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REGULATION IN OLDER ADULTS

The Relationship Between Cognitive Decline and Emotion Regulation in Older Adults
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Abstract

While prior literature has established improved emotion regulation and impaired cognitive control in older adults, this study sought to understand the relationship between these variables. Older adults typically show deficits in executive functioning, selective attention, and error-monitoring, but they also show an enhanced “positivity bias,” a preference for positive information. We hypothesized that the older adults who had the highest degree of cognitive control would also be those with the greatest positivity bias, and assessed 20 older and 20 younger adults on a number of measures. The principal paradigm was a flankers-type task that employed emotional faces, through which we attempted to measure the ERN as well as positivity bias. However, difficulty was confounded with emotionality in this task, and subsequent results did not support the hypotheses. While some of the expected age and task-related effects were found, there was little evidence of an enhanced positivity bias, impaired selective attention, or impaired error-monitoring in the older adults. Correlational analyses also did not support the expected result—there was no correlation, among the older adults, between cognitive control measures and the positivity bias. Strangely, however, this correlation did exist among the younger adults. Possible reasons for our surprising results, limitations of the study, and potential avenues of future research are discussed.

Introduction

When your grandfather asks you what your major is for the 10th time or lets slip an inappropriate joke, you might start to wonder what exactly constitutes healthy cognitive decline. Researchers have been making strides in understanding the processes underlying these age-related issues from both neural and cognitive perspectives. Many of the most important deficits associated with normal aging, such as attention and self-monitoring, are in the domain of cognitive control. Interestingly, however, one facet of this domain improves with age; older adults actually seem to be better than younger adults at regulating their emotions. This may be the source of older adults' generally improved affect, and in conjunction with the declines seen in other cognitive areas, this fascinating paradox could serve as an important entryway into a discussion of healthy aging.

This topic is of increasing importance now, as the world's demographics have begun to dramatically change. The World Health Organization reported in March, 2012, that between the years 2000 and 2050, the percentage of the world's population over the age of 60 will increase from 11% to 22%. That is 2 billion older adults by 2050. Further, the number of older adults who live into their 80s and 90s is significantly increasing due to improved healthcare and technology (World Health Organization, 2012). The aging of the baby-boom generation is adding to this demographic shift in the United States, and raises a number of questions regarding the cost of healthcare and social security for these older adults. Because of this large and growing elderly population, it has become increasingly important to study issues of healthy and pathological aging. Cognitive control deficits play a primary role in everyday issues experienced by older adults, and a better understanding of these deficits would hopefully lead to a better

understanding of how to ensure healthy aging and treat pathological aging, and thus lead to a group of healthier, higher functioning, and more independent older adults.

In this experiment, the relationships between different facets of cognitive control that are affected by age were examined. While many of these aspects of cognitive aging have been individually investigated in the literature, there remains a gap in our understanding of how these pieces are connected to one another. In this study, the relationship in older adults between declines in general executive functioning, selective attention, and error-monitoring will be linked to an increase in emotion regulation. We hope to achieve a greater understanding of this apparent paradox—the coexistence of deficits and improvement within the domain of cognitive control in older adults—through the use of a paradigm that allows us to measure a number of these aspects of top-down control through one task. First, however, we must thoroughly review the findings and theories in each of these cognitive domains.

Cognitive Aging

Frontal Lobe Theory

Many theories attempt to explain the cognitive deficits associated with aging. While some researchers have proposed a model of general slowing or compensatory brain activation (e.g. Gunning-Dixon et al., 2003; Roldan-Tapia et al., 2012), the model that will serve as the foundation for our study is the frontal lobe theory of aging. The underlying basis of this theory is that that normal aging is accompanied by changes in the structure and functioning of the brain. Deficits in the frontal lobe and dopamine system play a particularly critical role in cognitive declines associated with aging. As people age, structural changes in the frontal lobe mirror increasing deficits in a number of cognitive areas including memory, inhibition, attention, and

generally executive functioning. These are all aspects of cognitive control, and they all implicate the prefrontal cortex (Braver & Barch, 2002; Tisserand & Jolles, 2003).

Braver and Barch (2002) argue that context processing, “the mechanism used to maintain task-relevant information against the interfering and cumulative effects of noise over time” (p. 811) underlies attention, working memory and inhibition. It is thus an important basis of top-down support. This context processing system is actively maintained in the dorsolateral region of the PFC (DL-PFC), which creates the context representation, maintains it, and updates it as needed. Dopamine projections to the PFC then regulate access to the context information, play a role in updating it, and prevent irrelevant information from interfering. Braver and Barch (2002) further claim that age-related deficits in cognitive domains are due to an impaired PFC or dopaminergic system, and subsequently impaired context processing system. One piece of evidence supporting this theory is that during a cognitive control task involving context representation, younger adults showed significantly greater PFC activation than older adults (Braver & Barch, 2002).

The PFC is generally thought to support the “highest level of cognitive organization, serving as the central executive of the brain” (West, 1996, p. 276). It plays a key role in attention, memory, planning, and executive functions (Fabiani, 2012). Despite the importance of this brain region, there is significant evidence that the PFC is the region of the brain that is effected most dramatically and earliest by aging (West, 1996). Cognitive processes supported by the frontal lobe are the first to decline with age, and older adults perform worse than younger adults on measures of frontal lobe function (West, 1996). Similarities in deficits between older adults and patients with PFC damage further implicate the PFC as heavily involved in cognitive aging (Fabiani, 2012).

Supporting this theory is evidence of relatively large structural changes in the PFC as we age. Essentially, the frontal lobe, particularly the PFC, has disproportionate volume loss (Pfefferbaum et al., 1998; Raz, 2000; Tisserand & Jolles, 2003). West (1996) reported that over a lifetime, the temporal, parietal, and occipital lobes have an overall 1% reduction in brain volume, while the PFC has a 10-17% reduction in volume. Similarly, in four years, the PFC was the only cortical region that showed a reduction in resting regional cerebral blood flow (rCBF) (West, 1996). There is generally both a decrease in grey matter volume as well as a decrease in white matter connectivity and myelin in the PFC (Fabiani, 2012; Tisserand & Jolles, 2003; Amenado & Diaz, 199). These volume losses are due to a reduction in neuron size, loss of dendritic branches, and a reduced number of synapses (West, 1996).

Dopamine functioning within the PFC is also altered with age (Braver & Barch, 2002). The PFC concentration of dopamine was reduced by 56% in older monkeys compared to younger monkeys, and in humans, it has been found that there is a 39% reduction in dopamine receptor binding potential in the frontal cortex in older adults compared to younger adults (West, 1996). Using PET, Backman et al. (2000) also found gradual age-related deterioration of dopaminergic receptor binding in striatal regions. Beyond reduced binding capacity, it has also been found that there are actually fewer dopamine receptors in the frontal cortex in older adults (Kaasinen et al., 2000). These findings indicate that the PFC generally has a reduced amount of available dopamine.

To summarize, when looking at older samples, researchers find parallel deficits in context processing, attention, inhibition, working memory, the dopamine system, and the PFC. According to Braver and Barch (2002), this can be explained by the less reliable, faster decaying context representations of older adults, which is due to disrupted dopamine projections to the

PFC. On a more fundamental level, these findings indicate that deficits in the frontal lobe cause the impaired cognitive control of older adults.

Executive Functioning

Accompanying these structural changes, as previously mentioned, is a decline in executive functioning (Braver & Barch, 2002; Roldan-tapia et al., 2012; Salthouse et al., 2003; Schreiber et al., 2011; West, 1996). Executive Functioning is a broad term used to describe cognitive control processes “responsible for planning, assembling, coordinating, sequencing, and monitoring other cognitive operations” (Salthouse et al., 2003, p. 566). Lezak (1995, as cited in Salthouse et al., 2003) defined executive functions as “those capacities that enable a person to engage successfully in independent, purposive, self-serving behavior” (p. 42). While its definition is not cut-and-dried, executive functioning is generally considered a higher-order cognitive construct that is based in the frontal lobes, particularly the PFC (Salthouse et al., 2003), and responsible for a large number of cognitive abilities. It is often used as an overarching umbrella term for top-down cognitive control processes including inhibition, working memory, and attention (Salthouse et al., 2003).

Considering the frontal lobe hypothesis of aging, and the fact that executive functions are based in the frontal lobe (essentially by definition), it makes sense that older adults have impaired executive functioning. This has been shown through the use of a number of paradigms, but the “gold standard” (Delis, Kaplan, & Kramer, 2001, p. 2) is the Wisconsin Card Sorting Task. In the WCST, subjects have to sort a pile of cards based on continually changing rules. The task thus requires a working memory maintenance of task rules, flexibility in response to feedback, and inhibition of the prior rule (Salthouse et al., 2003). Older adults and people with PFC damage have trouble adjusting to the new rules, and often show perseveration—they

continue to sort based on an old rule (even sometimes when they explicitly acknowledge that they are behaving incorrectly) (West, 1996). These findings are just a small part of the vast literature examining deficits in different aspects of executive functioning that occur with age.

Attention Control

One specific facet of executive functioning that seems to be impaired in older age is attentional control. Converging evidence from behavioral, EEG, and neuro-imaging studies has shown that older adults have deficits in selective attention, the ability to focus on relevant information while inhibiting irrelevant distracting information. Selective attention is generally believed to be a part of top-down cognitive control mechanisms originating in the prefrontal cortex. Some researchers have claimed that older adults function similarly to younger adults and that results from selective attention tasks simply indicate a general slowing as we age (Salthouse, 2010). However, the vast majority of studies have found that older adults have a significantly diminished ability to inhibit irrelevant information and are more easily distracted as compared to younger adults, and indicate that something more complex than a generalized slowing is occurring.

When selectively attending to a stimulus, it is also necessary to inhibit any other information that may occur in the context of the stimuli. A diminished inhibitory system could therefore account for reduced selective attention abilities, and inhibition has been a process investigated by many researchers for this reason (Fabiani et al., 2006; Hasher et al., 1991; Hasher & Zacks, 1998). Hasher and Zacks (1998) proposed a specific theory of the diminished inhibitory system in older adults. They claim that older adults' lack of inhibition affects attention at every stage of information processing—at the time of input, all information is encoded more, it is then processed more, and at the time of retrieval, more information is present

for potential retrieval. They thus propose that a lack of inhibition causes the impaired attention control of older adults because they are more likely to encode, process, and retrieve irrelevant, distracting stimuli.

Many researchers also propose that working memory (another executive function) plays an important role in selective attention. Lavie et al. (2004) proposed that the inhibition of irrelevant information requires the identification of the stimuli as non-target/distracting through comparison with memory templates and the subsequent suppression of the processing of this information. Under this hypothesis, impaired selective attention in older adults could be due to a failure to maintain appropriate memory templates and/or problems inhibiting the processing of irrelevant information. West (2004) proposed a similar argument, that older adults have difficulty in representing task context, and this is what leads to impaired selective attention.

Numerous studies have shown that older adults have impaired selective attention. There have been mixed results on the error rates of older adults on selective attention tasks—some researchers have found that they have similar error rates to younger adults (Endrass et al., 2012; Falkenstein et al., 2001; Nieuwenhuis et al., 2002), while others have shown that they make more errors (Matthewson et al., 2005). However, the reaction times of older adults have consistently been shown to be slower in these tasks (Endrass et al. 2012).

The Stroop task, wherein subjects are asked to name the color of a colored word when the color and word are either incongruent (BLUE- presented in red) or congruent (BLUE- presented in blue), has been a frequently used paradigm to assess selective attention and inhibition of irrelevant information. Studies have found that older adults show a significantly greater Stroop interference effect (longer response times and more errors in incongruent trials) as compared to younger adults (West, 2004; West & Alain, 1999; West & Alain, 2000). This implicates their

selective attention abilities because selective attention is necessary to focus on the target stimulus dimension (the color) while inhibiting the non-target dimension (the word).

The flanker task similarly assesses the selective attention abilities of older adults. The task requires participants to control their attention to a central target stimulus while simultaneously inhibiting interference from the flanking stimuli. On incongruent trials, older adults are less able to inhibit the flanker interference and have slower response times to name the target stimuli than younger subjects (Colcombe et al., 2005; Shaw, 1991; Zeef & Kok, 1993).

Hasher et al. (1991) also investigated the inhibition involved in selective attention in older adults through the use of negative-priming effects. They used a letter-naming task in which subjects had to name one of two letters. Half of the trials were “sequential,” where the previous trial’s irrelevant letter served as the current trial’s target, and half of the trials were control trials where the target and distracter were different from the previous trial. Younger adults showed the expected negative-priming effects—they were slowed to name a letter that had previously been a non-target on sequential trials because when it was a non-target, they would have inhibited their processing of it. On the other hand, older adults didn’t show these negative-priming effects, because on a given trial, older adults were unable to inhibit the irrelevant letter. The researchers concluded from their findings that older adults’ impaired inhibition at both encoding and retrieval allows for the activation of irrelevant information, which slows or prevents their subsequent attempt to retrieve target information.

A number of studies have found similar results looking at the inhibition of auditory stimuli through the N170 event-related-potential (ERP). The N170 is a negative going waveform that occurs approximately 170 ms after the onset of a stimulus and represents attention to a novel auditory stimulus. Fabiani et al. (2006) played a train of 5 repeated, identical tones that

participants were instructed to ignore while they engaged in another task (reading). Younger adults were quickly able to suppress these tones (demonstrated by reduced N170s). Older adults, however, had a slower decrease in N170 amplitude—they weren't capable of completely inhibiting their attention from the repeating tone. Other studies (Amenado & Diaz, 1999; Chao & Knight, 1997; Fabiani, Friedman & Cheng, 1998; Fabiani & Friedman, 1995) have found the same results in very similar tasks. Fockert et al. (2009), however, used a different type of task, a mismatch task, to look at inhibition in older adults through the N170. In their task, the target was a famous name that had to be categorized as a politician or pop star, next to a distracting face of either a politician or pop star. As expected, older adults showed greater N170s and behavioral interference effects from incongruent faces.

Load theory provides a possible theoretical basis for why older adults have worse selective attention. The theory states that high load on executive functions increases the interference effect of irrelevant distracting stimuli because selective attention requires cognitive control (Lavie et al., 2004; Lavie, 2005). Many studies have shown this effect in a variety of tasks and increasing cognitive load in a variety of ways (Fockert et al., 2009; Fockert et al., 2001; Lavie et al., 2004; Lavie, 2005). Younger adults have actually been shown to perform similarly to older adults if they are given a dual task (and thus have reduced available attentional resources). Dywan et al. (1998) found that giving younger adults a secondary task made it more difficult for them to inhibit responses to familiar but non-target lures in a source-monitoring task, and Engles et al. (1995) saw similar results in a negative priming task with an additional attentional task for younger adults. These findings indicate that the source of older adults' reduced selective attention abilities may be a lack of cognitive control capacity (which can be thought of as equivalent to a younger adult having high cognitive load).

Research on patients with frontal lobe lesions also indicates that cognitive control processes are connected to selective attention through the PFC. These patients have acquired deficits in both cognitive control and selective attention. They are often easily distracted and find it difficult to focus their attention on goal-relevant stimuli when there is other, irrelevant, but more salient, stimuli (Lavie et al. 2004). It thus makes sense that older adults, who naturally have reduced cognitive resources and top-down control due to PFC deterioration (Fockert et al., 2009), have reduced attentional abilities. While the exact neural circuitry of selective attention deficits in older adults is not known, the inhibition of irrelevant information and use of working memory templates are implicated in effective control of attention, and the PFC, particularly the DLPFC is thought to be involved (Matthewson et al., 2005).

Error-Monitoring

Another aspect of executive functioning that seems to be greatly affected by aging is error-monitoring. Error-monitoring is an adaptive process that helps people prevent future mistakes and can be quantified through a scalp-recorded ERP component called the error-related negativity (ERN or Ne). The ERN is a negative-going wave (on a graph of time vs. electrical potential, the wave is going from positive towards negative) that is generally elicited 80-150 ms after an incorrect response, when the individual recognizes that an error has been made. These errors are usually so-called “slips” rather than serious mistakes—they are accidental erroneous responses that can usually be immediately recognized as incorrect (Gehring, Liu, Orr, & Carp, 2012). There isn't consensus in the field about what the ERN specifically represents, but there are a number of ways to define it and theories regarding its significance. Generally, the ERN can be thought of as an internal response to/or detection of an error, and is related to adjusting one's behavior to prevent future errors. This performance monitoring is part of executive functioning

and plays an important role in goal-directed behavior and flexible adaptation (Schreiber et al., 2011)

The ERN is usually measured at midline frontocentral scalp locations because that is where it is most prominent (Gehring et al., 2012; Matthewson et al., 2005). It makes sense that frontocentral locations show the ERN the strongest, because there is converging evidence that the ERN is generated in the anterior cingulate cortex (ACC) in the frontal lobes (Gehring et al., 2012; Matthewson et al., 2005; Schreiber et al., 2011). The ACC is responsible for many cognitive control functions of the brain, including the adaptation of behavior to changing contextual demands. In addition to brain electromagnetic source analysis, fMRIs have shown BOLD signal increases in the ACC related to errors, recordings in monkeys (and even rats) has shown error-related activity in the ACC, and patients with ACC damage show an ERN for erroneous and correct trials, further implicating the ACC as responsible for the ERN (Mathalon et al., 2003).

It is further believed that connections from the ACC to the lateral PFC are critical for the generation of an ERN (Gehring et al., 2012). Patients with lateral PFC lesions showed an ERN on correct trials and/or reduced ERNs on error trials (Gehring et al., 2012). Mathalon et al. (2003) theorized that the DL-PFC is responsible for differentiating the ERN signal for correct and incorrect responses by focusing attention to relevant target information and regulating and distinguishing conflicting/competing responses. One theory connecting the PFC and ACC is that the ERN is a signal of detection of conflict/errors and signals to the PFC to use cognitive control to prevent future errors (Kerns et al., 2004).

Modulating this connection between the ACC, the PFC, and the ERN is the mesencephalic dopamine system. Holroyd and Coles (2002) proposed that a subject faced with unexpected

reward or punishment will have altered dopamine levels in the ACC. When results are worse than expected (as in an error), there is a sudden decrease in dopamine levels. Because dopamine is heavily implicated in the reward pathway of the brain and is a reinforcing neurotransmitter, it's sudden decrease in concentration acts as a negative learning signal (it doesn't reinforce the previous behavior). This signal is then conveyed to the ACC where apical dendrites of pyramidal motor neurons become disinhibited and the ERN is generated (Holroyd & Coles, 2002).

As previously mentioned in regards to the frontal lobe theory of cognitive aging, the PFC and dopaminergic system are both somewhat deteriorated in older adults. Because of the active role these systems have been shown to play in error-monitoring, it is unsurprising that older adults have an altered error-processing system. A number of studies using different paradigms and stimulus types have indeed found that the ERNs of older adults (of varying age ranges) have reduced amplitude compared to younger adults (Endrass et al., 2012; Falkenstein et al., 2001; Mathalon et al., 2003; Matthewson et al., 2005; Nieuwenhuis et al., 2002; Schreiber et al., 2011; West, 2004). This has been shown even when accuracy is the same or controlled for, and, further, it is known that it is not related to any general age-related ERP reduction in older adults (Matthewson et al., 2005).

Most of the studies investigating this age-related deflation of the ERN have used simple speeded response paradigms (often variations of the flankers task), where there is no confusion about whether or not a mistake was made, and these mistakes could be easily corrected. However, Matthewson et al. (2005), in addition to employing a classic flankers task in their study, also used a source memory task. This recognition task, which is more complex and nuanced than the simple speeded response type tasks, was used to determine whether different

tasks would show the same age-related ERN effect. In the source memory task they used, participants studied a list of 25 common five-letter words and then had a recognition task that included the 25 study words in addition to 75 new words, 25 of which were presented twice (thus acting as a lure). On both the flankers and source-memory task, the older adults had a significantly smaller ERN on error trials than the younger adults. While the ERN for younger adults was easily recognizable in both tasks, for older adults the ERN was more gradual and shallower. Mathalon et al. (2003) also used a more complex task in which participants had to indicate whether or not a picture matched the word that preceded it. They too found that the task didn't alter the effect—older adults still demonstrated reduced ERNs. These studies strengthen the implications of the reduced ERNs of older adults by demonstrating that it is not a task-specific or stimulus-specific effect.

As a whole, these findings indicate that the error-monitoring system of older adults is operating differently in some way from younger adults' error-monitoring system. It seems as though older adults are not as effective at performance monitoring as their younger counterparts. Nieuwenhuis et al. (2002) also have reported that older adults are slower at reinforcement learning, a process which is connected to error-monitoring because it depends on an individual's ability to adaptively alter their performance based on feedback (which could include the internal feedback of recognizing an error). This provides some more “real-life” evidence that the error-monitoring systems of older adults may be impaired.

Emotion Regulation

In stark contrast with older adults' generally diminished levels of cognitive control and decline in executive function domains, significant research has suggested that older adults have an enhanced ability to regulate emotion as compared to younger adults. A number of studies

have found that older adults are actually happier than younger adults—they are better able to recover quickly from, and reduce, negative emotional states, maintain positive emotional states, and display less physiological arousal when experiencing negative emotions (Mather & Carstensen, 2003; Samanez-Larkin et al., 2009). Further, on subjective self-reports of emotional control, older adults rate themselves significantly higher than younger people (Samanez-Larkin et al., 2009).

Older adults' focus on emotion regulation has been reported in several studies using different stimuli and tasks. Samanez-Larkin et al. (2009) had older subjects perform a regular flankers task and a modified flankers task that used emotional words as the flankers and targets (words were both positive and negative in valence). They found that older adults were more susceptible to interference than younger controls in the non-emotional flankers, as would be expected, but were less susceptible to interference in the emotional task (regardless of the valence of the words). Other studies have found evidence that, generally, deficits in cognitive tasks that are seen in older adults can be minimized when the task involves emotional stimuli or judgments (Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005 as cited in Samanez-Larkin et al., 2009). These findings indicate that older adults are usually more focused on and motivated by emotional information.

More naturalistic studies have also examined emotional regulation in older adults and this general propensity to focus on emotional information. Fredericson and Carstensen (1990) and Fung, Lai, and Ng (2001) found that older adults preferred to spend time with emotionally meaningful familiar social partners as compared to younger adults. Hashtroudi, Johnson, and Chrosniak (1990) asked participants to imagine a scenario, and later, when asked about their imagined situation, older adults were more likely to remember emotions, thoughts, and

evaluations rather than context or perceptual aspects of the situation. More generally, older adults are simply more likely to remember any emotional information (Carstensen & Turk-Charles, 1994). Essentially, emotional information seems to be more salient and important to older adults.

Positivity Bias

Much more hotly contested in the literature is the existence of a so-called “positivity effect” for older adults. Mather and Carstensen (2005) claim that it is in part this positivity effect that leads to the enhanced positive affect of older adults. The argument is that older adults don’t just have an “emotionally relevant focus,” where memory and attention would be biased towards *any* emotional information (as part of their enhanced emotion regulation); but rather that older adults have an “emotionally gratifying focus” where they bias their memory and attention toward information that will foster positive affect and protect against negative affect. According to a recent review article by Reed and Carstensen (2012), more than 100 studies have been published addressing the positivity effect and aging, and the general consensus has been that older adults focus more on positive information (or at least focus less on negative information) than their younger counterparts. It isn’t clear to what degree the positivity effect is due to enhanced attention to positive stimuli versus diminished attention to negative stimuli, but whatever the root, the result is that older adults are differentially allocating their attention based on the valence of the emotional information they are presented with.

This has been demonstrated in a variety of cognitive domains and through a number of paradigms. In memory tasks, Mather and Carstensen (2003) have found that older adults have better recall for positive than negative faces. Older adults also retrieve more positive than negative memories and look back on the past more positively (Mather, 2006). In attention tasks

such as the one that will be employed in this study, older adults have been shown to preferentially allocate their attention towards positive information and/or away from negative information. Mather and Carstensen (2003) investigated attentional biases in older adults through a task where subjects had to identify where a dot had appeared, either behind the area where a neutral or emotional face had been. They found that older subjects would respond significantly faster if the dot were behind the neutral or positive face rather than the negative face. Using eye-tracking measurements, they also found that older adults direct their gaze towards happy and away from sad faces. Further, when making decisions, studies have shown that older adults pay more attention to positive information (Mather et al., 2005).

Goeleven et al. (2010) used an attention task that also employed inhibition of irrelevant information to examine age-related differences in attention to emotional stimuli. In their paradigm, subjects were presented with a pair of emotional faces—one would be the target and the other a distracter, and they would be asked to evaluate the target as positive or negative (thus requiring inhibition of the distracting face). In prime trials, participants would first be shown another face that would either be emotionally congruent or incongruent with the target probe face. Effective inhibition of the prime would cause participants to be slower to respond to the target face if it was of the same affect as the priming face. Older adults showed reduced interference effects from negative stimuli and subsequently less inhibition of the negative stimuli (i.e. older participants were faster to respond than younger when both the prime and target were negative). This supports the theory that older adults are allocating less attention to negative information (rather than allocating more attention to positive information).

Socioemotional Selectivity Theory

Socioemotional selectivity theory maintains that this positivity bias and enhanced emotion regulation is due to the shifting priorities of older adults who realize that their time is limited. As people confront the end of their life, they become more motivated to maintain an emotional balance and focus on what they consider important—emotions. Emotional satisfaction and a sense of meaning become more important than concerns about the future or a desire to increase knowledge (Mather & Carstensen, 2003). Because of this shifting in goals, older people allocate more of their cognitive resources towards emotional regulation (Mather & Carstensen, 2003; Mather & Carstensen, 2005; Reed & Carstensen, 2012; Samanez-Larkin et al., 2009). We naturally selectively attend to information that is consistent with our current goals, and this explains why older adults naturally attend more to emotional information (Goeleven et al., 2010).

Support for this theory comes from studies showing that younger adults exhibit a similar change in attentional focus when time limits and “endings” are emphasized (Mather & Carstensen, 2003). This provides evidence that the positivity bias and enhanced emotion regulation are motivated by the feeling of an impending end (and subsequent adjustment of goals) and is a cognitively controlled process (Mather & Carstensen, 2005; Reed & Carstensen, 2012). This positivity bias is thus considered an adaptive strategy that relates to well being, and could be especially useful as a coping strategy for older adults (Goeleven et al., 2010).

According to socioemotional selectivity theory, because the positivity bias is a cognitively controlled function related to motivation, it should be weakest when cognitive resources are depleted, if processing is more automatic than controlled, and if there is outside interference or goal-imposition (Reed & Carstensen, 2012). Reed and Carstensen (2012) propose that the positivity bias will be greatest for people with good cognitive control because it

requires this top-down support. Mather and Knight (2005) found some evidence to support this. In their study, older subjects with the highest scores on a measure of executive functioning displayed the most positivity bias, but that preference for positive information was eliminated when the individuals' cognitive control resources became occupied by a secondary attentional task. Isaacowitz et al. (2009) found similar results. They found that older adults with high executive control had more positive gaze preference and also avoided negative mood changes. These findings support the idea that cognitive capacities are required for a positivity bias to occur.

Emotion Regulation and the Brain

While the exact neural processes underlying the positivity bias specifically and emotion regulation generally are not well understood, more research is being done to try to localize these functions to regions of the brain, with promising results linking cognitive control to emotional control. Mather and Carstensen (2005) suggest that increased inhibition of neural activity involved in processing negative information might originate in the PFC (through top-down modulation), the same area that is responsible for other cognitive control processes. Samanez-Larkin et al. (2009) found that a task that was both emotional and cognitive (the emotional flankers task described earlier) activated the same frontal lobe regions as the purely cognitive task (a simple flankers task), indicating an overlap in localization for emotion regulation and cognitive control at the very least. However, it is also thought that perhaps the DL-PFC is more responsible for attention, memory, planning, and inhibition, while the orbitofrontal cortex (OFC), another regions of the PFC, is more responsible for emotional control and social behavior (Tisserand & Jolles, 2003).

Williams et al. (2006) proposed a slightly more precise mechanism of the neural processes underlying the positivity bias associated with aging. They found that, in older adults, emotional stability (i.e. emotion regulation) was predicted by greater medial prefrontal activation for negative emotional input processing and less activation for positive stimuli. This implies that older adults are allocating their cognitive resources (represented by degree of PFC activation) to control negative emotional response, while permitting responses to positive stimuli to carry on without the same modulation from the PFC.

The ACC and amygdala have also been implicated in emotion regulation processes. St. Jacques et al. (2010) had older and younger subjects look at emotionally valent pictures while in an fMRI scanner and found that older adults showed greater functional connectivity between the right amygdala (a generator of fear/negative response) and the ACC (involved in processing of emotional information). They claimed that this was evidence that emotional priorities lead older adults to engage the ACC more than younger individuals and use it to down-regulate the impact of negative pictures (through relations with the amygdala). Gunning-Dixon et al. (2003) also found that older adults recruited the ACC more and activated the amygdala less than younger adults when processing the emotional affect of faces. They suggest that this is evidence of a general “age-related reorganization of the cortical networks used for facial emotion discrimination” (Gunning-Dixon et al., 2003, p. 292). While the relationships between the ACC, amygdala, OFC, and PFC are not clear, a number of studies have indicated their involvement in emotion regulation and cognitive control, and researchers are beginning to piece together the ways in which they may work in conjunction with one another to produce the positivity bias in older adults.

Young and the Negativity Bias

In stark contrast to the positivity effect observed in older adults, younger individuals actually display a negativity bias. Vaish, Grossmann, and Woodward (2008) defined this bias as the “propensity to attend to, learn from, and use negative information far more than positive information” (p. 383). Carretie et al. (2001) found that young people had larger P200 peaks (an ERP related to attention) and shorter latencies for negative stimuli. Using a similar paradigm to the one that we are proposing, Fenske and Eastwood (2003) found that younger adults preferentially allocated their attention to negative faces (they experienced greater interference from negative flanking faces). Eastwood et al. (2001) found that in a search display task with schematic emotional faces, younger subjects were fastest to find the negative face. Both of these studies (Fenske & Eastwood, 2003; Eastwood et al., 2001) also found that positive stimuli seemed to expand the scope of attention and allow for greater interference/distraction. A number of other studies using different methodologies have also shown that younger people are more impacted by negative stimuli (Amabile & Glazebrook, 1982; Crandall, 1975; Smith et al., 2003).

The Intersection of Executive Functioning, Attention, the ERN, and Emotion

The first part of this paper has described how executive functioning, attention, error-monitoring, and emotion regulation are effected by age, and how they are related to the brain and age-related changes in the brain. While the research documenting these effects has been extensive, there is a lack of work attempting to connect these functional changes through any sort of unified theory. These functional changes associated with age are clearly associated with each other as they each involve cognitive control and the prefrontal cortex, yet declines are associated with age in all of these domains except for emotion regulation, in which there is apparent improvement with age. Therein lies the paradox—how are older adults able to improve their

top-down emotion regulation control while their other top-down controlled processes deteriorate?

If we are to accept the socioemotional selectivity theory as the basis of the positivity effect, then we could resolve this paradox as being the result of a shift in priorities as adults come closer and closer to death (and the subsequent redistribution of cognitive resources). Mather and Carstensen (2005) support this theory, claiming that “at least some of the presumed aging deficits reported in the literature reflect behavioral shifts as much as fundamental neural deterioration” (p. 496). Essentially, their argument would be that older adults are more motivated to engage in emotion regulation, and thus put their (limited) cognitive resources towards this goal.

A natural corollary of this theory would be that adults who have more cognitive resources to begin with (as evidenced by their higher scores on measures of executive functioning, attention, and error-monitoring), have more resources available to allocate to emotional regulation. This theory would then predict that older adults with a greater positivity bias would show a larger ERN, better executive functioning, and better selective attention. Alternately, one could propose the exact opposite effect—that older adults who show a greater positivity effect are using their limited resources to do so, and thus will be taking away from their error-monitoring and attentional tasks (and perform worse on them). This would predict that older adults with a greater positivity bias would show a smaller ERN and impaired selective attention/executive functioning because they are “using up” all of their resources.

Another theory behind this apparent paradox is that perhaps the DL-PFC is more responsible for executive functions, while the OFC is more responsible for emotion regulation, and disproportionate atrophy with increasing age might explain the differing rates of decline

(Carstensen, 2006). West (1996) did in fact find that the DL-PFC declined at a different rate than the OFC (which only showed decline during the late 7th decade and beyond). These divergent explanations imply different relationships between measures of executive functioning and emotion regulation in older adults. They predict different correlations between these measures, and this study will attempt to test these differing hypotheses against one another.

While no study has attempted to measure the positivity bias, attentional control, and error-monitoring through one task, some studies have addressed the connections between a few of these domains, the frontal lobe, and executive functioning. Chao and Knight (1997) found that the percentage of errors on the Wisconsin card sort task (a measure of executive functioning) was positively correlated to the N1 auditory response in older adults to a repeated tone (a measure of selective attention). This supports the logical correlation between impaired selective attention and impaired executive functioning in older adults. Mather and Knight (2005) found that older adults who did worse on tests of cognitive control were less likely to show positivity effects in memory tasks. Mather and Carstensen (2005) also cite a number of studies indicating that older adults who have frontal lobe damage (due to strokes or lesions) are more likely to have impaired executive functioning and late onset depression (as well as not being responsive to antidepressants). This implies a potential relationship between the frontal lobe, executive functioning, and emotion regulation.

Current Study

The goal of the present study was to use both behavioral and EEG data to investigate age-related effects on executive functioning, selective attention, error-monitoring, and the positivity bias, and then correlate these effects with one other. While the effects of age on these individual aspects of cognitive control have been well studied, the relationships between them are unclear

and there remains a gap in the literature. So, beyond the replication of these previously demonstrated effects, our principal aim was to achieve a greater understanding of the paradoxical relationship between the increased emotion regulation and decreased cognitive control usually seen in older adults. This paper has considered competing theories that could explain this relationship, and we intended to test the differing predictions of these theories against one another through a battery of tasks.

To do this, we compared older and younger adults on measures of executive functioning, attentional control, error-monitoring, and the positivity effect, and further looked within the older group at individual differences in the positivity effect (and how it is correlated to these other measures). We administered some tasks from the Wechsler Adult Intelligence Scale (WAIS) to measure executive functioning generally, a standard flankers task to elicit a baseline ERN and measure of attentional control, an emotional faces flankers task to elicit the ERN in conjunction with a measure of positivity bias, and a facial recognition task to elicit the positivity effect in a less cognitively demanding situation.

Our first intention was to replicate the results found in prior literature involving the effect of age on attention, error-monitoring, and the positivity bias. Significant previous research, including studies employing the flankers task, has shown that older adults have impaired error-monitoring (as evidenced by a reduced ERN compared to younger adults) (Schreiber et al., 2011; Endrass et al., 2012; Matthewson et al., 2005; Nieuwenhuis et al., 2002; Mathalon et al., 2003; West, 2004; Falkenstein et al., 2001), and we therefore anticipated seeing this effect in both of our flankers tasks. We additionally expected to find reduced selective attention abilities for older adults as compared to younger adults on both flankers tasks, because this has also been thoroughly supported in the literature (West, 2004; West & Alain, 2000; West & Alain, 1999;

Colcombe et al., 2005; Shaw, 1991; Zeef & Kok, 1993; Hasher et al., 1991; Fabiani et al., 2006; Amenado & Diaz, 1999; Fabiani, Friedman and Cheng, 1998; Fabiani & Friedman, 1995; Chao & Knight, 1997; Fockert et al., 2009). While somewhat more inconsistent, many studies have also found that older adults exhibit a positivity effect (see Reed & Carstensen, 2012 for a review), and we believe both the emotional flankers task and facial recognition task have the potential to elicit it. On the other hand, prior literature has demonstrated that younger adults show the opposite effect, a negativity bias (Carretie et al., 2001; Ito et al., 1998; Vaish, Grossmann, & Woodward, 2008; Fenske & Eastwood, 2003; Eastwood et al., 2001), and we therefore think it is possible that the emotional flankers task and facial recognition task elicit a negativity bias in the younger group.

Overall, we expect to see that, compared to younger adults, older adults will show impaired executive functioning (they will do worse on the WAIS tasks and the selective attention task, and will also have smaller ERNs), but enhanced emotion regulation (they will exhibit a positivity effect). Though it seems paradoxical that older adults are declining in these cognitive domains and improving in emotion regulation, theories have been presented which could explain for this effect. In particular, Mather and Carstensen (2005) explain that older adults may be employing their executive functioning abilities to regulate emotion. This leads to two novel alternate hypotheses about how these measures will correlate with one another, and will hopefully shed light on the differing explanations about the relationship between executive functioning and emotion regulation in older adults. The first possibility is that older adults who show the greatest positivity bias are those who have the most cognitive capacity, and they will therefore have the best selective attention and the largest ERN. Alternatively, it is possible that the older adults who show the greatest positivity bias are taking all of their cognitive control

capacities and putting it towards emotion regulation, and, therefore, will actually have the most reduced ERN and most impaired selective attention on the emotional flankers task.

Through the rigorous testing of these hypotheses, we hoped that this study would illuminate some of the more intricate relationships between different top-down modulated processes, and bring insight into theories of cognitive aging and, in particular, its relationship to emotion regulation.

Specific hypotheses and alternative explanations

1. Older adults will show impaired selective attention
 - a. The older group will have longer response times (and may make more errors) on the incongruent trials of both flankers tasks (standard and emotional)
2. The ERN will be smaller for older adults on both flankers tasks (indicating an impaired error-monitoring system)
3. Older adults will show a positivity effect compared to younger adults
 - a. In attention task: On incongruent trials, positive faces will be more distracting as flankers (longer response times) and more compelling as targets (shorter response times) for older adults vs. younger adults
 - b. It is also possible that, as compared to the standard flankers task, the introduction of emotional information will cause the ERN to be greater in the emotional task as compared to the standard task for older adults, because older subjects will be more motivated to perform well (and increased motivation leads to greater ERNs)
 - c. In memory task: Older adults will remember more of the positive affective faces and fewer negative affective faces than younger adults

4. Younger adults will show a negativity bias
 - a. In attention task: Negative faces will be more distracting as flankers on incongruent trials (longer response times), and more compelling as targets (shorter response times)
 - b. In memory task: Younger adults will remember more of the negative affective faces and fewer positive affective faces
5. In our older group, better executive functioning, better selective attention, greater ERN, and greater positivity bias will all be positively correlated.
 - a. Alternative hypothesis: positivity bias will consume all of the older adults' cognitive capacity, and therefore be correlated to a lower ERN and worse selective attention on the emotional flankers task.

Methods

Participants

We recruited 21 older adults and 23 Haverford College students to participate in this study. The older adults were recruited from a database managed at Bryn Mawr College (under the advisement of Anjali Thapar). This database holds the names, contact information, and some behavioral measures for a number of older adults. From this database, approximately 20 healthy older adults (those that had previously shown no indication of cognitive decline) were called and asked if they would like to participate in a study regarding aging at Haverford College. Younger adults were all students from Haverford College recruited through online student boards, personal contacts, and social networking. The mean age in the older group was 69.4 (range=65-75, n=19) (excluding one older adult whose age was not reported), while the average age in the younger group was 20.05 (range=18-23, n=20). Both groups were fairly similar in terms of level

of education attained. All of the young adults were attending 4-year college (and many indicated an intention to attain further education). Of the older adults, all but 1 had some college or a 2-year degree, and 10 had more than a 4-year degree. The gender ratios were also similar in the two groups—15 young females and 5 young males, and 17 older females and 3 older males. The only demographic variable in which our two groups did differ significantly was race. All of the older adults were white, while the younger group was 60% white, 15% black, and 20% Asian. Overall, however, it appears as though our two groups were well matched and no confounding variables were introduced. All subjects received compensation for participating before leaving.

Materials

1. Mini Mental State Exam

To ensure that we are studying “healthy aging” and to eliminate subjects who may be showing any signs of dementia or significantly impaired cognitive abilities, we administered the Mini Mental State Exam (Folstein et al., 1975), and excluded the 1 participant who scored below our cut-off score from data analysis. This brief, 10 minute, 30-item questionnaire involves simple language (repeat what I have said), memory (what word did I tell you earlier?), orientation (what is today’s date?), and visual-spatial (copy this drawing) questions. It is scored on a 30- point scale, with any score above 25 indicating healthy cognitive functioning. We administered this test to both the older and younger groups, and used 25 as our cut-off score (with scores below 25 indicating that some sort of dementia might be developing).

2. Wechsler Adult Intelligence Scale (WAIS)- Mental Control and Arithmetic

After the MMSE, we administered the Mental Control and Arithmetic components of the WAIS. The WAIS is a test designed to test adult intelligence, and these two subtests have been

shown to correlate highly with the more overarching score, which is indicative generally of cognitive functioning. This task thus provided us with a baseline measure of cognitive control outside of our principal flankers paradigm (which is specific to attention). In the mental control task, subjects have to recite and manipulate sequences (e.g. count to 20 forwards and backwards as fast as you can). In the arithmetic task, participants were tested on their numerical reasoning and problem solving abilities through 12 simple math questions (e.g. soft drinks are sold 6 cans to a package. If you want 36 cans, how many packages must you buy?). Questions were administered orally and participants were not allowed to use paper or pencil.

3. Non-emotional (Standard) Flankers Task

Before administering the emotional flankers task, participants completed a standard Eriksen letter flankers task to obtain baseline ERN and attentional control measurements. The flankers task has been shown to elicit errors in healthy populations and is an effective way to elicit the ERN and measure selective attention. By employing a non-emotional version of the task, we aimed to replicate previous research showing a reduced ERN in older adults without the added variable of emotionality. This also proved to be a useful tool in teaching participants how a flankers-type task works before it became slightly more complex (in the emotional face version).

The classic Eriksen flanker task consists of trials of congruent (MMMMMMM) and incongruent (MMMNMMM) letter strings. Participants are asked to identify the central “target” letter via a keystroke as quickly and accurately as possible. After a practice round, we presented 480 trials, with half of the trials congruent and the other half incongruent using M, N, and W as the possible targets and flankers. Trials were presented in a random order in 10 blocks of 48 trials (with a 1280 ms rest period between trials). The letter strings were presented on a black

screen in white uppercase letters for 150 ms. A solid black screen was then presented until the participant made a response (either pushing 1, 2, or 3). Response time was measured as time from the onset of the stimulus (the letter string) until the keystroke (3 key options, 3 fingers).

4. Emotional Flankers Task

The heart of our study was the emotional flankers task. This task mimicked the standard flankers task, but employed positive (happy), negative (sad), and neutral affective faces as targets and flankers. There were 9 trial types—targets and flankers were either positive (happy), negative (sad), or neutral. These 9 trial types, half congruent and half incongruent, were randomly intermixed as a total set of 480 trials split into 10 blocks of 48 trials (with a 1280 ms rest period between trials). Subjects were presented with a row of three faces for 250 ms, and asked to identify the central target face via a keystroke (1 for happy, 2 for neutral, or 3 for sad). A similar type of task has been effectively used in a study by Fenske and Eastwood (2003) and Horstmann et al. (2006). Fenske and Eastwood (2003) investigated selective attention to emotional stimuli through a flanker task using schematic affective faces and found that congruency effects were preserved. Horstmann et al. (2006) had the same results, but also found some evidence suggesting that perceptual differences between the schematic face drawings are the root of differing attentional allocation.

To protect our study from this potential confounding effect, we used real photographs of expressive faces (rather than schematic drawings). We obtained these images from the Radboud Faces Database (Langner et al., 2010), which had been pre-tested by Langner et al. (2010) for shown facial expression, intensity of expression, clarity of expression, genuineness of expression, attractiveness, and valence. The researchers found that there was very high recognition of the intended facial expressions. We employed 24 Caucasian adult posers, half female and half male

(out of a total set of 67 models). The posers are facing the camera head-on, are all wearing plain black t-shirts, and were cropped just below the chin and above the top of the head. We believed that the use of real models would lead to higher error rates, make the emotions more salient and real, and make it less likely that a simple perceptual difference would cause a difference in attentional allocation (as suggested by Horstmann et al.). We also used multiple posers to prevent participants from using a simple feature of the individual to distinguish between emotions. Further, each poser was only used for a neutral expression and either positive or negative expression (not both) to reduce confounding variables in the later recognition task.

5. Demographics Questionnaire

After the emotional flankers task and before the facial memory task, we asked participants to fill out a survey with some relevant demographic information. The questionnaire asked participants about their education level, age, race, and gender. This was to ensure that there were no confounding differences between our younger and older participants.

It is particularly important that we obtained demographic information for this study because cognitive deficits associated with aging have been correlated with a number of demographic factors. Education level, IQ, fitness, health, nutrition, access to healthcare, and socioeconomic status have all been positively correlated to cognitive resources and are moderating factors in the aging process (Fabiani, 2012). Gordon et al. (2008) found evidence that education level is correlated to preserved white matter connections in the frontal lobe. West (1996) also showed that higher levels of education provided protection against the larger Stroop effect normally observed in older adults. Unsurprisingly, fitness and health also play a role in cognitive maintenance during aging in a number of direct and indirect ways (Fabiani, 2012; West, 1996).

6. Recognition Task

Before participants left, we asked them to complete a brief facial recognition task as another measure of the positivity bias. Some studies have indicated that the positivity bias only appears when the experimental task allows subjects to freely allocate their attention without the imposition of artificial experiment task goals (and subsequent supplanting of chronically activated goals) or acknowledgement of the affective component (Mather & Carstensen, 2003; Mather & Knight, 2006; Samanez-Larkin et al., 2009; Reed & Carstensen, 2012). In addition, there is evidence that the positivity bias only occurs in non-automatic, controlled, strategic processes (Reed & Carstensen, 2012). Other researchers have argued that there is a delayed onset of the positivity bias due to a need to consciously reallocate cognitive resources (Issacowitz et al., 2009a; Williams et al., 2006). Further support for this theory comes from the fact that older adults still show an automatic attentional bias to threat. It seems to only be the more consciously top-down controlled emotion which is effected by age (Mather & Carstensen, 2005). Because the flankers task is a speeded-response task with imposed task demands that are intended to effect participants' attention, it is possible that it relies upon a mix of automatic and controlled processes and thus would not elicit the positivity bias.

The recognition task was intended to protect against this possibility by providing another measure of the positivity bias distinct from the flankers task. In this facial recognition task, participants were presented with 32 neutral faces (16 old- 8 originally happy and 8 originally sad, and 16 new), and asked whether a certain face was presented before (in the flankers task) or not. The faces were shown until participants made a response, and there was 1,000 ms of rest between trials. Enhanced recognition for faces that were originally positive (or reduced recognition of faces that were originally negative) would indicate that during the task the

participant was more deeply encoding and paying attention to the positive information (the happy face posers), and this would be a sign of the positivity bias. This sort of task has been used before (e.g. Mather & Carstensen, 2003) and was intended to provide a good additional measure of the positivity effect.

Procedure

We attempted to run subjects in their optimum cognitive functioning windows (approximately 9:00 am to 4:00 pm for older adults and later in the evening for younger adults). After accompanying subjects to the testing room and outlining the tasks they would be completing, they were asked to sign an informed consent waiver and a waiver asking for their consent to share data between labs at Bryn Mawr and Haverford College. Participants then sat opposite of two experimenters at a table and the MMSE, Mental Control, and Arithmetic tasks were administered. Next, participants were fitted with the Quik-Caps and seated in front of a computer in another room to complete the standard flanker task, the emotional flanker task, the demographics questionnaire, and the recognition task. After the recognition task, participants were taken back to the set-up room, had the cap removed, and were paid.

Electrophysiological Recording and Data Processing

Electrodes were applied using an elastic cap (Quik-Caps) fitted with sintered Ag/AgCl electrodes. Data was continuously recorded from 4 midline scalp sites (Fz, FCz, Cz, Pz). Signals were amplified through a NuAmps amplifier controlled by Neuroscan software, with a sampling rate of 1000 Hz and a bandpass of 0.1-40 Hz (-3 dB). Data was referenced on-line to the right mastoid and digitally re-referenced off-line to the average of left and right mastoids. Eye movements were monitored via electrodes above and below the left eye and at the outer

corner of both eyes. Recordings from these four sites were used to compute bipolar horizontal and vertical EOG channels off-line.

Artifacts were addressed off-line in three stages. First, upon visual inspection, portions of the EEG recording with large non-blink artifacts were manually excluded. Second, the effect of blinks were minimized using the Neuroscan software's regression-based algorithm for ocular artifact reduction. Finally, remaining artifacts in the EEG were identified using a +/- 150 mv threshold, and corresponding epochs were excluded.

Data processing to extract the ERN included creating epochs around each response marker (button-press onset), beginning 200 ms before and extending until 600 ms after the response. Epochs were baseline-corrected, with baseline defined by voltages in the interval from 200 to 100 ms pre-response, and averaged separately for correct and error trials. We defined the ERN as the peak negative amplitude between -50 and 100 ms after the participant's response.

Results

Data Exclusion

Three older subjects placed their hands on the wrong keys for a block of trials at some point, and so these blocks were excluded from analyses. Six subjects (2 young and 4 old) also had all, or the vast majority, of their ERN data from the face flankers task excluded from analyses due to technical difficulties (data stopped recording before or during the task). If a subject did not respond on a particular trial, that trial was excluded from ERN analyses but included as an error for accuracy data. We also had one older subject fail to pass our MMSE cut-off score of 25, and so this person's data were excluded from all analyses.

Cognitive Measures

We performed an independent samples t-test to investigate whether there were any age-related differences in the cognitive measures. Means for these measures are presented in Table 1. While we had intended for our older and younger groups to have equivalent MMSE scores, the older group that we used for our analyses did have marginally lower MMSE scores ($t(41)=1.8$, $p=.09$, adjusted for inequality of variance). As expected, the older group performed significantly worse on the Mental Control task ($t(41)=3.8$, $p<.001$). On the arithmetic task, however, while the data went in the expected direction (the older group performed somewhat worse), it did not come close statistical significance ($t(41)=1.1$, $p=.28$).

	MMSE		Mental Control		Arithmetic	
	Young	Old	Young	Old	Young	Old
N	23	20	23	20	23	20
Mean	29.0	28.3	28.4	22.7	10.9	9.6
SD	.20	.35	1.0	1.1	.80	.89

Table 1. Measures of Executive Functioning in Young and Old.

Letter flankers Task

To analyze the letter flankers task, we performed a mixed 2x2 ANOVA on accuracy (proportion correct) and response time. The factor of age had 2 levels—old and young, and the factor of trial type had 2 levels—congruent and incongruent. The expected congruency effect was found for both measures: participants in both groups were significantly faster ($F(1,41)=171.8$, $p<.001$) and more accurate ($F(1,41)=30.61$, $p<.001$) on congruent trials than incongruent trials. The mean accuracy for congruent trials was 93.8% (SEM=1.3) versus 90.6% (SEM=1.5) for incongruent trials. The mean response time on incongruent trials was 591 ms (SEM=21), while on congruent trials it was 528 ms (SEM =19).

In terms of age-related effects, older adults differed significantly from the younger in terms of response time ($F(1,41)=19.88, p<.001$), but not accuracy. So while they were slower overall, they were no less accurate than the young group. Mean response time was 649 ms (SEM=29) for the older group and 470 ms (SEM=27) for the younger group.

While we expected there to also be an interaction effect—with older adults doing significantly worse on incongruent trials than the younger adults—this was not the case. There was a trending group \times trial type interaction for accuracy ($F(1,41)=3.04, p=.09$), but the means reveal that the difference lay in older adults worse accuracy on congruent trials. The younger adults had a mean of 95% accuracy on congruent trials (SEM=2) and 90% on incongruent trials (SEM=2), while older adults had a mean of 93% on congruent trials (SEM=2) and 90% on incongruent trials (SEM=2)

Emotional Flanker Task

We ran a 3x3x3 mixed ANOVA to analyze the accuracy and response times on the face flankers task. The factors of target and flanker emotion each had 3 levels (happy, sad, neutral), and the between-subjects factor of age had 2 levels (old, young). While we expected, based on the literature, to see a typical congruency effect in this task (with greater accuracy and faster response times on congruent trials), there was no interaction between target and flanker emotion. There was no statistical difference in performance, in terms of accuracy or response time, when all of the faces displayed the same emotion versus when the flankers displayed an emotion different from the target.

There was, however, a main effect of target emotion on accuracy ($F(2,82)=56.85, p<001$), and a post-hoc Bonferroni test revealed significant differences ($ps < .05$) between all three emotions—with accuracy being greatest on happy, then neutral, and accuracy worst when a sad

face was the target. Response time results also supported this main effect of target emotion ($F(2,82)=96.12, p<.001$) and indicated the same order of ease (with fastest responses on happy target trials and slowest responses on sad target trials). Means for these measures are presented in Table 2. There was also a trend for flanker emotion on accuracy ($F(2,82)=3.14, p=.059$; see Table 3). Post-hoc Bonferroni test revealed that subjects did significantly better when the flankers were sad vs. neutral.

Target Emotion	Mean (SEM) Accuracy	Mean (SEM) RT
Happy	94.6% (1.0)	480 ms (18)
Neutral	85.6% (1.8)	574 ms (18)
Sad	74.7% (2.2)	603 ms (19)

Table 2. Mean Accuracy and Response Time on Emotional Flankers Task Based on Target Emotion

Flanker emotion	Mean (SEM) Accuracy
Happy	85.4% (1.6)
Neutral	83.8% (1.5)
Sad	85.6% (1.2)

Table 3. Mean Accuracy on Emotional Flankers Task Based on Flanker Emotion

We also found a significant interaction effect of target emotion by flanker emotion in the accuracy data ($F(4,164)=5.97, p<001$; see Figure 1). Accuracy was worse when the target was sad regardless of flanker emotion, but this interacted with flanker emotion in such a way that accuracy was absolutely the worst on trials of sad targets with neutral flankers. Accuracy was also slightly worse on trials of neutral target/ happy flankers.

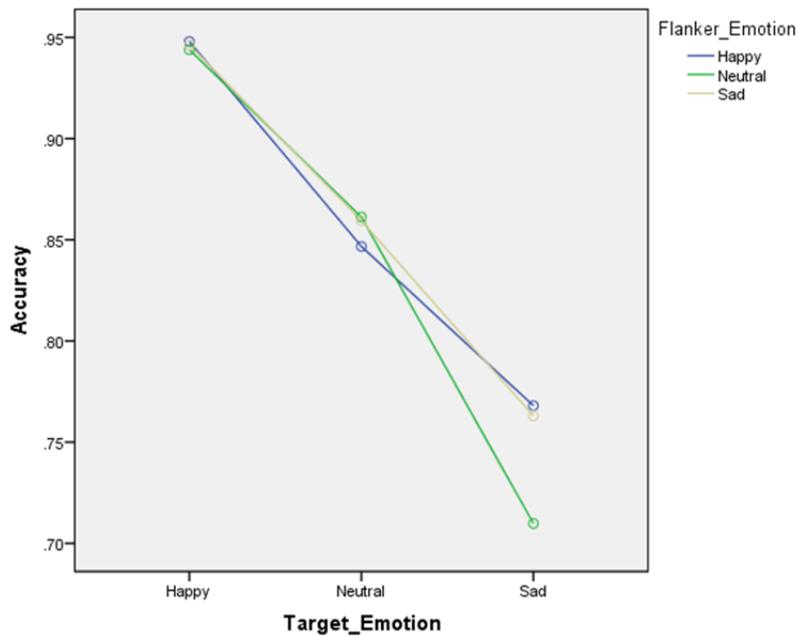


Figure 1. Interaction Effect of Flanker Emotion x Target Emotion on Accuracy

A significant 3-way interaction of target emotion x flanker emotion x group on accuracy was also found ($F(4,164)=4.93, p<.001$; see Figures 2 and 3). When examining only happy target trials, there was a trend for flanker emotion by group where older adults did worse than the young when flankers were neutral ($F(2,82)=2.91, p=.06$). When the target was sad, there was a significant interaction for flanker emotion by group ($F(2,82)=3.21, p=.05$), with young individuals doing significantly worse on happy flankers. And finally, when the target was neutral, there was a trend for flanker emotion by group ($F(2,82)=3.038, p=.066$) in which the old did worse than the young when flankers were happy, and the young did worse when the flankers were sad.

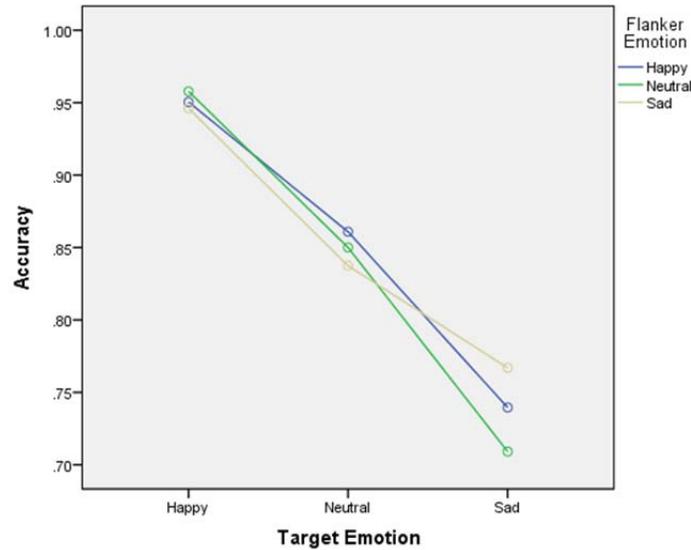


Figure 2. Interaction of Target Emotion x Flanker Emotion on Accuracy for Younger Adults

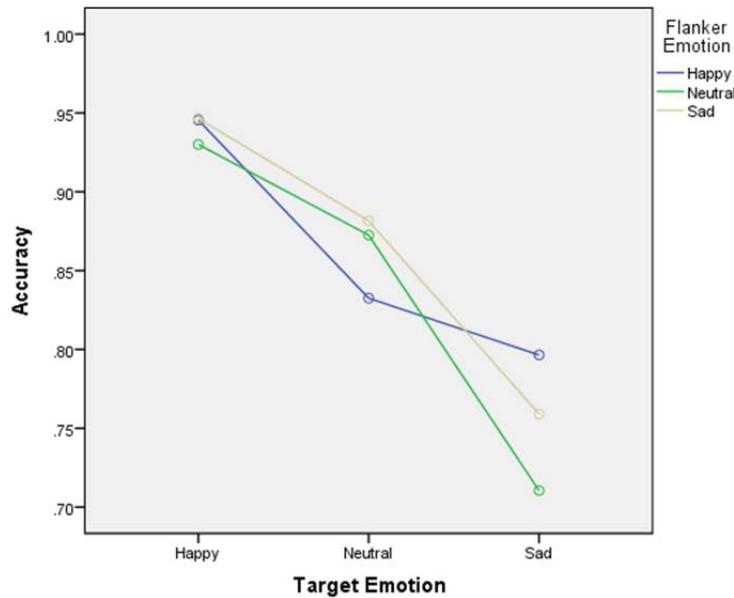


Figure 3. Interaction of Target Emotion x Flanker Emotion on Accuracy for Older Adults

We also hypothesized that there would be age related differences in this task. We predicted that the older adults would show a greater congruency affect (indicating worse selective attention) and greater positivity bias (being significantly more accurate and faster on

trials with a happy target, and significantly less accurate and slower on trials with happy flankers). However, none of these predictions were validated by the results ($F \leq 1$ for all age-related analyses).

Memory Task

We performed a mixed 2x2 ANOVA on memory task data for both accuracy and response time. The two factors were age (old vs. young) and the emotion the face was originally displayed in (happy vs. sad). There was a main effect of original emotion on accuracy ($F(1,41)=13.03, p=.001$). Subjects were significantly more accurate remembering faces that were originally sad (Mean=73.3%, SEM=3) vs. originally happy (Mean=63.2%, SEM=4). There was also an expected main effect of age on accuracy and response time. The older group was significantly less accurate than the younger group ($F(1,41)=6.2, p=.017$) and had significantly slower response times ($F(1,40)=12.34, p=.001$). Means for these measures are presented in Table 4. We expected to also find an interaction effect of original emotion by age on both accuracy and response time—older adults would be significantly more accurate and faster remembering faces that were originally displayed as happy. However, this was not validated; there was no significant interaction between age and original emotion.

Group	Mean (SEM) Accuracy	Mean (SEM) RT
Young	76.8% (4.7)	954 ms (100)
Old	59.7% (5.0)	1749 ms (111)

Table 4. Mean Accuracy and Response Time on Memory Task for Young Vs. Old

ERN

The ERN, in both the letter and face flankers tasks, was defined as the peak amplitude beginning 50 ms pre-response and ending 100 ms post-response. A true ERN would appear as a larger negative peak in this window on error trials. See Figures 4 and 5 for waveforms averaged

by group and trial type (error vs. correct) at the FCz site (the site where the ERN is most prominent) in the letter and face flankers task.

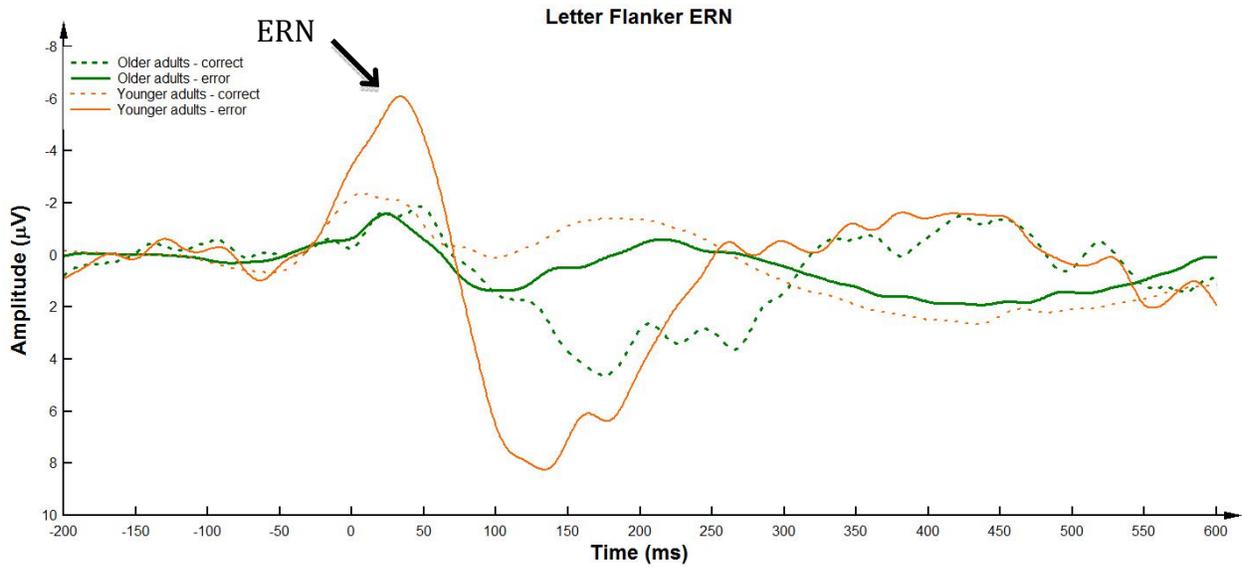


Figure 4. Average waveform for young and old on error and correct trials on the letter flankers task.

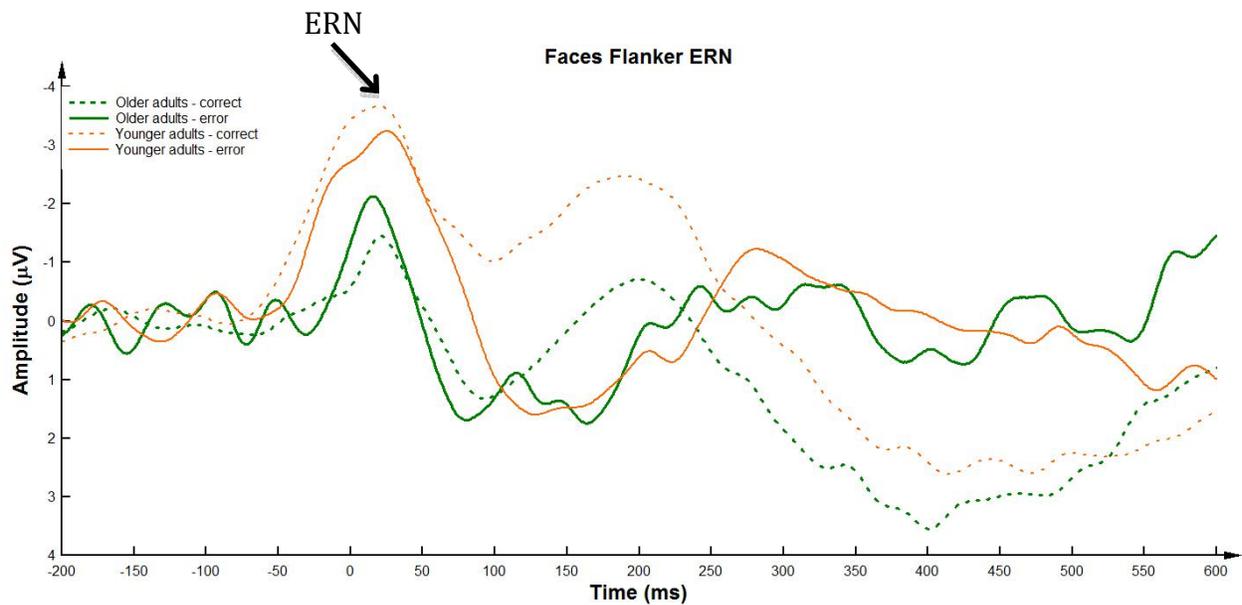


Figure 5. Average waveform for young and old on error and correct trials on the face flankers task.

We ran a mixed 4x2x2 ANOVA on our letters flankers task, with the factors of accuracy (error vs. correct trial), electrode site (Fz, FCz, Cz, Pz), and group (old vs. young). We did see the expected ERN in error-trials for both the young and old group. There was a significantly greater ERN (more negative) on trials where subjects made errors ($F(1,37)=30.7, p<.001$; see Table 5 for means and Figure 4 for waveform). A significant interaction between electrode site and trial type ($F(3,111)=4.5, p=.019$) was also found. This is a typical effect that is often found in the literature (Gehring et al., 2012), in which the ERN is strongest at the FCz site (refer to Table 6 for means). A marginal interaction of electrode site by group was also present ($F(3,111)=3.15, p=.06$; see Table 7). However this result lay outside of the hypotheses and was not further explored.

Trial Type	Mean (SEM) Amplitude of ERN (μ V)
Error	-3.02 μ V (.37)
Correct	-5.78 μ V (.61)

Table 5. Mean ERN Amplitude (in Microvolts) by Trial Type in Letter Flankers Task.

		Site- Mean (SEM) Amplitude of ERN (μ V)			
		Fz	FCz	Cz	Pz
Trial Type	Correct	-2.81 (.33)	-2.96 (.34)	-2.90 (.47)	-3.93 (.50)
	Error	-5.84 (.64)	-6.24 (.69)	-5.67 (.66)	-5.35 (.60)

Table 6. Mean ERN Amplitude by Electrode Site in Letters Flankers Task.

		Site- Mean (SEM) Amplitude of ERN (μV)			
		Fz	FCz	Cz	Pz
Age Group	Young	-4.73 (.59)	-5.57 (.62)	-5.12 (.70)	-4.59 (.70)
	Old	-3.92 (.61)	-3.63 (.64)	-3.45 (.72)	-4.16 (.72)

Table 7. Mean ERN Amplitude by Electrode Site for Young vs. Old in Letter Flankers Task

We also ran a mixed 4x2x2 ANOVA on the face flankers task but were surprised to find no evidence of any ERN at all in either group (see Figure 5 for waveform). There was no difference in ERN amplitude on error versus correct trials ($F(1,37)=2.79, p=.103$). In the analysis of the face flankers task, however, we did find a main effect of electrode ($F(3,111)=5.814, p=.001$; see Table 8 for means), an interaction of electrode site by group ($F(3,111)=5.044, p=.012$; see Table 9 for means), and an interaction between accuracy and electrode ($F(3,111)=4.826, p=.018$; see Table 10 for means). These results were not relevant to the hypotheses, however, and were not explored further.

Electrode Site	Site- Mean (SEM) Amplitude of ERN (μV)
Fz	-4.21 (.66)
FCz	-4.28 (.69)
Cz	-4.05 (.70)
Pz	-3.47 (.67)

Table 8. Mean ERN amplitude by Electrode Site in Face Flankers Task

		Site- Mean (SEM) Amplitude of ERN (μ V)			
		Fz	FCz	Cz	Pz
Age Group	Young	-5.46 (.91)	-5.85 (.96)	-5.49 (.98)	-4.26 (.94)
	Old	-2.95 (.94)	-2.71 (.98)	-2.61 (1.0)	-2.68 (.96)

Table 9. Mean ERN Amplitude by Electrode Site for Young vs. Old in Face Flankers Task

		Site- Mean (SEM) Amplitude of ERN (μ V)			
		Fz	FCz	Cz	Pz
Trial Type	Correct	-3.57 (.51)	-3.76 (.55)	-3.66 (.60)	-3.4 (.60)
	Error	-4.85 (.87)	-4.79 (.89)	-4.44 (.87)	-3.59 (.81)

Table 10. Mean ERN Amplitude by Electrode Site in Face Flankers Task

While previous literature had indicated that older adults should show a reduced ERN compared to younger adults, this prediction was not supported in either the face flankers or letter flankers task. There was no interaction between age and trial type ($F < 1$).

Correlational Analyses

The heart of this study lies in predictions regarding the correlations between these various measures within each age group. For these analyses, a number of variables had to be defined. The ERN was quantified as the peak amplitude in the window -50-150 ms surrounding the response on correct trials minus the amplitude on error trials. The congruency effect was defined as response time on the letter flankers task incongruent trials minus response time on congruent trials. The positivity effect was defined based on the 3-way interaction of target emotion by flanker emotion by group (see Figures 2 and 3). This measure thus incorporated age and emotion related effects and the exact definition was based on the appearance, in Figures 2 and 3,

of a significant difference between older and younger adults' accuracy based on flanker emotion when the target was neutral. Positivity bias was thus indexed as accuracy on neutral target/ sad distracter trials minus accuracy on neutral target/ happy distracter trials. Because both targets were neutral, this measure was a simple comparison of how distracted subjects were by negative vs. positive flankers.

Within the older group, as expected, there was a trend that individuals who scored higher on the MMSE had a larger ERN ($r(19)=.393$, $p=.096$), and a smaller congruency effect ($r(20)=-.409$, $p=.074$). Score on the arithmetic task was also significantly positively correlated with score on the mental control task ($r(20)=.433$, $p=.057$). Surprisingly, the older subjects within the older group seemed to show a smaller congruency effect ($r(19)=-.551$, $p=.014$). Contrary to our predictions, there was no correlation between any of the cognitive measures and our measure of the positivity bias.

Within the younger group there was a trend that those who scored better on the mental control task showed a smaller congruency effect ($r(23)=-.355$, $p=.096$). There was also a trend that those with the largest ERN showed the greatest positivity bias ($r(20)=.419$, $p=.066$). Positivity bias also significantly negatively correlated with the congruency effect—the younger adults who showed the most positivity bias had the smallest congruency effect ($r(23)=-.581$, $p=.004$).

Discussion

This study intended to correlate a number of cognitive control measures with a measure of emotion regulation within older and younger adults. Our fundamental research question was whether or not older adults who are in the best “cognitive shape” are also those who exhibit the greatest preference for positive information. In undertaking this overarching question, we

anticipated seeing a number of age-related effects in various tasks—we expected to see older adults having impaired executive functioning, selective attention, and error-monitoring, and an enhanced positivity bias compared to younger adults. While much of the results did not go in the direction we had anticipated, and we did not see all of the age-related and task-related effects that we would expect, our robust dataset did lead to some interesting conclusions and indicated that at least some of our tasks and measures were effective. In this section, our results will be examined, and potential explanations for results contrary to our hypotheses and past research will be presented along with limitations of this study and potential avenues of future research.

Executive Functioning

In terms of age-related effects on executive-functioning measures, our results did, for the most part, indicate a general cognitive decline in the older adults. While we had intended for our two age groups to have equivalent scores on the MMSE as a baseline level of cognitive capacity (indicating healthy cognitive functioning), the older group that we used for our analyses did end up having marginally lower MMSE scores. However, by employing the MMSE cut-off score of 25, we believe that all of the older adults were cognitively healthy (no signs of dementia), and this slight variation in scores is only indicative of a slightly higher baseline level for the younger adults.

The older group, as predicted, did significantly worse on the Mental Control task than the younger adults. They had an impaired ability to manipulate and recite sequences—they were slower and made more mistakes. While this may indicate impaired cognitive functioning, it is also important to consider the impaired motor coordination of older adults. Their lower scores could just reflect their inability to recite sequences quickly, rather than their inability to process them quickly. Older adults are generally slower than younger adults, and this effect was actually

seen in all tasks involving response time—the older adults were significantly slower than younger adults in the letter flankers task, the emotional flankers task, and the memory task.

While it is impossible to determine if this difference in Mental Control scores is a measure of motor coordination slowing or cognitive slowing, it is an effect that is well documented in the literature and fits with a model of age-related decline.

On the arithmetic task, the older group also did do somewhat worse (as hypothesized), but the difference did not approach statistical significance. This task, standing alone, may have not been the best measure of executive functioning. When administering the task it became clear that some individuals were far more nervous and uncomfortable with being put on the spot than others, and it seemed as though this affected performance. Buelow and Frakey (2013), in fact, did find that levels of math anxiety correlated with performance on the arithmetic portion of the WAIS—people who were more anxious about math did significantly worse on this subtest. It is possible that math anxiety would be confounded between the two age groups because our younger sample consisted exclusively of students who are presumably more accustomed to testing and have taken a course in mathematics more recently. Many individuals also emphasized that they were not good at math, and it is possible that specific deficit doesn't reflect executive functioning generally. It thus seems as though performance on this task might be more correlated with education, math abilities, and anxiety, rather than executive functioning.

The implications of this, in terms of our dataset, aren't clear, but is possible that this helps explain why score on the arithmetic task was not correlated to either the MMSE, mental control, or error-monitoring measures for younger adults. Perhaps, because of younger adults differing anxiety levels or math abilities, this measure did not truly gauge executive functioning and cognitive control (as these other tasks did). However, for older adults, mental control score

and arithmetic score were positively correlated, so perhaps they did not feel the same anxiety. Further, the older adults were all coming from a more similar math level than the younger adults—presumably none of the older adults ever use math, while some of the younger adults may have to use math more regularly than others.

Attention

However, while we did see some of these expected effects of age on executive functioning, we wanted to specifically look at attentional abilities in older adults, and results here did not agree with the hypotheses. The expected task congruency effect in the letter flankers task was evident—participants in both groups were significantly faster and more accurate on congruent trials than incongruent trials, however this was not true in the emotional flankers task. In the emotional flankers task, there was no statistical difference in response time or accuracy on incongruent vs. congruent tasks. Further, we predicted, based on extensive previous literature employing a variety of tasks and dependent measures, that older adults would show impaired selective attention compared to the younger adults, and this prediction was not supported. There was a trending effect of group x trial type for accuracy on the letter flankers task, but the means reveal that the difference lay in older adults worse accuracy on congruent trials (rather than incongruent trials). We thus did not see the expected enhanced congruency effect in older adults—they were no slower or less accurate on incongruent trials (vs. congruent trials) than the younger adults in either the letter flankers task or the emotional flankers task. This violated our expectation that the flanking incongruent information would be more distracting to older adults, who have been shown to be more easily distracted and less attentive than younger adults. While accuracy differences based on age on the flankers task have been disputed in the literature,

studies have universally shown that older adults have slower response times on incongruent trials (Colcombe et al., 2005; Shaw, 1991; Zeef & Kok, 1993), so it is unclear why we did not see this effect.

Error-Monitoring

We did find the expected ERN in the letter flankers task—there was a significantly greater ERN on trials where subjects made errors and a typical significant interaction between electrode site and trial type (the ERN is usually most apparent at the FCz site). This indicates that, in the classic flankers task, subjects understood when they were making an error, activating their automatic error-monitoring system and thus creating this negative-going peak. In the emotional flankers task, however, there was actually no indication of any ERN for either the younger or older adults. There was no negative-going peak after subjects' errors—error trials and correct trials weren't significantly different. This indicates that subjects were incapable of determining whether they were right or wrong on each trial. This is probably due to the design of the emotional flankers task, and is discussed in further detail in the “limitations” section of this paper.

We also expected to see an age-related effect on the ERN. We hypothesized, based on extensive prior literature, that the ERN would be attenuated in the older adults. Because there was no ERN present in the emotional flankers task at all, it is unsurprising that the older adults didn't show a reduced ERN in that context. However, it is extremely surprising that we didn't find this effect in the letters flankers task. While it appears in our average waveform for the letter flankers task as though the older adults had a reduced amplitude ERN, statistically this was

not supported—older adults appear to have been equally effective at monitoring their performance as the younger adults.

This reduced ERN in older adults has been shown consistently in previous research (Endrass et al., 2012; Falkenstein et al., 2001; Mathalon et al., 2003; Matthewson et al., 2005; Nieuwenhuis et al., 2002; Schreiber et al., 2011; West, 2004) and is reflective of older adult's impaired self-monitoring system. It is unclear why we did not find this effect—we employed the same task as many previous studies and had a similar sample. However, there have been a few studies that also did not find a reduced ERN and may give a clue to our results. A study by Eppinger et al. (2008) found no evidence of a reduced ERN in older adults in a learning task where accuracy was equivalent between the two age groups. In most of the studies showing a difference in ERN based on age, there was also a difference in accuracy, so it is possible that the older adults did not show a reduced ERN in this task because they were just as accurate as the younger adults—they had an equally strong representation of what was correct/incorrect.

Pietschmann et al. (2011) also used a learning task and found no evidence of a reduced ERN in their older adults. They concluded, based on their various trial types, that the introduction of time pressure may force older adults to monitor their errors more specifically, and that this is perhaps the cause for their equivalent ERNs. The older adults in our sample did seem to be very pressured by time limits (many noted that they felt as though the letters flashed too quickly). It is also possible that the nature of our task created this effect. Both of these studies that didn't find an attenuated ERN in older adults were learning tasks, and while our task was not intended to be a learning task, the older adults definitely faced a learning curve. Most older adults had to perform multiple practice rounds and only picked up how the task worked

over time. However, neither of these studies gives a definitive explanation for these surprising results, and neither can we.

Positivity Bias

Contrary to our predictions, there was very little indication in either the emotional flankers task or memory task that the older adults showed a true positivity bias. Positive faces were not significantly more distracting as flankers or more compelling as targets for the older adults vs. younger adults. In the memory task, older adults did not remember significantly more of the previously happy faces than the younger adults. In addition to finding no evidence to support the idea that older adults have a positivity bias, there was also no evidence that the younger adults had a negativity bias. They were no more distracted by sad flankers or compelled by sad targets, and they didn't have enhanced memory for the negative faces as compared to the positive faces.

The only potential indication of a positivity effect was a significant 3-way interaction of target emotion x flanker emotion x group on accuracy in the emotional flankers task. When looking just at happy target trials, there was a trend for flanker emotion by group where older adults did worse than the young when flankers were neutral (NHN). When the target was sad, there was a significant interaction for flanker emotion by group, with young individuals doing significantly worse on happy flankers (HSH). And finally, when the target was neutral, there was a trend for flanker emotion by group in which the old did worse than the young when flankers were happy (HNH), and young did worse when the flankers were sad (SNS). This last piece—the trend that older adults did worse with happy flankers and younger adults did worse

with sad flankers—does actually fit with our hypotheses. The older adults seemed to have been more distracted by happy flankers, and the younger adults were more distracted by sad flankers.

Correlational Analysis

The novel aspect of this study lay in examining the relationship between these various measures, and here, the results did not lead to any clear conclusions and did not support our central hypothesis. While we had predicted that, within the older adults, all of our measures of cognitive control (executive functioning, selective attention, error-monitoring) would be positively correlated with one another and with the positivity bias, our results were not this straightforward. Within the older group we found a trend that individuals who scored higher on the MMSE had a larger ERN and a smaller congruency effect. These results all make sense on the grounds that higher MMSE scores, greater ERN, and smaller congruency effect are all associated with greater cognitive control. Score on the arithmetic task was also significantly positively correlated with score on the mental control task, which makes sense considering they are both part of a larger WAIS score and supposed to be measuring the same thing, executive functioning.

Surprisingly, we also found that the older subjects within the older group seemed to show a smaller congruency effect. This is opposite to expectations based on the assumption that the older adults are the less cognitively intact ones (and thus the ones that would be more distracted on incongruent trials). It is unclear why we found this unexpected result, but perhaps we just had a remarkably high-functioning group of very old adults. Also, our critical connection between cognitive control and emotion regulation was not found. Contrary to our predictions, there was no correlation between any of the cognitive measures and our measure of the positivity bias.

This, presumably, is due to issues related to our measure of the positivity bias, and will be further discussed later in this paper.

While our hypotheses were all based within the older group, we also examined correlational relationships within the younger group. Here we found that there was a trend that those who scored better on the mental control task showed a smaller congruency effect. Again, it makes sense that individuals who did better on one measure of cognitive control would also do better on another.

There was also a trend that those with the largest ERN showed the greatest positivity bias. This is actually the result we expected to see in the older adults, and its appearance in the younger group was unexpected and difficult to explain. Why would the younger adults who were better at self-monitoring show a greater positivity effect? The positivity bias was also significantly negatively correlated with the congruency effect—the younger adults who showed the most positivity bias had the smallest congruency effect. This piece of evidence is in line with the previous correlation between ERN and positivity bias. For some reason, the younger adults with more cognitive capacity (as evidenced by larger ERNs and reduced congruency effect) showed the greatest positivity bias (at least by our very specific measure of positivity bias).

While the socioemotional selectivity theory would explain this result in older adults (as being based on a change in motivations due to impending death), it is unclear why higher cognitive functioning younger adults would prefer positive information. Studies have found that the imposition and focus on time-limits and endings has produced a positivity bias in younger adults (Mather & Carstensen, 2003), so perhaps the more highly cognitively functioning younger adults were, for some reason, more focused on endings than the lower cognitively functioning younger adults (maybe the highest functioning were college seniors thinking about graduation).

This relationship between younger adults, cognitive control, and emotion regulation lies outside the scope of this paper, but would certainly be worth further investigation.

Limitations

The emotional flankers task appears to have been a major flaw in this study, and perhaps the key to much of our unexpected results. This exact task set-up had never been used before—it was invented for this study to assess the positivity bias in a new and different way. While the faces employed had been validated, they had never before been used in a flankers type task and there have been no other experiments which have attempted to measure the ERN and positivity bias in a single task. We took a risk in employing this novel task, and, unfortunately, it did not pay off. The task should have been more rigorously designed and screened before implementation because it turned out to be rather confusing to participants.

A great number of subjects, both young and old, told researchers after the testing session that they had a very hard time distinguishing the sad and neutral faces from each other (and that the happy faces were much easier to distinguish). Presumably this is because the happy faces had open mouths showing teeth, while both the sad and neutral faces were closed-mouth, and subjects were given very little time to determine what the target was (250 ms). This conflation of difficulty with emotion is probably the reason why our data from this task was messy and unexpected—there was no congruency effect, no ERN, and no positivity bias. People were confused and didn't understand when they were right or wrong, and speed and accuracy was determined by ease of recognition of the expression (rather than being representative of attentional allocation). Further, this task turned out to really entail automatic processing, and, as previously discussed, there is evidence to suggest that automatic tasks are ineffective in eliciting

the positivity bias (Mather & Carstensen, 2003; Mather & Knight, 2006; Reed & Carstensen, 2012; Samanez-Larkin et al., 2009; Reed & Carstensen, 2012).

In addition to this anecdotal evidence regarding difficulty, our data also support this conclusion. There was a main effect of target emotion on accuracy and response times, with subjects performing significantly better (higher accuracy and faster response times) when targets were happy, and worst when targets were sad. It makes sense that performance was enhanced when the target was happy because that was the easiest face to distinguish—participants only had to quickly recognize that teeth were showing. There was also a trend of flanker emotion affecting accuracy, with subjects doing significantly better when the flankers were sad vs. neutral (perhaps because neutral flankers were so difficult to distinguish from sad targets). We also found a significant interaction effect of target emotion by flanker emotion on accuracy—everyone did worse on trials of sad targets with neutral flankers because these two expressions were so difficult to distinguish.

In the memory task, the data support a main effect of original emotion on accuracy. Subjects were significantly more accurate remembering faces that were originally sad vs. originally happy. It is possible that this is because the responses to trials with happy faces were so automatic that subjects were faster and didn't truly look at the face or encode it to memory. The smile was so salient that they didn't really 'take in' the appearance of the subject at all. On the other hand, because it was hard to distinguish sad from neutral faces, it is possible that subjects spent more time looking at and engraining the negative posers. Perhaps they had to find another way to distinguish the negative and neutral trials, so they focused more on features than affect. All of these results, however, indicate that the emotional flankers task was ineffective in truly eliciting a positivity bias. The conflation of difficulty and emotionality prevents us from

fully understanding why subjects allocated attention as they did, and prevents us from reaching a conclusion about the effect of age on emotional attention allocation.

Suggestions for Future Research

There are a number of ways in which this experiment could be improved upon. The critical component of this study that would need to change is the emotional flankers task. There were a number of issues with this task and a number of ways in which it could potentially be fixed. One possibility would be to employ schematic faces rather than actual photographed posers. A schematic emotional flankers task has successfully been used before to measure the ERN (i.e. Fenske & Eastwood, 2003; Hortsmann et al., 2006). However this type of task has still never been used to assess a positivity bias, and while difficulty certainly would be less confounded with emotionality, Hortsmann et al. (2006) did suspect that perceptual differences in the schematic faces may lead to differences in difficulty. Using posers with closed-mouth smiles would be another option, but again, it would be important to pre-test any new type of measurement of the positivity bias. A “safer” option might just be to use a previously tested measure of the positivity bias that is less automatic. Past studies have employed memory tasks (Mather & Carstensen, 2003), eye-tracking tasks (Mather & Carstensen, 2003), and inhibition of priming tasks (Goeleven et al., 2010), as well as others.

In addition to altering this study to more effectively answer the questions we originally asked, there are a number of other manners in which our research questions could be investigated and expanded upon. Using fMRI, it would be possible to more closely look at the neural basis of cognitive decline in older adults. Specifically, it would be interesting to look at the brain regions responsible for these different aspects of cognitive control. Is the OFC more activated for tasks

involving emotion regulation and the DL-PFC more activated for tasks involving other sorts of cognitive control? Are the individuals with greater OFC activation the individuals with a greater positivity bias? And how does that correlate to DL-PFC activation and other measures of cognitive control?

I also think that this relationship between emotion regulation and cognitive control is implicated in the emotional gut-reaction aspect of the ERN. Is it possible that older adults have reduced ERNs because they have this emotional aspect of error-monitoring under control? Studies have shown that younger adults with anxiety, depression, and OCD (for review see Olvet & Hajcak, 2008), or individuals with a negative affect/emotionality (Luu et al., 2000) have exaggerated ERNs; they are more sensitive to their own errors. On the other hand, perhaps older adults, who are generally more emotionally stable and positive, are insensitive to their own errors (and thus have reduced ERNs). Studies looking at the motivation of older adults to perform correctly and investigate how much they “care” about committing an error, could help shed light on this issue.

Bringing this back to the real-world would also be an important step. How do we apply this knowledge to make older adults happier and functioning at a higher level? I think eventually, with greater understanding of how different brain regions deteriorate in healthy aging, it would be possible to understand what areas need to be protected and what the differences are between healthy and pathological aging. Also, perhaps by looking at the enhanced emotion regulation in older adults, knowledge from this could transfer to an enhanced understanding of younger people’s emotion regulation, and how it could be improved if pathological.

Conclusions

To the best of our knowledge, this is the first study to attempt to correlate a number of different cognitive measures with a measure of the positivity bias within younger and older adults. While we found a number of the expected task and age-related effects (ERN on error trials, congruency effects, impaired executive functioning in older adults), our principal paradigm, the emotional flankers task, was severely confounded by difficulty, and resulting data has to be viewed with skepticism. Because of this, we found no real evidence of a preference for positive information among the older adults, and our subsequent correlational analyses led to no significant conclusions about the relationship between emotion regulation and cognitive control in older adults.

However, while our expectations were not met, this research adds to the field by illuminating potential confounds in a task of attentional allocation to emotional stimuli. With this study, researchers now know that, when looking at naturalistic emotional faces, happiness is significantly easier to determine and could confound a study. Further, while the data did not indicate a relationship between executive functioning and the positivity bias in older adults, it did indicate that this unique and intriguing relationship exists in younger adults, and this deserves further investigation. Are younger adults with greater cognitive power also those who focus more on positive information? The reasons and implications of this could be important and interesting avenues of future research.

References

- Amabile, T. M., & Glazebrook, A. H. (1982). A negativity bias in interpersonal evaluation. *Journal of Experimental Social Psychology, 18*(1), 1-22.
- Amenado, E., & Diaz, F. (1999). Ageing-related changes in the processing of attended and unattended stimuli. *NeuroReport, 10*, 2382-2388.
- Backman, L., Small, B., Wahlin, A., & Larsson, M. (2000). Cognitive functioning in very old age. In F. I. M. Craik & T. A. Salthouse (Eds.), *The Handbook of Aging and Cognition* (499-558). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.
- Braver, T. S., Barch, D. M., Keys, B. A., Carter, C.S., Cohen, J. D., Kaye, J. A... Reed, B. R. (2001). Context processing in older adults: evidence for a theory relating cognitive control to neurobiology in healthy aging. *Journal of Experimental Psychology, 130*, 746-763.
- Buelow, M. T., & Frakey, L. L. (2013). Math Anxiety Differentially Affects WAIS-IV Arithmetic Performance in Undergraduates. *Archives of Clinical Neuropsychology*.
- Carretie, L., Mercado, F., Tapia, M., Hinojosa, J. A. (2001). Emotion, attention, and the 'negativity bias,' studied through event-related potentials. *International Journal of Psychophysiology, 41*, 75-85.
- Carstensen, L. L., & Turk-Charles, S. (1994). The salience of emotion across the adult life span. *Psychology and Aging, 9*, 259-264.
- Carstensen, L. L. (2006). The influence of a sense of time on human development. *Science, 312*, 1913-1915.

- Chao, L. L., & Knight, R. T. (1997). Prefrontal deficits in attention and inhibitory control with aging. *Cerebral Cortex*, 7, 63-69.
- Colcombe, S. J., Kramer, A. F., Erickson, K. I., & Scalf, P. (2005). The implications of cortical recruitment and brain morphology for individual differences in inhibitory function in aging humans. *Psychology and Aging*, 20, 363-375.
- Crandall, J. E. (1975). "Negativity Bias" in Evaluative Ratings. *The Journal of Social Psychology*, 95(1), 109-116.
- Delis, D. C., Kaplan, E., & Kramer, J. H. (2001). *Delis-Kaplan executive function system*. Psychological Corporation.
- Dywan, J., Segalowitz, S. J., & Webster, L. (1998). Source monitoring: ERP evidence for greater reactivity to nontarget information in older adults. *Brain and Cognition*, 36(3), 390-430. Eastwood et al., 2001
- Endrass, T., Klawohn, J., Gruetzmann, R., Ischebeck, M., & Kathmann, N. (2012). Response-related negativities following correct and incorrect responses: Evidence from a temporospatial principal component analysis. *Psychophysiology*, 49, 733-743.
- Engle, R. W., Conway, A. R., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science*, 6(2), 122-125.
- Eppinger, B., Kray, J., Mock, B., & Mecklinger, A. (2008). Better or worse than expected? Aging, learning, and the ERN. *Neuropsychologia*, 46(2), 521-539.
- Fabiani, M., & Friedman, D. (1995). Changes in brain activity patterns in aging: the novelty oddball. *Psychophysiology*, 32(6), 579-594.

- Fabiani, M., Friedman, D., & Cheng, J. C. (1998). Individual differences in P3 scalp distribution in older adults, and their relationship to frontal lobe function. *Psychophysiology*, *35*(06), 698-708.
- Fabiani, M., Low, K. A., Wee, E., Sable, J. J., & Gratton, G. (2006). Reduced suppression or labile memory? Mechanisms of inefficient filtering of irrelevant information in older adults. *Journal of cognitive neuroscience*, *18*(4), 637-650.
- Fabiani, M. (2012). It was the best of times, it was the worst of times: A psychophysiology's view of cognitive aging. *Psychophysiology*.
- Falkenstein, M., Hoormann, J., & Hohnsbein, J. (2001). Changes of error-related ERPs with age. *Experimental brain research. Experimentelle Hirnforschung. Experimentation cerebrale*, *138*(2), 258.
- Fenske, M. J., & Eastwood, J. D. (2003). Modulation of focused attention by faces expressing emotion: evidence from flanker tasks. *Emotion*, *3*(4), 327.
- de Fockert, J. W., Rees, G., Frith, C. D., & Lavie, N. (2001). The role of working memory in visual selective attention. *Science*, *291*(5509), 1803-1806.
- de Fockert, J. W., Ramchurn, A., van Velzen, J., Bergström, Z., & Bunce, D. (2009). Behavioral and ERP evidence of greater distractor processing in old age. *Brain research*, *1282*, 67-73.
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). *Mini-Mental State: a practical method for grading the cognitive state of patients for the clinician*. Pergamon Press.
- Fredrickson, B. L., & Carstensen, L. L. (1990). Choosing social partners: how old age and anticipated endings make people more selective. *Psychology and aging*, *5*(3), 335.

- Fung, H. H., Lai, P., & Ng, R. (2001). Age differences in social preferences among Taiwanese and Mainland Chinese: the role of perceived time. *Psychology and aging, 16*(2), 351.
- Gehring, W. J., Liu, Y., Orr, J. M., & Carp, J. (2012). The error-related negativity (ERN/Ne). *Oxford handbook of event-related potential components, 231-291*.
- Goeleven, E., De Raedt, R., & Dierckx, E. (2010). The positivity effect in older adults: The role of affective interference and inhibition. *Aging & Mental Health, 14*(2), 129-137.
- Gordon, B. A., Rykhlevskaia, E. I., Brumback, C. R., Lee, Y., Elavsky, S., Konopack, J. F., ... & Fabiani, M. (2008). Neuroanatomical correlates of aging, cardiopulmonary fitness level, and education. *Psychophysiology, 45*(5), 825-838.
- Gunning-Dixon, F. M., Gur, R. C., Perkins, A. C., Schroeder, L., Turner, T., Turetsky, B. I., ... & Gur, R. E. (2003). Aged-related differences in brain activation during emotional face processing. *Neurobiology of Aging; Neurobiology of Aging*.
- Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Vol. 22* (pp. 193-225). San Diego, CA: Academic Press.
- Hasher, L., Stoltzfus, E. R., Zacks, R. T., & Rypma, B. (1991). Age and inhibition. *Journal of experimental psychology: Learning, memory, and cognition, 17*(1), 163.
- Hashtroudi, S., Johnson, M. K., & Chrosniak, L. D. (1990). Aging and qualitative characteristics of memories for perceived and imagined complex events. *Psychology and Aging, 5*(1), 119.
- Holroyd, C. B., & Coles, M. G. (2002). The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. *Psychological review, 109*(4), 679.

- Horstmann, G., Borgstedt, K., & Heumann, M. (2006). Flanker effects with faces may depend on perceptual as well as emotional differences. *Emotion; Emotion*, 6(1), 28.
- Isaacowitz, D. M., Toner, K., & Neupert, S. D. (2009). Use of gaze for real-time mood regulation: effects of age and attentional functioning. *Psychology and aging*, 24(4), 989.
- Isaacowitz, D. M., Allard, E. S., Murphy, N. A., & Schlangel, M. (2009). The time course of age-related preferences toward positive and negative stimuli. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 64(2), 188.
- Ito, T. A., Larsen, J. T., Smith, N. K., & Cacioppo, J. T. (1998). Negative information weighs more heavily on the brain: the negativity bias in evaluative categorizations. *Journal of personality and social psychology*, 75(4), 887.
- Kaasinen, V., Vilkmán, H., Hietala, J., Någren, K., Helenius, H., Olsson, H., ... & Rinne, J. O. (2000). Age-related dopamine D2/D3 receptor loss in extrastriatal regions of the human brain. *Neurobiology of aging*, 21(5), 683-688.
- Kerns, J. G., Cohen, J. D., MacDonald III, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science*, 303(5660), 1023-1026.
- Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D.H.J., Hawk, S.T., & van Knippenberg, A. (2010). Presentation and validation of the Radboud Faces Database. *Cognition & Emotion*, 24(8), 1377—1388. DOI: 10.1080/02699930903485076
- Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology: General; Journal of Experimental Psychology: General*, 133(3), 339.

- Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in cognitive sciences*, 9(2), 75-82.
- Luu, P., Collins, P., & Tucker, D. M. (2000). Mood, personality, and self-monitoring: negative affect and emotionality in relation to frontal lobe mechanisms of error monitoring. *Journal of experimental psychology. General*, 129(1), 43-60.
- Mathalon, D. H., Whitfield, S. L., & Ford, J. M. (2003). Anatomy of an error: ERP and fMRI. *Biological psychology*, 64(1), 119-141.
- Mather, M., & Carstensen, L. L. (2003). Aging and attentional biases for emotional faces. *Psychological Science*, 14(5), 409-415.
- Mather, M., & Carstensen, L. L. (2005). Aging and motivated cognition: The positivity effect in attention and memory. *Trends in cognitive sciences*, 9(10), 496-502.
- Mather, M., Knight, M., & McCaffrey, M. (2005). The allure of the alignable: younger and older adults' false memories of choice features. *Journal of Experimental Psychology: General*, 134(1), 38.
- Mather, M., & Knight, M. (2005). Goal-directed memory: the role of cognitive control in older adults' emotional memory. *Psychology and aging*, 20(4), 554.
- Mather, M. (2006). Why memories may become more positive as people age. *Memory and emotion: Interdisciplinary perspectives*, 135-158.
- Mather, M., & Knight, M. R. (2006). Angry faces get noticed quickly: Threat detection is not impaired among older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 61(1), P54-P57.

- Mathewson, K. J., Dywan, J., & Segalowitz, S. J. (2005). Brain bases of error-related ERPs as influenced by age and task. *Biological Psychology*, *70*(2), 88-104.
- Mikels, J. A., Larkin, G. R., Reuter-Lorenz, P. A., & Carstensen, L. L. (2005). Divergent trajectories in the aging mind: changes in working memory for affective versus visual information with age. *Psychology and aging*, *20*(4), 542.
- Nieuwenhuis, S., Ridderinkhof, K. R., Talsma, D., Coles, M. G., Holroyd, C. B., Kok, A., & Van der Molen, M. W. (2002). A computational account of altered error processing in older age: dopamine and the error-related negativity. *Cognitive, Affective, & Behavioral Neuroscience*, *2*(1), 19-36.
- Olvet, D. M., & Hajcak, G. (2008). The error-related negativity (ERN) and psychopathology: Toward an endophenotype. *Clinical psychology review*, *28*(8), 1343-1354.
- Pfefferbaum, A., Sullivan, E. V., Rosenbloom, M. J., Mathalon, D. H., & Lim, K. O. (1998). A controlled study of cortical gray matter and ventricular changes in alcoholic men over a 5-year interval. *Archives of general psychiatry*, *55*(10), 905.
- Pietschmann, M., Endrass, T., & Kathmann, N. (2011). Age-related alterations in performance monitoring during and after learning. *Neurobiology of aging*, *32*(7), 1320-1330.
- Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings.
- Reed, A. E., & Carstensen, L. L. (2012). The theory behind the age-related positivity effect. *Frontiers in Psychology*, *3*, 339.
- Roldán-Tapia, L., García, J., Cánovas, R., & León, I. (2012). Cognitive reserve, age, and their relation to attentional and executive functions. *Applied Neuropsychology*, *19*(1), 2-8.

Samanez-Larkin, G. R., Robertson, E. R., Mikels, J. A., Carstensen, L. L., & Gotlib, I. H. (2009).

Selective attention to emotion in the aging brain. *Psychology and Aging; Psychology and Aging*, 24(3), 519.

Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential

mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology: General*, 132(4), 566.

Salthouse, T. A. (2010). Selective review of cognitive aging. *Journal of the International*

neuropsychological Society, 16(5), 754.

Schreiber, M., Pietschmann, M., Kathmann, N., & Endrass, T. (2011). ERP correlates of

performance monitoring in elderly. *Brain and cognition*, 76(1), 131-139.

Shaw, R. J. (1991). Age-related increases in the effects of automatic semantic activation.

Psychology and aging, 6(4), 595.

Smith, N. K., Cacioppo, J. T., Larsen, J. T., & Chartrand, T. L. (2003). May I have your attention,

please: Electrocortical responses to positive and negative stimuli. *Neuropsychologia*, 41(2), 171-183.

St Jacques, P., Dolcos, F., & Cabeza, R. (2010). Effects of aging on functional connectivity of

the amygdala during negative evaluation: A network analysis of fMRI data. *Neurobiology of aging*, 31(2), 315-327.

Tisserand, D. J., & Jolles, J. (2003). Special issue on the involvement of prefrontal networks in

cognitive ageing. *Cortex*, 39, 1107-1128.

Vaish, A., Grossmann, T., & Woodward, A. (2008). Not all emotions are created equal: the

negativity bias in social-emotional development. *Psychological bulletin*, 134(3), 383.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging.

Psychological bulletin, 120(2), 272.

West, R., & Alain, C. (1999). Event-related neural activity associated with the Stroop task.

Cognitive Brain Research, 8(2), 157-164.

West, R., & Alain, C. (2000). Age-related decline in inhibitory control contributes to the increased Stroop effect observed in older adults. *Psychophysiology*, 37(2), 179-189.

West, R. (2004). The effects of aging on controlled attention and conflict processing in the Stroop task. *Journal of Cognitive Neuroscience*, 16(1), 103-113.

Williams, L. M., Brown, K. J., Palmer, D., Liddell, B. J., Kemp, A. H., Olivieri, G., ... & Gordon, E. (2006). The mellow years?: Neural basis of improving emotional stability over age. *The Journal of Neuroscience*, 26(24), 6422-6430.

World Health Organization. March 28, 2012. Interesting facts about ageing. Retrieved from: <http://www.who.int/ageing/about/facts/en/index.html>.

Zeef, E. J., & Kok, A. (1993). Age-related differences in the timing of stimulus and response processes during visual selective attention: Performance and psychophysiological analyses. *Psychophysiology*, 30(2), 138-151.