN A MEDIAN SPLIT OF THE DEPRESSON COMPOSITE IS USED

Table A-3. Statistical results for Experiment 2 when a median split of the depression composite is used.

	Young Adults		Older Adults		Age Effect	
	F	*p*	*F*	*p*	*F*	*p*
Error rates (%)						
Congruency	359.061	.000	155.723	.000	22.758	.000
Congruency x depression	3.190	.088	.352	.560	1.141	.292
Cue	10.032	.004	5.112	.036	1.880	.178
Cue x depression	3.947	.060	1.072	.314	2.832	.100
Congruency x cue	7.767	.011	16.659	.001	5.036	.030
Cong x cue x depression	1.857	.187	.131	.721	1.070	.307
Block	16.670	.000	11.152	.004	1.376	.248
Block x depression	2.079	.163	.353	.560	.018	.894
Block x congruency	25.848	.000	17.188	.001	.026	.872
Block x congruency x depression	.256	.618	.267	.612	.532	.470
Block x cue	2.430	.133	1.987	.176	.475	.495
Block x cue x depression	.055	.817	.005	.943	3.441	.071
Reaction time (msec)						
Congruency	132.305	.000	138.657	.000	.031	.862
Congruency x depression	.033	.857	.454	.509	.363	.550
Cue	13.276	.001	8.568	.009	.628	.433
Cue x depression	.006	.938	.403	.533	.288	.594
Congruency x cue	38.479	.000	23.583	.000	2.812	.101
Cong x cue x depression	.150	.702	.342	.566	.137	.713
Block	63.510	.000	71.576	.000	.089	.767
Block x depression	.041	.841	.524	.479	.420	.521
Block x congruency	22.309	.000	23.302	.000	.044	.834
Block x congruency x depression	.687	.416	.090	.767	.126	.724
Block x cue	6.216	.021	4.331	.052	.248	.621
Block x cue x depression	.241	.628	.243	.628	.492	.487

APPENDIX G
DEPRESSION-RELATED EFFECTS WITH AND WITHOUT ANXIETY AS A COVARIATE

Table A-4. Depression-related effects with and without anxiety as a covariate.

	Current Results		Anxiety As a Covariate	
	F	*p*	*F*	*p*
Age x depression x congruency effect on error interference	5.12	< .05	3.96	.054
Congruency x cue x depression effect on RT interference in older adults	11.24	< .01	14.49	<.001
Cue x depression effect on P3b in young adults	5.37	< .05	4.27	.053
Cue x depression effect on parietal slow wave in older adults	6.16	< .05	5.49	<.05
Laterality x congruency x depression effect on NSW in young adults	6.09	< .05	1.42	.248

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