

***Mindfulness Disposition and Cognitive and Emotional Control in Older Adults: A  
Conceptual Review***

***THESIS***

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By

Pilar Angeline Abando De Leon, B.S.

Graduate Program in Psychology

The Ohio State University

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Master's Examination Committee:

Dr. Ruchika Shaurya Prakash, Advisor

Dr. Michael Vasey

Dr. Andrew Leber

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## *Abstract*

Controlled regulatory processes involve systematic means of adjusting psychophysiological functioning according to external or internal directives. In the process of developmental maturation, this ability to regulate thoughts and emotions in a controlled manner deteriorates, and with it, the overall quality of life. The study of mindfulness disposition as an inter- and intra-individual variable has recently garnered significant attention, with mounting evidence supporting the association of trait mindfulness with various cognitive, emotional, and most recently, neural health benefits. These findings, however, have been predominantly limited to young adults, and it is poorly understood what the effects of mindfulness disposition are in relation to older adults' cognitive, affective, and neural processes. In the current work, we present a comprehensive review of how cognitive and emotional control change, behaviorally and neurally, as a function of age and examine how a mindfulness-based model may have the potential to counteract such nuanced age-related alterations in controlled regulatory processing. By developing more refined methods of examining age-related changes in cognitive, affective, and neural functioning, we move closer towards understanding the complex controlled regulatory processes of the brain and our potential ability to protect them by harnessing basic, pre-existing neuroprotective resources.

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## *Vita*

2006.....Fenton High School, Bensenville, IL  
2010.....B.S., University of Illinois, Urbana-Champaign, IL

## Publications

- Spielberg, J.M., **De Leon, A.A.**, Heller, W., Bredemeier, K., Engels, A.S., Warren, S.L., Crocker, L.D., Sutton, B.P., & Miller, G.A. (In Press). Habituation to negative stimuli distinguishes types of anxiety. *Brain and Behavior*
- Ryan, K.A., Hammers, D., **De Leon, A.A.**, Biden, H., Frey, K., Burke, J., Albin, R., Giordani, G. (In Press). Agreement among neuropsychological and behavioral data and PiB findings in diagnosing Frontotemporal Dementia. *Neuropsychology*
- Prakash, R.S., **De Leon, A.A.**, Mourany, L., Lee, H., Voss, M.W., Boot, W.R., Basak, C., Fabiani, M., Gratton, G. & Kramer, A.F. (2012). Examining neural correlates of skill acquisition in a complex videogame training program. *Frontiers in Human Neuroscience*.
- Prakash, R.S., **De Leon, A.A.**, Klatt, M., Malarkey, W., & Patterson, B. (2012). Mindfulness disposition and default- mode network connectivity: Implications for perseverative cognition. *Social, Cognitive, and Affective Neuroscience*.
- Prakash, R.S, **De Leon, A.A**, Rolley, K., Malarkey, W., Patterson, B., & Klatt, M. (In Review). Mindfulness disposition and neural correlates of emotion perception. *Cognitive, Affective, and Behavioral Neuroscience*.

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## ***Chapter 1: Introduction***

The process of aging signifies a remarkable metamorphosis of the human brain. Gradual alterations in the structural and functional neuroanatomy of the brain over the course of a lifetime culminate in fundamental changes in qualitative day-to-day functioning. In the U.S., the aging of the baby boomer generation has not only instigated an increase in the resources and services devoted to older people, but has also given rise to the specialized field of gerontology research. A central focus of this field of work lies in securing the quality of life of older adults, a large-scale endeavor which involves first, transliterating the elements of human vitality into primitive, remediable processes of controlled, regulatory behavior and secondly, developing strategies by which to support or strengthen the age-related break-downs associated with such processes in old age. Controlled regulatory processes involve systematic means of adjusting psychophysiological functioning according to external or internal directives. In an important sense, controlled processing represents the pinnacle of complex and intelligent human behavior, allowing for flexible, dynamic action and influencing the individual's ability to subjectively experience, react to, and interact with the natural world and its day-to-day happenings,

The centerpiece of controlled regulatory processing is differentiated into two complementary processes, cognitive control and emotional control. Although cognitive and emotional processes have been traditionally construed as separate and independent, the former involving mental operations such as planning and problem-solving and the latter pertaining to the psychophysiological generation and regulation of mood and affect, extensive research suggests that on various levels, the two are inextricably linked, mainly separated only by the affective significance of the given stimulus to the system. For example, whereas a failure of cognitive control may take the form of context-inappropriate behavior, such as reading a word when instructions dictate that one should only name the ink color in which the word is printed, impaired emotional regulation may be represented as an inability to suppress a fear response even after the emotion-eliciting event has long passed. Because the neural basis of controlled regulatory processing involves a complex of top-down and bottom-up pathways that are mutually engaged and influenced by emotional and cognitive processes, the relationship between cognition and emotion is by extension a reciprocal and interdependent one. Indeed, various studies have provided evidence of a direct correspondence between poor affective functioning and subsequent impairment in cognitive control performance, as is often noted in cases of anxiety and depression (Langenecker, 2006). Increasingly, cognitive and emotional control are being recognized as complementary regulatory control processes that locally function in tandem but yet follow divergent functional trajectories with age. A multitude of studies have documented the paradoxical emergence of age-related enhancement in



emotional efficacy in the midst of general diminishment in overall cognitive functioning. What is clear is that, given the integrated mental architecture shared by emotion-cognition processes, older adults' aptitude for emotion regulation represents an opportunity to harness enhanced abilities in one domain to bolster deficits in other related areas.

With the expectations of what older adults believe they should be capable of steadily rising, especially in the context of today's increasingly complex environment, a critical understanding of the mechanistic organization of cognitive and emotional functioning and their potential flexibility across the developmental lifespan represents the core of current investigative efforts to better classify, understand, and counteract overall age-related declines in functioning. The present work reviews current literature in the aging field regarding cognitive and emotional functioning in older adults and presents a novel mindfulness-based model for conceptualizing the relationship between mindfulness and emotion-cognition control processes and its subsequent implications for the dynamics of brain functioning in the elderly. The following sections recapitulate the neuroscience field's most current understanding of (1) cognitive control, (2) emotional control, (3) the changes incurred in each sub-process as a function of age, and (4) the general amenability of such regulatory control processes to neuroplastic enrichment.

### **Dual-Systems Model of Controlled Regulatory Processes**

In psychology, the most prominent accounts of human behavior involve a dual-process model. According to these accounts, the determinants of behavior are based on

two different modes of information processing, which, although recognized by varying terms, such as spontaneous vs. deliberate (Fazio, 1999), automatic vs. controlled (Schiffrin & Schneider, 1977), proactive vs. reactive (Braver & Cohen, 2001), and hot vs. cool (Metcalf & Mischel, 1999), refer to two discrete modes of cognition, one being slow, deliberate, and effortful, and the other being fast, automatic, and impulsive. Whereas the controlled mode of processing involves the overcoming of reflexive habits and the generation of new action plans in different situations, the automatic mode of processing is thought to be conditionally triggered by certain situational factors, affective evaluations, and/or select behavioral tendencies. Control processes, whether cognitive or emotional in nature, are subject to the same set of external and internal contingencies and operate in the same basic fashion. A study by Hoffman and colleagues (2008) demonstrated that the automatic personality trait of angeriness, characterizing an individual's tendency to associate the self with the emotional concept of angeriness was predictive of the degree of negative social feedback in a provoking situation for individuals low in working memory capacity but not those that were high. This study suggests that, consistent with the dual-process view, automatic and controlled precursors compete with another for behavior determination and that the greater the ability to retain a single representation in a quickly retrievable state (i.e., working memory capacity), the more successful one is in inhibiting the influence of automatic precursors and maintaining self-regulatory standards which may then be used for goal-directed emotional regulation (Hoffman et al. 2008). Thus, in this review, we present the

interrelated processes of cognitive control and emotional control as parallel branches of the dual-processing model, each varying slightly in its particular function, but ultimately sharing a common neurocognitive mechanism of operation.

**Cognitive control.** The construct of cognitive control involves a set of executive control functions that enable information processing and behavior to vary flexibly and adaptively on a moment-to-moment basis according to current goals. Historically, the development of cognitive control capacity has been characterized by a linear function from infancy to adolescence, but with advanced stages of aging, this trend may be more accurately depicted as an inverted parabola, with older adults showing pronounced declines in cognitive control processes. One of the most consistent findings in cognitive aging research is the presence of a breadth of cognitive deficits in older adults, including learning, episodic memory, working memory, and inhibition (Park & Reuter-Lorenz, 2009). Newer work indicates that general cognitive dysfunction in the elderly may actually be rooted in a core age-related deficiency in controlled cognitive processes. Governing these higher-order cognitive processes is an integral cognitive control component, the functional impairment of which, whether through aging, neurodegenerative disease, or traumatic brain injury, results in compromised executive functioning (Unsworth et al., 2012). Successful performance in many cognitive contexts, including everyday situations in our complex environment, is inherently linked, to varying degree, to our ability to selectively and purposefully direct behavior towards a given outcome or goal. Such cognitive control processes, based on the internal

representation of contextual or task-related goals, enable the supersedence of automatic responses in favor of less salient, task-related goals.

Extant theories of executive functioning suggest that the cognitive control system largely enacts the active maintenance of contextual or goal-related information and inhibition of pre-potent, goal-irrelevant representations and responses via working memory processes (Braver et al., 2007; Gray et al., 2003). Working memory, reflecting the “ability to simultaneously maintain and process goal-relevant information,” is associated with the suppression of reflexive responses, avoidance of distracting stimuli, and rapid focusing of attention (Conway & Engle, 1996). Working memory capacity is particularly critical in situations involving various relevant distracters and/or automatic behaviors which conflict with goal behavior. Inter- and intra-individual differences in working memory have been shown to be a strong predictor of various cognitive abilities, including language comprehension, fluid intelligence, and learning (Kane & Engle, 2003). According to the goal-maintenance account of controlled processing, the core of this critical working memory system is a controlled-attention component, which is thought to account for the association between working memory measures and complex, higher-order cognitive processes (Kane & Engle, 2003).

The controlled-attention component of working memory, the underlying mechanism upon which cognitive control operations appears to be reliant, has been associated with the active maintenance of goals or contexts and functions to appropriately bias responses towards a goal state (Kane & Engle, 2003). Context here can be broadly

thought of as a subset of representations which can influence how other representations are to be used to guide behavior (e.g., instructions, a cue, previous stimuli) (Braver et al., 2007). While inhibitory mechanisms are thought to play an important role in the suppression of irrelevant information and overriding of automatic behaviors (Gerard et al., 1991), newer research proposes that effective cognitive control is more likely dually determined, the successful execution of controlled processing involving not just competition resolution, but goal maintenance (i.e., the maintenance of contextual information) as well. It is suggested that the operation of the controlled-attention mechanism is fundamentally contingent on the immediate accessibility of goal information. In the context of a classic cognitive control paradigm such as the Stroop task, for example, the resolution of attentional interference appears to rely on a series of hierarchical goal abstractions (i.e., the active maintenance of “intention”, Braver & Cohen, 1999). Supporting this view, research indicates that individuals with higher working memory capacity are better at both maintaining goal-related information as well as resolving conflicting responses in interference-rich situations (Rednick and Engle, 2011). Thus, the goal-maintenance account of cognitive control insists that the function of working memory extends beyond the mere preservation of contextual representations of external stimuli, encompassing the maintenance of internal goal representations and action plans as well.

Abundant neuropsychological and neurophysiological evidence suggests the prefrontal cortex (PFC), a brain region critically involved in working memory, to be one

of the main neural corollaries of higher-order cognitive control (Norman & Shallice, 1986; Shallice, 1982; Shallice, 1988; Baddeley, 1986). The diminished functionality of the lateral PFC has long been known to underlie behavioral tendencies of goal neglect in clinical and non-clinical populations, from patients with severe frontal damage to healthy individuals with lower general fluid intelligence (Mesulam, 2002; Duncan, 1995). In the context-processing theory of cognitive control (Braver, 2000), the PFC plays a key role in controlled processing. This model of cognitive control hinges on three main assertions: 1) the PFC is specialized for the representation and maintenance of context information; 2) context representations act to mediate control by modulating information flow along the pathways required to support performance of a task; and 3) context information is maintained in the PFC as a stable and self-sustaining pattern of neural activity. Contrary to the classic Baddeley model of working memory (Baddeley, 1986), the context-processing view makes the radical assertion that the representation and storage of contextual information, the critical components underlying cognitive control, are actually neurobiologically integrated (not separate) functions subserved by the PFC (context here merely representing a key component of working memory). The PFC is suggested to both represent and actively maintain contextual, goal-relevant information, with PFC-mediated goal representations in working memory serving to influence the transcription of contextual representations into appropriate, goal-driven behavior (Braver & Cohen, 2001).

The successful exercise of control over thought and behavior is accomplished through the PFC's exertion of top-down control on the posterior and subcortical brain regions involved in task-specific processing based on online goal representations (Miller & Cohen, 2001; Tamber-Rosenau et al., 2011). Specifically, the lateral PFC (LPFC) is associated with the representational coding of temporal context and internal behavioral goals; the storage and maintenance of contextual representations in a highly accessible form; and the down-stream biasing of activity in other cortical regions involved in task-specific processes, such as action selection and memory retrieval. Here, the PFC's unique ability to bias the information processing stream as well as preparatory behavior in a top-down fashion based on current goals/context is depicted as an emergent by-product of the large-scale neural interactions between the PFC and various other neurobiological components with specialized processing functions (Braver et al., 2007). The concerted activity of the PFC and areas such as the anterior cingulate cortex (ACC), involved in interference detection, the posterior cortex, involved in the selective processing of sensory information and storage of domain-specific knowledge, and medial temporal lobe (MTL) structures, involved in associative binding and memory consolidation, enable the production of context-specific, goal-relevant behavior (Braver & Cohen, 2001).

In summary, the hierarchy of cognitive processes associated with executive function is operationally linked to the integrity of the working memory system and its specific capacity to dynamically maintain and process contextual, goal-related

information. Thus, it is suggested that the concept of cognitive control, the ability to engage in goal-driven behavior, is fundamentally reliant on the individual's initial capacity to actively sustain intention throughout a period of time. Studies indicate that this ability, governed by the controlled-attention component of working memory and primarily housed in the PFC, plays a critical role in a subset of various cognitive functions.

**Emotional control.** In conjunction with controlled cognitive processing, the ability to exert effective control over emotional experiences represents a biologically adaptive and psychologically constructive exercise of self-regulation. In the dual-process model of controlled regulatory processing, the modulation of emotion is particularly delicate, as affective regulation, unlike pure cognitive control processing, involves individual managing outward behavioral expression as well as internal subjective experience. In emotional control too, the line between effective and ineffective regulation is less clear than in studies of cognitive control. Emotion regulation, referring to the individual capacity to change the subjective experience of emotion, including the temporal context in which it is experienced as well as the intensity and behavioral expression of that emotion (Gross, 1998), has important implications for decision-making, social functioning, psychopathological development, homeostatic processes, and overall quality of life. The process model of emotion dictates that the emotion-generative process begins with the evaluation of an emotional cue, which thereby triggers a set of physiological, psychological, and behavioral response tendencies (Gross, 2003). At any



time point during this multi-level cascade process, a number of emotion regulation strategies may be employed to modulate the experiential outcome associated with the emotion-eliciting event. To the extent that emotional responding is changed based on attentional redirection or a reinterpretation of emotion-eliciting situations, emotional regulation has been thought of as being conceptually linked to cognitive control. In fact, according to process models of emotion regulation, the most powerful forms of emotion regulation indeed involve the cognitive control of emotion (McRae et al., 2012). Emotional control may therefore be understood as a regulatory mechanism utilizing a variable combination of attentional control and cognitive change, processes localized to the same distributed neural system (Ochsner, 2005). Thus, although regulatory strategies differ from emotional suppression to cognitive reappraisal of the situation to response-focused coping, evidence suggests that the functional architecture recruited in emotional control remains the same, namely involving many of the same areas that support controlled cognitive processing.

The neural circuitry of emotional processing involves key regions of the frontal cortex, specifically the mPFC and dlPFC, as well as subcortical structures such as the amygdala and other association cortices. The established structural and functional connections between this frontal-based top-down network and subcortical bottom-up processing system represent the integrated neural infrastructure through which emotional responses are generated, coordinated, and modulated based on the allocation of cognitive resources. A failure in either system, resulting in either an amplification of the emotional

cue's saliency or a failure to appropriately dampen emotional reactivity, may be sufficient to impede the successful deployment of emotional control. The amygdala, responsible for the automatic detection of emotions and the generation of physiological responses, is associated with emotional reactivity and plays an important role in processing salient, goal-relevant information. Numerous studies have shown that this structure not only supports the recognition of emotional facial expressions in day-to-day social contexts, but also modulates the encoding of declarative knowledge related to affective stimuli (Adolphs, 1999). In psychopathological conditions like anxiety which involve a heightened sensitivity to threat and an excessive fear response, the amygdala displays a dysfunctional pattern of activation, showing enhanced activation in response to affective stimuli as well as a failure to habituate over time (Blair, 2003). Studies in emotion research further indicate that amygdala dysfunction is also generally accompanied by an impairment of the orbitofrontal cortex (OFC), a region sharing extensive projections with the amygdala and playing a critical role in the affective representation of reinforcers and decision-making. Coupled with increased sustained activation of the amygdala is also the disrupted functioning of frontal cognitive-control regions like the dlPFC. With decreased top-down prefrontal activation, excessive limbic activity is left unchecked, thereby further supporting the monopolization of cognitive resources by the reflexive, bottom-up system associated with visceral reactivity. Through this interactive process, the effective exercise of emotional control is rendered ineffective (Rosenkranz et al., 2003).

In studies of emotional control, a prominent area of interest involves determining whether effective emotion regulation involves altering the low-level, bottom-up system of automatic processing or focusing on enhancing higher-level, top-down networks involved in cognitive reappraisal. To evaluate the relative contributions of top-down vs. bottom-up processes, a study by Ochsner and colleagues (2009) utilized a more nuanced method of studying emotional processes. By using a combination of aversive images (bottom-up trials) and neutral images that required cognitive reinterpretation as negative (top-down trials), this study found evidence suggesting that the generation of emotion utilizes separate but closely related mechanisms of top-down and bottom-up processing. Here, the amygdala is coactive with either the top-down system, used to access higher-level cognitive representations of the stimuli's meaning, or with the bottom-up system involved in processing perceptual representations of the stimuli. Consistent with the dual-process model of emotional control, findings imply that neither a purely bottom-up nor a purely top-down mechanism of control, but instead, a combination of both are needed to fully explain the generation of emotion and determine its effective regulation. Thus, in parsing apart these two related pathways of emotional control, the present study, as will be described, argues for the use of an emotional paradigm that involves both top-down and bottom-up mechanisms.

## ***Chapter 2: Cognitive and Emotional Control in Older Adults***

While sharing an integrated neuroarchitecture and operating using a similar dual-process system, cognitive and emotional control, when studied in the context of aging, is remarkably divergent. A paradox that has long perplexed the aging research field is the emergence of an age-related enhancement in emotional efficacy in the midst of general diminishment in basic cognitive functioning. It appears that, at the peak of human development, cognitive control capacity is at its greatest whereas emotion regulation ability is at its lowest, and that this trend is interestingly reversed with advanced age. The following sections review in detail this pattern of change in emotional and cognitive functioning in older adults, concluding with a consideration for how this age-related advantage in the emotional functioning of the elderly may be utilized to bolster evident deficits in cognitive functioning.

### **Cognitive Aging**

Emerging theories of healthy cognitive aging suggest that age-related variation in cognitive functioning is fundamentally linked to aging-based deficiencies in cognitive control (Braver et al., 2008; De Jong, 2001). There has been unequivocal evidence demonstrating that older adults, in comparison to young adults, consistently demonstrate poorer executive control capabilities, showing marked deficits in the ability to maintain task items online and/or quickly and accurately manipulate information (Goh, 2012; Park

& Reuter-Lorenz, 2009). Cross-sectional and longitudinal research confirm that older adults experience difficulty performing tasks that require attending and responding to multiple sources of information, with age-related declines in executive processes occurring around 30 years of age and declining steadily across the lifespan (Park & Reuter-Lorenz, 2009).

In describing the root cause of age-related cognitive control decline, a unified theory of cognitive aging by Gazzaley and colleagues suggests that impairments in controlled cognitive processing arise from a disturbance in the top-down processing stream, caused by the intrusion of internal or external stimuli, or simply put, a general intrusion in goal maintenance (Gazzaley et al., 2005). At the interface of bottom-up, involving externally-generated information, and top-down, involving internally-generated information, processes lies the locus of cognitive control (Sarter et al., 2001), with failures of controlled cognitive processing being linked to the top-down control system's vulnerability to interference, resulting in either reflexive, bottom-up predominant processing or a default, goal-irrelevant mode of cognition (Smallwood et al., 2011). Sustained attention or goal maintenance involves a component of selectivity, reflecting the ability to focus on relevant stimuli while ignoring irrelevant stimuli. Thus, a breakdown in active goal maintenance invariably results in a compromised working memory system, which corresponds to impaired attentional filtering and reduced goal-directed behavior, expressed as increased cognitive engagement with other free-floating internal

thoughts (i.e., failure to focus, associated with mind-wandering) or external, irrelevant stimuli in the environment (i.e., failure to ignore, associated with response conflict).

Consistent with the latter case, Gazzaley and colleagues specified a model of cognitive aging in which age-related deficits in the cognitive control of working memory are based on a fragile, error-prone goal-maintenance system that is biased towards irrelevant contextual information (Gazzaley et al., 2005). Healthy aging is herein conceptualized as a problem in which the attentional filtering of older adults becomes increasingly diffuse so as to include not only relevant stimuli, but extraneous irrelevant stimuli as well. A number of functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG) studies report a selective deficit in the ability of older adults to ignore or suppress task-unrelated information, with evidence for enhanced memory of distractor stimuli as well as attentional overprocessing of task-irrelevant information, which strongly correlates with diminished working memory performance (Gazzaley et al., 2005). In as far as goal maintenance represents a process of resistance to attentional interference, findings implicate that cognitive control decline in the elderly is indeed a problem of impaired top-down modulation, specifically in relation to the component associated with the controlled-attention mechanism of working memory.

This is also largely consistent with general findings concerning the neurobiological underpinnings of cognitive control. The theory of context-processing in aging suggests that controlled processing in older adults becomes increasingly vulnerable to disruption over time due to age-related declines in PFC functioning (Braver & Barch,

2002). The structural and functional deterioration of the PFC in older adults is indeed one of the most consistently-reported findings in aging research. In older adults, the diminished ability for top-down modulation of irrelevant information is reflected by a general pattern of enhanced cortical activation in frontal regions. On tasks of cognitive control, for example, older adults, relative to young, demonstrate cortical overactivation in areas of the task-positive Cognitive Control Network (CCN), comprised of dorsolateral prefrontal cortex (DLPFC), inferior parietal cortex, and supplementary motor areas (Reuter-Lorenz et al., 2000; Cabeza et al., 2004), which is involved in goal-directed behavior. Moreover, older adults show a failure to modulate neural activity in these areas in response to increased task demands (Reuter-Lorenz et al., 2006; Prakash et al., 2009), suggesting a general deficiency and inflexibility in the utilization of PFC-based cognitive control resources (Reuter-Lorenz & Park, 2010).

Furthermore, older adults exhibit age-related changes in the overall spatial distribution of neural activation during cognitive control tasks. Specifically, older individuals show an increase in PFC activity, along with diminished activity in more posterior regions, collectively termed the Posterior-to-Anterior Shift in Aging (PASA; Davis, 2008). Studies have suggested that the coupling of age-related frontal overactivation with attenuated activity in occipito-temporal regions may be indicative of a compensatory strategy of cortical recruitment, wherein anterior brain regions are recruited to compensate for the sensory processing deficits in more posterior regions which are consistently associated with aging. However, in light of the context-processing

theory of cognitive control, this phenomenon could be reasonably reframed as being associated with an early disruption in goal maintenance, which at the time of probe presentation, results in a failure to appropriately activate associative-sensory posterior regions in preparation for organized action. This may ultimately lead to a prolonged, effortful, and augmented recruitment of prefrontal regions in an effort to reactivate contextual information (Velanova et al., 2007).

This is also consistent with what has been described as the problem of “the stickiness of processing” (Clapp et al., 2011), which suggests that aging is associated with difficulty in disengaging from irrelevant, distracting stimuli and reestablishing task-set maintenance after interference. Recent fMRI research provides evidence to suggest that during a scene-based delayed recognition task with an embedded interruption by a face-based secondary task, older adults, but not young adults, showed a failure to disengage from the interrupting stimulus and an inability to reestablish functional connections associated with the original stimulus (Clapp et al., 2011). The study found that in older adults the functional connectivity between a region of the PFC, the middle frontal gyrus, and the parahippocampal place area, responsible for processing place information, once interrupted, was never recovered, suggesting older adults’ diminished ability to reactivate internal representations and to dynamically switch between functional brain networks involved in cognitive control. New evidence also suggests that such functional changes in the organization of cognitive control processes take place independent of intrinsic changes in sensory regions, implying that susceptibility to



cognitive control impairment likely lies in the top-down control system and its functional integrity (A. Gazzaley, September 25, 2012).

Corroborating evidence suggests that age-related shifts in the patterns of local brain activity and connectivity associated with cognitive control are paralleled by interesting age-related changes in the temporal dynamics of controlled processing. Velanova and colleagues (2007) found evidence of a temporally-extended response in the PFC of older adults, relative to young adults, during a controlled processing task. Specifically, older adults showed a failure to engage top-down attentional sets during early stages of a memory retrieval process, along with an increased recruitment of PFC regions during later stages. Findings suggested an age-related shift from an early- to late-onset cognitive control strategy in older adults, wherein the failure of older adults to effectively filter incoming information resulted in an increased cognitive load at later processing stages. The aging brain, therefore, appears to be less effective at implementing early-selection processes during controlled processing, which leads to a shift in the reliance on elaborative late-selection processes. New research suggests that this temporal lag in neural activity is not constrained to cognitive control, but also occurs with memory retrieval (Early-to-late-shift-in-aging; Dew et al., 2011).

In sum, age-related declines in cognitive functioning appear to follow a systematic, mechanistic pattern of change that can largely be related to general alternations in frontal-based cognitive control processes. These involve but are not limited to (1) increased reliance on frontal cognitive-control-related regions, (2)

diminished activity in posterior sensory-processing regions, and (3) the utilization of a temporally-lagged, late-onset strategy in older adults during controlled cognitive processing. Thus, the phenomenon of age-related cognitive decline encompasses a variety of dynamic age-related changes in neural functioning, all of which can be linked to a fundamental impairment in cognitive control, and perhaps more specifically, the capacity for goal-relevant task-set maintenance.

The Dual Mechanisms of Cognitive Control provides a computational connectionist model of the neural dynamics of cognitive control, one capable of theoretically integrating empirical findings regarding the general trend of age-related shifts in cognitive functioning so frequently observed in the aging brain (Braver et al., 2007). This model advances a more nuanced view of age-related variation in cognitive control, one which posits a shift in older adults' reliance on different types of cognitive control strategies, rather than a global diminishment of controlled processes throughout aging, a view which cognitive aging research has traditionally espoused. The dual mechanisms of control (DMC) account explicitly frames older adults' impaired ability to engage in efficient, preparatory processes in terms of an age-related shift from a proactive mode of cognitive control (a cognitive strategy reflective of a top-down bias and characterized by preparatory attention and a strong goal-relevant focus) to a reactive mode (a cognitive strategy reflective of a bottom-up reactivation of task-goals and characterized by increased goal-irrelevant processing and late correction), especially during the processing of high cognitive demand events (e.g., interference resolution).

Unlike some models of cognitive control, the DMC framework provides strong age-specific predictions about expected behavioral patterns as well as associated neural and temporal dynamics based on the documented proactive-reactive shift in aging.

Proactive control, if engaged, involves maintaining task goals over trials to enhance early selection of task-appropriate stimuli. Efficient performance, as evident in fast reaction times (RTs) and highly accurate performance, should reflect successful recruitment of proactive control. By contrast, slow trials predominantly reflect “last moment” recruitment of reactive control and are expected to be associated with decreased accuracy compared to fast trials.

At a neural level, this mode of control is associated with an anticipatory and sustained activation of the LPFC at the onset of the imperative stimulus. In contrast, reactive control, reflecting a systematic bias and recurrent processing of bottom-up inputs, is behaviorally linked to longer response times but high accuracy. Neurally, this mode is associated with the activation of the anterior cingulate cortex (ACC) and a latent and transitory activation of the LPFC and other medial temporal lobe (MTL) structures.

In fact, this finding is one of the most consistent in the cognitive aging literature. A well-known delayed-response task designed to differentiate between the two control strategies is the AX-CPT, a modified version of the classic Continuous Performance Test (CPT) (Rosvold et al., 1956) which requires the maintenance of probe goals in the context of cues. In this task, participants are presented with cue-probe pairs and instructed to make a target response to the X-probe, but only when it follows an A-cue

(AX). On all other trials, nontarget responses are required. “AX” trials occur with high frequency (70%), with all other nontarget trials occurring in low frequency (10% frequency for “AY”, “BX”, and “BY” sequences, respectively), such that the A-cue and X-probe become strongly associated. Based on this design, two types of biases are induced to examine the utilization of contextual cues to update task goals. First, “AY” trials introduce an expectancy bias which leads to a context-induced error and a tendency to make false alarms when the target A-cue is followed by a nontarget probe (“Y” instead of “X”). Secondly, “BX” trials involve a target response bias which leads to a tendency to make a prepotent response when an X-probe follows a non-A-cue (“B” instead of “A”). Consistent with the theoretical age-related shift from a proactive control strategy, where response is mediated by cue, to a reactive control strategy, where response is mediated by the probe, older adults show a pattern of errors that suggests a failure to take advantage of cue information and a tendency to instead wait for the target. A study by Paxton (2008) demonstrated that activation in lateral PFC regions associated with goal maintenance during cue-related trials was diminished in older adults, whereas during probe-related trials, activity in these same regions was enhanced.

These findings are complemented by a number of investigations examining the functional and temporal dynamics of cognitive control. For example, recent work has suggested that over the course of highly controlled cognitive tasks, older adults demonstrate a behavioral tendency to shift from an early- to late-onset executive strategy (ELSA). Based on a combined blocked/event-related design, Paxton and colleagues

(2008) revealed enhanced sustained (i.e., across-trial) activity but a reduction in transient trial-related activation in LPFC among older adults, suggesting that age-related impairments in goal maintenance abilities may cause a compensatory shift in older adults from a proactive to a reactive cognitive control strategy (Paxton et al., 2008).

In summary, aging appears to be associated with a less efficient reactive-control mode of processing (Braver & Barch, 2002). Older adults' impaired ability to actively maintain representations of context, corresponding to an increased susceptibility to intrusive goal-irrelevant information, ultimately leads to a behaviorally-inappropriate and/or temporally protracted response. The DCM theory outlines a view of cognitive aging in which changes in higher-order cognitive processes emerge as a product of relative variation in controlled-processing. This model of cognitive aging is relatively compatible with other theories of aging, including the well-known inhibitory deficit account of aging (Hasher and Zacks, 1998) and the theory of attentional control deficiency in aging (Balota et al., 2000), which implies that failures of cognitive control can be more simply reduced to a fundamental failure in selecting and maintaining an appropriate goal or task-set (De Jong, 2001). It is proposed that, at a basic level, aging involves a neurocognitive shift in preferential cognitive control strategy such that older adults appear to experience a reduction in their mental attunement to the demands of their immediate environment. What remains to be explored is whether this systematic shift in cognitive aging is associated with certain stable intra-individual differences, which may

be comparable to the variation in control strategy observed as a function of motivational orientation, arousal level, and proneness to anxiety (Braver et al., 2007).

### **Emotional Aging**

A lifespan analysis of emotion suggests that despite a pervasive pattern of impairment in cognitive, sensory, and motor capabilities, aging is associated with the preservation of emotional processing abilities. In fact, older adults, relative to young adults, demonstrate greater emotional stability (Carstensen et al. 1999) as well as higher levels of affective well-being (Carstensen et al., 2011; Charles et al., 2007). Research suggests that older adults may experience increased motivation to regulate emotion (Kennedy et al., 2004) and that they are generally better at utilizing and adapting regulation strategies according to the stressor (Blanchard-Fields, 2007). Findings also support the idea that aging may be associated with a diminished capacity to exert control over one's environment, thus, older adults may be inclined to modify their self-views through the use of emotion regulation to adjust to a given situation, rather than attempting to alter the situation itself (Heckhausen & Schulz, 1995). One of the most highly-accepted theories for the paradoxical increase in emotional well-being during old age is the socioemotional selectivity theory (Carstensen, 1995), which posits that it is the shift in time perspective that leads older adults to place greater importance on emotional goals and to pay attention to the affective significance of information. Specifically, while young adults may perceive time as being more expansive, older adults, since they are closer to the perceived end of life, appear to be more focused on optimizing and enriching

their emotional experience. Indeed, older adults, relative to young, have been showed to be more likely to focus on the emotional meaning of information as well as how a particular experience makes them feel (Mather & Carstensen, 2005).

In recent years, affective neuroscience has provided a platform for understanding this variation in terms of age-related differences in the neural bases of emotion regulation. The Fronto-amygdalar Age-related Differences in Emotion (FADE, St. Jacques et al., 2009) theory, for one, has outlined a unified theory of older adults' enhanced affective functioning based on a mechanistic, age-related shift in the interaction between the key neural regions involved in emotional processing. The FADE account suggests that the superior emotional regulation associated with the aging brain is reflected by reduced amygdala activation, coupled with increased recruitment of the frontal cortex, particularly the medial and lateral areas of the prefrontal cortex, during the perception of negative emotional stimuli. This converges with the findings of a number of neuroimaging studies reporting concurrent age-related alterations in the activity of the mPFC with that of the amygdala during emotional processing in older adults. Consistent with the idea that emotional well-being in older age is associated with a shift from automatic processing to more controlled processing of emotion via the recruitment of the mPFC (Williams et al., 2006), studies have shown an age-related increase in mPFC recruitment during the perception of negative pictures in comparison to neutral pictures (St Jacques et al., 2009; Williams, et al., 2006). Meanwhile other studies report that older adults, relative to young, exhibit diminished activation of the amygdala in response to

negative affective stimuli. Collectively, findings suggest that aging is associated with diminished subcortical activation in the face of negative stimuli, along with increased activation of cortical areas involved in executive control (Samanez-Larkin, & Carstensen, 2012). Given the synergistic relationship between emotional and cognitive control processes and the paradoxical divergence in older adults' functional trajectory in these respective domains (i.e., older adults' reduced cognitive abilities on the one hand, and enhanced emotion regulation abilities on the other), the next step in aging research appears to involve not only identifying the ways in which emotional and cognitive control processes work in concert, but also implementing strategies to promote a synergistic enhancement of emotion-cognition functions in the elderly.

### **Mindfulness**

For many decades, researchers have investigated various strategies for enhancing cognitive functioning in older adults (Edwards et al, 2002; Kramer & Erickson, 2007; Noice et al., 2008; Verhaeghen et al., 1992; Willis et al., 2006). In the field of aging research, this investigation has led to the exploration of alternative, more holistic strategies for remediating age-related cognitive decline, recently culminating in a renewed interest in the Eastern-based practice of mindfulness as an effective and generalizable form of attentional training. Considered to be the conceptual antithesis to mind-wandering or goal neglect (Mrzaek, 2012), the construct of mindfulness is characterized by a purposeful, non-judgmental manner of paying attention and relating to the mind, body, and immediate experience, and may be empirically measured in both



state and trait dimensions. Substantial research in the health field has advocated the efficacy of mindfulness, indexed in both forms, in a variety of medical, social, educational, intercultural, and age group populations (Kabat-Zinn, 2003). Mindfulness, as will be shown in this section, strengthens the neural circuitry of emotion-cognition interactions as well as enhances the critical resting-state system which underlies the functionality of the two inter-related networks. From this standpoint, the study of mindfulness appears to be uniquely capable of modifying not only the neuroarchitecture associated with controlled regulatory processing, but also the elementary infrastructure on which the brain's baseline functioning is contingent. In fact, a burgeoning body of work provides evidence suggesting that mindfulness may serve as a powerful and dynamic neuroprotective factor in overall functioning.

The ability of mindfulness to capitalize on the integrated neuroarchitecture of emotion-cognition interactions by engaging the frontal executive system during purely cognitive, performance-focused, organization-related activities, such as keeping in mind a list of to-do items during the workday, as well as during more spontaneous, hasty, emotionally-evocative encounters in day-to-day life, such as maintaining a sense of calm during unexpected traffic rather than reacting with automatic irritation, makes it a particularly versatile form of attentional training. Unlike traditional cognitive training paradigms whose exercise of cognitive control abilities is narrowly circumscribed to a given training session, mindfulness is dynamic, continually used to access and train cognitive control regions in both cognition-based and emotion-eliciting contexts.

One primary avenue for the efficacy of mindfulness in targeting inhibitory control processes during purely cognitive tasks may be its promotion of single-minded goal-maintenance in the face of internal disruptions or interruptions. Mindfulness disposition, characterized by (1) the self-regulation of attention and (2) focal orientation to present moment experiences, is thought to effectively promote cognitive control by fundamentally reducing cognitive vulnerability to reactive modes of mind (Bishop, 2002). The present-focused attention, characteristic of individuals high in trait mindfulness may, thus, theoretically serve to prime a neurocognitive mode of consciously-controlled, preparatory, goal-relevant information processing. A main component of mindfulness disposition involves the tendency to regulate affective experiences, which includes recognizing ongoing emotional states, experiencing them fully in an accepting, non-judgmental manner, and then mentally distancing or detaching from the emotional experience. As a result, trait mindfulness is associated with a diminished tendency to routinely react to and engage with transitory thoughts, physical sensations, and attention-provoking stimuli, theoretically promoting control over reflexive mental tendencies during day-to-day situations.

As noted earlier, working-memory-capacity-related differences in goal neglect, such as the internal or external intrusions frequently experienced by older adults during challenging cognitive control tasks, may be due in part to variation in the control of conscious thought. In as far as goal-neglect errors and related differences in working memory capacity during cognitive control performance have been suggested to stem in

part from momentary failures of conscious thought control (Kane & Engle, 2003), individual differences in mindfulness disposition might be theorized to directly relate to the controlled-attention component (i.e., the goal-maintenance component of the cognitive control of working memory), the successful functioning of which is thought to directly support proactive control strategies. To this end, trait mindfulness is hypothesized to be associated with increased moment-to-moment awareness by virtue of its habitual promotion of goal-directed, controlled processing (Cahn & Polich, 2006). By continuously exercising the selective direction of attention, individuals with higher levels of mindfulness disposition are predicted to demonstrate an enhanced ability to sustain cognitive focus on task-relevant dimensions (i.e., ability to focus) and reduce distraction from automatic, goal-irrelevant representations and responses (i.e., ability to ignore) (Mrazek et al., 2012; Smallwood et al., 2004).

Several studies have in fact shown that higher levels of mindfulness appear to be related to enhanced attentional abilities, including attention orienting (Fan et al., 2005), selective attention (Tang et al., 2007), sustained attention (Chambers et al., 2008) and working memory capacity (Jha et al., 2010; Chambers et al., 2008). Formal mindfulness training programs too have been successful in enhancing information processing abilities (Zeidan et al., 2010) and promoting cognitive flexibility (Moore & Malinowski, 2009). Furthermore, complementary neuroimaging research has provided greater insight into the nature of mindfulness-induced enhancements of cognitive control and associated changes in the structure and function of the brain (e.g. Davidson et al., 2000; Jha et al., 2007;

Lazar et al., 2005; Xiong & Doraiswamy, 2009). Evidence from cross-sectional MRI studies, for example, suggest a relationship between mindfulness disposition and enhanced functioning of cortical areas associated with higher-level cognitive control, particularly key areas of the Cognitive Control Network, including the PFC, as well as improved functional integrity of key large-scale brain networks.

Besides promoting enhanced cognitive control through the purposeful exercising of top-down inhibitory control strategies during cognitive performance situations, mindfulness also serves to strengthen the executive system shared by emotion-cognition processes by simultaneously training emotional regulation abilities. In much the same way as the presence of psychopathology hampers controlled cognitive processing, enhancing general emotion regulation skills too translates to improvements in cognitive control functioning. Mindfulness, involving an attitudinal orientation of curiosity, openness, and acceptance, has been linked to emotional intelligence in its shared focus on perceptual clarity to one's emotional state (Salovey et al., 1990). A number of studies have in fact attributed the efficacy of mindfulness in reducing symptoms of stress and negative affect to its capacity to modify emotion regulation abilities (Chambers et al., 2008), with evidence suggesting that emotion regulation is directly engaged during the active performance of mindful exercises (Bishop et al., 2002). By enhancing behavioral self-regulation (Lykins & Baer, 2009) and reducing the routine tendency to emotionally react to transitory thoughts and physical sensations (Ramel et al., 2004; Teasdale et al., 2000), mindfulness practice is thought to decrease negative affect, stress, and mood

disturbance (Brown & Ryan 2003), and protect against symptoms of anxiety and depression, including worry (Prakash et al., 2012). In fact, core components of mindfulness have been integrated into clinical usage in therapeutic models ranging from Dialectical Behavioral Therapy (Linehan, 1994) to Mindfulness-based Cognitive Therapy (Segal et al., 2002).

Complementary MRI studies show evidence suggesting that mindfulness training acts on ventral frontal cortical networks involved in regulating the interplay between the representation of emotion and executive function. Studies have shown that mindfulness may strengthen the functionality of such cognitive control areas by engaging effortful emotion regulation (Macrae et al., 2004). By regulating the flow of information from memory and associative systems to those involved in the internal representation of goals and self-knowledge, mindfulness effectively engages regions like the MPFC during emotional control processes (Kring et al., 2011). In regularly activating these frontal neural regions, during strict cognitive control performance as well as in situations requiring more subtle, spontaneous regulation of emotion, mindfulness strengthens the interconnected corollaries of emotion-cognition processes, thereby enhancing executive functioning on the whole. This is especially significant when considered in light of evidence suggesting that older adults are more adept at emotion regulation tasks than purely cognitive control tasks. By providing more than one route, one of those pathways already being optimally utilized by older adults in the deployment of controlled cognitive processes, to tap into the neural circuitry of cognitive control, mindfulness allows for

greater flexibility and more effectively promotes regular practice in day-to-day life. Thus, in the context of cognitive rehabilitation, mindfulness, using a multi-pronged approach to engaging top-down control regions, appears to represent an especially promising means of buffering age-related decline in cognitive control.

In reviewing the evidence presented thus far regarding the capacity of mindfulness to improve awareness of present thoughts through attentional regulation and interoceptive awareness, it seems reasonable to speculate that mindfulness disposition would not only enhance cognitive control operations by boosting the capacity for conscious, top-down control, but would also reduce engagement in extraneous, goal-unrelated thoughts in the first place. In other words, mindfulness may effectively promote cognitive control in a two-fold manner, (1) by increasing the strength of the goal maintenance signal and (2) reducing the interfering presence of goal-irrelevant noise. In fact, mounting research points to the ability of mindfulness disposition to enhance the functional dedifferentiation of the brain's critical large-scale networks. The Default-Mode Network (DMN), comprised of medial cortical regions, including the precuneus, posterior cingulate cortex (PCC), medial prefrontal cortex (MPFC), and lateral parietal and temporal regions, shares a unique antithetical relationship with cognitive control regions such that the up-regulation of activity in frontoexecutive areas during task performance is accompanied by a concomitant suppression of activity in the default network (i.e., task-induced deactivation; Kelly et al., 2008). The constant, dynamic balance between these two neural systems presumably reflects the brain's vacillation

between different modes of information processing (Buckner, 2008), the DMN putatively involved in internal, self-referential processes related to endogenous attention (Mayer et al., 2010) and the task-positive cognitive control network in exogenous, goal-directed attention during cognitive performance. Evidence has linked the anticorrelational relationship between the DMN and TPN with general cognitive functioning (Kelly et al., 2008; Uddin et al., 2009), with research findings suggesting that appropriate balance of activity between both networks is critical for effective controlled processing. Studies indicate that the DMN has the capacity to modulate activity in task-positive areas involved in controlled cognitive processes (Uddin et al., 2009) and that the intrinsic coherence of the default system directly influences the magnitude of activity in such cognitive control regions (Mennes et al., 2010).

A study of age-related differences in DMN suppression during a task of increasing working memory load (Prakash et al., 2012) found that during task performance, older adults failed to suppress these cortical regions that were unrelated to the task, and that the impaired ability to inhibit activation of default regions was associated with poor behavioral performance, providing empirical evidence for the context-appropriate activity of this network for behavioral performance. In another independent line of research, a study from our lab demonstrated that older adults, relative to young, showed reduced negative correlations between regions of the DMN and those of the cognitive control network, signifying the critical deterioration of older adults'

ability to dynamically coordinate and modulate the crucial large-scale networks of the brain in response to the demands of the external environment.

Given the critical impact of DMN integrity on executive control processes and the age-related decreases in DMN activity and connectivity, an effective means of mitigating age-related cognitive decline involves not only enhancing neural activity during cognitive control operations, but also effectively increasing the connectivity strength of the different resting-state networks supporting cognitive functioning. In another preliminary study from our lab, we examined the putative impact of an eight-week mindfulness intervention on the plasticity of such large-scale networks in a group of older adults. The study, involving 25 older adults who were randomized to either a mindfulness training group or an active control group, showed that mindfulness was associated with an increase in the dedifferentiation between the two large-scale networks of the elderly, such that individuals in the mindfulness group showed increased negative correlations between regions of the DMN and cortical areas comprising the fronto-executive (FE) network involved in cognitive control. Given its capacity to effectively increase the dedifferentiation between two of the brain's most critical large-scale networks in relation to cognition, a clear marker of enhanced functional integrity, mindfulness signifies a promising avenue to improving controlled cognitive processing.

Taken together, preliminary results highlight the instrumental value of mindfulness as a pre-existing neuroprotective factor with the potential to improve controlled processing, both emotional and cognitive, in the elderly. This is particularly



significant when considering that to date, the majority of aging researchers have been relatively unsuccessful in mitigating cognitive impairment through a direct targeting of executive control abilities. Though the aging brain has considerable capacity for cognitive flexibility and neural reorganization, it appears that purely cognition-focused efforts have limited efficacy in actually improving the functional status of older adults (Park et al., 2009). Perhaps by contextualizing the monolithic construct of cognition within a unified framework of higher-order, regulatory control processes based on basic emotion-cognition interactions, it may be possible to circuitously improve cognitive functioning in the elderly. Mindfulness is not only uniquely and naturally effective in directly enhancing the operative processes involved in cognitive control, but through its concurrent strengthening of emotional functioning, it also boasts the capacity to exploit the neuroaffective advantage latent in older adults and thereby, enhance in an indirect manner the integrated neural architecture underlying emotion-cognition processes.

### *Chapter 3: Discussion*

Despite the successful outcomes associated with mindfulness, the study of the neurocognitive benefits of mindfulness in the elderly has been relatively scant. While a number of studies have assessed trait mindfulness and its impact on neurocognitive processes, these effects have been largely limited to a population of younger adults, and it is poorly understood what the effects of mindfulness disposition are in relation to older adults' cognitive and emotional control processes. Promising preliminary research from our lab indicates that mindfulness may help mitigate age-related declines in cognition and bolster emotional functioning. In order to better understand the nature of such mindfulness-related improvements in the controlled regulatory processing of the aging brain, it would be necessary to investigate the impact of mindfulness disposition on the cognitive, emotional, and neural functioning of a group of older adults. Future work would benefit from specifically examining how mindfulness disposition in older adults impacts (1) cognitive control, (2) affective functioning, and (3) the neural circuitry associated with cognitive and emotional regulation, as inferred from the activation patterns associated with attentional, affective, and resting-state cortical networks.

The unique capacity for flexible, consciously-controlled, dynamic behavior distinguishes the human species from all others, providing us with the seeds of adaptability and creativity and granting us a communicable sense of free will and a

degree of control over the environment. In the process of developmental maturation, this ability to regulate thoughts and emotions in a controlled manner deteriorates, and with it, the overall quality of life. In the current work, we present a comprehensive review of how cognitive and emotional control change, behaviorally and neurally, as a function of age and examine how a mindfulness-based model may have the potential to counteract such nuanced age-related alterations in controlled regulatory processing. It is hoped that the comprehensive review provided in this paper may be somehow used to guide future investigations of emotion-cognition processes in the elderly. By developing more refined methods of examining age-related changes in cognitive, affective, and neural functioning, we move closer towards understanding the complex metamorphosis of the aging brain and our powerful role in relationship to it.

## *References*

- Adolphs, R., Russell, J.A., & Tranel, D. A role for the human amygdala in recognizing emotional arousal from unpleasant stimuli (1999). *Psychological Science*, 10, 167-171. doi: 10.1111/1467-9280.00126.
- Baddeley, A. D. (1986). *Working Memory*. New York: Oxford University Press.
- Balota, D. A., Dolan, P. O., & Duchek, J. M. (2000). Memory changes in healthy older adults. In E. Tulving & F. I. M. Craik (Eds.), *The Oxford Handbook of Memory*. New York: Oxford University Press.
- Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can Training in a Real-Time Strategy Videogame Attenuate Cognitive Decline in Older Adults? . *Psychology and Aging*, 23, 765-777.
- Beckmann, C. F., Jenkinson, M., & Smith, S. M. (2003). General multilevel linear modeling for group analysis in fMRI. *NeuroImage*, 20(2), 1052-1063. doi: 10.1016/S1053-8119(03)00435-X.
- Bishop, S.R. (2002). What do we really know about mindfulness-based stress reduction? *Psychosomatic Medicine*, 64, 71-83.
- Blair, J.R.R. Neurobiological basis of psychopathy (2003). *The British Journal of Psychiatry*, 182, 5-7. doi:10.1192/bjp.182.1.5.
- Blanchard-Fields, F. (2007). Everyday problem solving and emotion: An adult developmental perspective. *Current Directions in Psychological Science*, 16, 26 –31.
- Botvinick, M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, 108, 624–652.
- Boynton, G. M., Engel, S. A., Glover, G. H., & Heeger, D. J. (1996). Linear systems analysis of functional magnetic resonance imaging in human V1. *Journal of Neuroscience*, 16(13), 4207-4221. doi: no doi
- Braver, T. S., & Barch, D. M. (2002). A theory of cognitive control, aging cognition, and

- neuromodulation. *Neuroscience and Biobehavioral Reviews*, 26, 809-817.
- Braver, T. S., & Cohen, J. D. (1999). Dopamine, cognitive control, and schizophrenia: The gating model. *Progress in Brain Research*, 121, 327-349.
- Braver, T.S. & Cohen, J.D. (2000). On the control of control: the role of dopamine in regulating prefrontal function and working memory. In *Attention and Performance* (Vol. XVIII) (Monsell, S. and Driver, J., eds), pp. 713-738, MIT Press
- Braver, T. S., & Cohen, J. D. (2001). Working memory, cognitive control, and the prefrontal cortex: computational and empirical studies. *Cognitive Processing*, 2, 25-55.
- Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake & J. N. Towse (Eds.), *Variation in Working Memory* (pp. 76-106): Oxford University Press.
- Braver, T. S., & West, R. F. (2008). Working memory, executive control, and aging. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 311-372). New York: Psychology Press.
- Brown, K. W., & Ryan, R. M. (2003). The benefits of being present: Mindfulness and its role in psychological well-being. *Journal of Personality and Social Psychology*, 84, 822-848.
- Buckner, R. L., Goodman, J., Burock, M., Rotte, M., Koustall, M., Schacter, D. L., . . . Dale, A. M. (1998). Functional anatomic correlates of object priming in humans revealed by rapid presentation event-related fMRI. *Neuron*, 20(2), 285-296. doi: 10.1016/S0896-6273(00)80456-0
- Buckner RL, Andrews-Hanna JR, Schacter DL. 2008. The Brain's default network: Anatomy, function, and relevance to disease. *Ann N Y Acad Sci* 1124:1-38.
- Bugg, J.M., Jacoby, L.L., & Toth, J.P. (2008). Multiple levels of control in the stroop. *Memory and Cognition*, 36, 1484-1494.
- Cabeza, R., Daselaar, S. M., Dolcos, F., Prince, S. E., Budde, M., & Nyberg, L. (2004). Task-independent and task-specific age effects on brain activity during working memory, visual attention and episodic retrieval. *Cerebral Cortex*, 14(4), 364-375. doi: 10.1093/cercor/bhg133.

- Carstensen, Laura L.; Isaacowitz, Derek M.; Charles, Susan T. (1999). Taking time seriously: A theory of socioemotional selectivity. *American Psychologist*, 54(3), 165-181. doi: 10.1037/0003-066X.54.3.165
- Carstensen, L. L. (1995). Evidence for a life-span theory of socioemotional selectivity. *Current Directions in Psychological Science*, 4, 151–156.
- Carstensen, Laura L.; Turan, Bulent; Scheibe, Susanne; Ram, Nilam; Ersner-Hershfield, Hal; Samanez-Larkin, Gregory R.; Brooks, Kathryn P.; Nesselroade, John R. (2011). Emotional experience improves with age: Evidence based on over 10 years of experience sampling. *Psychology and Aging*, 26(1), 21-33. doi: 10.1037/a0021285
- Cahn, B.R., & Polich, J. (2006). Meditation states and traits: EEG, ERP, and neuroimaging studies. *Psychological Bulletin*, 132, 180-211.
- Chambers, R., Lo, B.C.Y., & Allen, N.B. (2008). The impact of intensive mindfulness training on attentional control, cognitive style, and affect. *Cognitive Therapy Research*, 32, 303-322.
- Charles, S. T., & Carstensen, L. L. (2007). Emotion regulation and aging. In J. J. Gross (Ed.), *Handbook of Emotion Regulation*. New York: Guilford Press.
- Clapp, W. C., Rubens, M. T., Sabharwal, J., & Gazzaley, A. (2011). Deficit in switching between functional brain networks underlies the impact of multitasking on working memory in older adults. *Proceedings of the National Academy of Sciences USA*, 108, 7212-7217.
- Conway, A. R. A., & Engle, R. W. (1996). Individual differences in working memory capacity: More evidence for a general capacity theory. *Memory*, 4, 577-590.
- Crump, J.C.M., Vaquero, J.M.M., & Milliken, B. (2008). Context-specific learning and control: the roles of awareness, task relevance, and relative salience. *Consciousness and Cognition*, 17, 22-36.
- Dale, A. M., & Buckner, R. L. (1997). Selective averaging of rapidly presented individual trials using fMRI. *Human Brain Mapping*, 5(5), 329-340. doi: 10.1002/(SICI)1097-0193(1997)5:5<329::AID-HBM1>3.0.CO;2-5.
- Davis, S. W., Dennis, N. A., Daselaar, S. M., Fleck, M. S., & Cabeza, R. (2008). Que PASA? The posterior-anterior shift in aging. *Cerebral Cortex*, 18(5), 1201-1209. doi:

10.1093/cercor/bhm155.

Davidson, R.J., D.C. Jackson & N.H. Kalin. 2000. Emotion, plasticity, context, and regulation: perspectives from affective neuroscience. *Psychological Bulletin*, 126, 890–909

De Jong, R. (2001). Adult age differences in goal activation and goal maintenance. *European Journal of Cognitive Psychology*, 1-2, 71-89.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, 18, 193-222. doi: 10.1146/annurev.ne.18.030195.001205

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, 18, 193-222 doi: 10.1146/annurev.ne.18.030195.001205

Dew, I. T. Z., Buchler, N., Dobbins, I. G., & Cabeza, R. (2011). Where is ELSA? The early to late shift in aging. *Cerebral Cortex*, 22, 2542-2553.

Edwards, J. D., Wadley, V. G., Myers, R. S., Roenker, D. L., Cissell, G. M., & Ball, K. K. (2002). Transfer of a speed of processing intervention to near and far cognitive functions. *Gerontology*, 48, 329-340.

Fan, J., McClelland, B. D., Fossella, J., Flombaum, J. I., & Posner, M. I. (2005). The activation of attentional networks. *NeuroImage*, 26, 471-479. doi: 10.1016/j.neuroimage.2005.02.004.

Fazio, R. H., & Towles-Schwen, T. (1999). The MODE model of attitude-behavior processes. In S. Chaiken & Y. Trope (Eds.), *Dual process theories in social psychology* (pp. 97-116). New York: Guilford.

Gazzaley, A., Cooney, J. W., Rissman, J., & D'Esposito, M. (2005). Top-down suppression deficit underlies working memory impairment in normal aging. *Nature Neuroscience*, 8(10), 1298-1300. doi: 10.1038/nn1543.

Gazzaley, A., & Nobre, A. C. (2012). Top-down modulation: bridging selective attention and working memory. *Trends in Cognitive Sciences*, 16, 129-135.

Gazzaley, A. (2012). *Top-down modulation deficit in the aging brain-an emerging theory of cognitive aging*. Lecture presented at The Ohio State University.

- Gerard, L., Zacks, R. T., Hasher, L., & Radvansky, G. A. (1991). Age deficits in retrieval: The fan effect. *Journal of Gerontology: Psychological Sciences*, 46, P131-P136.
- Goh, J. O., An, Y., & Resnick, S. M. (2012). Differential trajectories of age-related changes in components of executive and memory processes. *Psychology and Aging*, 27, 707-719.
- Good, C. D., Johnsrude, I., Ashburner, J., Henson, R. N., Friston, K. J., & Frackowiak, R. S. J. (2001a). Cerebral asymmetry and the effects of sex and handedness on brain structure: A voxel-based morphometric analysis of 465 normal adult human brains. *NeuroImage*, 14(3), 685-700. doi: 10.1006/nimg.2001.0857
- Good, C. D., Johnsrude, I. S., Ashburner, J., Henson, R. N., Friston, K. J., & Frackowiak, R. S. (2001b). A voxel- based morphometric study of ageing in 465 normal adult human brains. *NeuroImage*, 14(1 pt. 1), 21-36. doi: 10.1006/nimg.2001.0786
- Gray, N. S., Snowden, R. J., Peoples, M., Hemsley, D. R., & Gray, J. A. (2003). A demonstration of within-subjects latent inhibition in the human: limitations and advantages. *Behavioural Brain Research*, 138, 1-8.
- Gross, J. Antecedent- and Response-Focused Emotion Regulation: Divergent consequences for experience, expression, and physiology (1998). *Journal of Personality and Social Psychology*, 74, 224-237.
- Gross, J.J. & John, O.P. Individual differences in two emotion regulation processes: implications for affect, relationships, and well-being (2003). *Journal of Personality and Social Psychology*, 85, 248-262.
- Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension and aging: a review and new view. In H. H. Bowerm (Ed.), *The Psychology of Learning and Motivation* (pp. 193-225). New York: Academic Press.
- Heckhausen, Jutta; Schulz, Richard. A life-span theory of control (1995). *Psychological Review*, 102 (2), 1995, 284-304.
- Hofmann, W., Gschwendner, T., Friese, M., Wiers, R.W., & Schmitt, M. Working Memory Capacity and Self-Regulatory Behavior: Toward an Individual Differences Perspective on Behavior Determination by Automatic Versus Controlled Processes (2008). *Journal of Personality and Social Psychology*, 95, 962-977.
- Hutchison, K. A. (2007). Attentional control and the relatedness proportion effect in semantic priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 33,



645– 662. doi:10.1037/0278-7393.33.4.645.

- Jenkinson, M., Bannister, P., Brady, M., & Smith, S. (2002). Improved optimization for the robust and accurate linear registration and motion correction of brain images. *NeuroImage*, 17(2), 825-841. doi: 10.1006/nimg.2002.1132.
- Jha, A.P., Stanley, E.A., Kiyonaga, A., Wong, L., & Gelfand, L. (2010). Examining the protective effects of mindfulness training on working memory capacity and affective experience in a military cohort. *Emotion*, 10, 54-64.
- Jha, A.P., Krompinger, J. Baime, M.J. (2007). Mindfulness training modifies subsystems of attention. *Cognitive and Affective Behavioral Neuroscience*, 7,109–119.
- Jongenelis, K., Pot, A. M., & Eisses, A. M. (2005). Diagnostic accuracy of the original 30-item and shortened versions of the Geriatric Depression Scale in nursing home patients. *International Journal of Geriatric Psychiatry*, 20, 1067-1074.
- Kabat-Zinn, J. (2003). Mindfulness-based interventions in context: Past, present, and future. *Clinical Psychology: Science and Practice*, 10, 144-156.
- Kane, M. J., & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology- General*, 132, 47-70.
- Karas, G.B., Burton, E.J., Rombouts, S.A., van Schijndel, R.A., O'Brien, J.T., Scheltens, P., McKeith, I.G., Williams, D., Ballard, C., Barkhof, F.(2003). A comprehensive study of gray matter loss in patients with Alzheimer's disease using optimized voxel-based morphometry. *NeuroImage* 18, 895 – 907.
- Kennedy, Q. et al. (2004) The role of motivation in the age-related positivity effect in autobiographical memory. *Psychol. Sci.* 15, 208–214.
- Kelly AM, Uddin LQ, Biswal BB, Castellanos FX, Milham MP. 2008. Competition between functional brain networks mediates behavioral variability. *Neuroimage* 39: 527-37.
- Kramer, A. F., & Erickson, K. I. (2007). Capitalizing on cortical plasticity: influence of physical activity on cognition and brain function. *Trends in Cognitive Sciences*, 11, 342-347.
- Kring A. M. (2011). The future of emotion research in the study of psychopathology. *Emot. Rev.*2, 225–228. doi: 10.1177/1754073910361986.
- Langenecker, S.A., Nielson, K.A., & Rao, S.M. (2003). fMRI of healthy older adults during

- stroop interference. *NeuroImage*, 21, 192-200.
- Lazar, S.W., Kerr, C.E., Wasserman, R.H., Gray, J.R., Greve, D.N., Treadway, M.T., McGarvey, M., et al., (2005). Meditation experience is associated with increased cortical thickness. *Neuroreport*, 16(7), 1893-1897.
- Linehan, M. M. (1994). Acceptance and change: The central dialectic in psychotherapy. In S. C. Hayes, N. S. Jacobson, V. M.
- Follette, & M. J. Dougher (Eds.), *Acceptance and change: Content and context in psychotherapy* (pp. 73–86). Reno, NV:Context Press
- Lykins, E. L. B., & Baer, R. A. (2009). Psychological functioning in a sample of long-term practitioners of mindfulness meditation. *Journal of Cognitive Psychotherapy*, 23, 226 – 241.
- MacLeod, C.M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin*, 109, 163–203.
- Macrae, C.N., Moran, J.M., Heatherton, T.F., Banfield, J.F., Kelley, W.M (2004) Medial prefrontal activity predicts memory for self. *Cerebral Cortex* 14:647–54.
- Mather, Mara; Carstensen, Laura L. “Aging and motivated cognition: The positivity effect in attention and memory.” *Trends in Cognitive Sciences*, v. 9 issue 10, 2005, p. 496-502.
- Mayer JS, Roebroek A, Maurer K, Linden DE. (2010) Specialization in the default mode: task-induced brain deactivations dissociate between visual working memory and attention. *Hum Brain Mapp* 31:126 –139.
- McRae, K., Gross, J. J., Weber, J., Robertson, E. R., Sokol-Hessner, P., Ray, R. D., Gabrieli, J. D. E., and Ochsner, K. N. (2012). The development of emotion regulation: an fMRI study of cognitive reappraisal in children, adolescents and young adults. *Social Cognitive and Affective Neuroscience*, 7, 11-22.
- Mennes M, Kelly C, Zuo XN, Di Martino A, Biswal B, et al. 2010. Inter-individual differences in resting state functional connectivity predict task-induced BOLD activity. *Neuroimage* 50: 1690-701.
- Mesulam, M. M. (2002). *The Human Frontal Lobes: Transcending the Default Mode through Continent Encoding*. (D. Stuss & R. Knight ed.). New York, NY: Oxford University Press.

- Metcalfe, J. & Mischel, W. (1999). A Hot/Cool-System Analysis of Delay of Gratification: Dynamics of Willpower. *Psychological Review*, 1, 3-19.
- Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, 2001, 167-202.
- Moore, A., & Malinowski, P. (2009). Meditation, mindfulness, and cognitive flexibility. *Consciousness and Cognition*, 18, 176–186.
- Mrazek, M. D., Smallwood, J., & Schooler, J. W. (2012). Mindfulness and mind-wandering: finding convergence through opposing constructs. *Emotion*, 12, 442-448. doi: 10.1037/a0026678
- Noice, H. & Noice, T. (2008). An arts intervention for older adults living in subsidized retirement homes. *Aging, Neuropsychology and Cognition*, 1, 1-24.
- Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R. J. Davidson, G. E. Schwartz & D. Shapiro (Eds.), *Consciousness and Self-regulation*: Plenum Press.
- Ochsner, K. N. & Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences*, 9(5), 242-249.
- Ochsner KN, Ray RR, Hughes B, McRae K, Cooper JC, et al. (2009) Bottom-up and top-down processes in emotion generation: common and distinct neural mechanisms. *Psychol Sci* 20: 1322–1331.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh Inventory. *Neuropsychologia*, 9, 97-113.
- Park, D. C., & Reuter-Lorenz, P. (2009). The adaptive brain: Aging and neurocognitive scaffolding. *Annual Review of Psychology*, 60, 173-196. doi: 10.1146/annurev.psych.59.103006.093656
- Paxton, J. L., Barch, D. M., Racine, C. A., & Braver, T. S. (2008). Cognitive control, goal maintenance, and prefrontal function in healthy aging. *Cerebral Cortex*, 18, 1010-1028.
- Prakash, R. S., Erickson, K. I., Colcombe, S. J., Kim, J. S., Voss, M. W., & Kramer, A. F. (2009). Age-related differences in the involvement of the prefrontal cortex in attentional control. *Brain and Cognition*, 71(3), 328-335. doi: 10.1016/j.bandc.2009.07.005 .

- Prakash, R.S, De Leon, A., Klatt, M., Malarkey, W., Patterson, B. (2012). Mindfulness disposition and default-mode network connectivity in older adults. *Social Cognitive and Affective Neuroscience*.
- Ramel, W., Goldin, P. R., Carmona, P. E., & McQuaid, J. R. (2004). The effects of mindfulness meditation on cognitive processes and affect in patients with past depression. *Cognitive Therapy and Research*, 28,433– 455
- Redick, T. S., & Engel, R. W. (2011). Integrating working memory capacity and context-processing views of cognitive control. *Quarterly Journal of Experimental Psychology*, 64, 1048-1055.
- Reuter- Lorenz, P. A., & Mikels, J. (2006). The aging brain: Implications of enduring plasticity for behavioral and cultural change. In P. Baltes, P. A. Reuter-Lorenz & F. Roesler (Eds.), *Lifespan development and the brain: The perspective of biocultural co-constructivism*. Cambridge, UK: Cambridge University Press.
- Reuter- Lorenz, P. A., & Park, D. C. (2010). Human neuroscience and the aging mind: A new look at old problems. *Journal of Gerontology: Psychological Sciences*, 65B(4), 405-415. doi: 10.1093/geronb/gbq035.
- Reuter-Lorenz, P. A., Jonides, J., Smith, E. E., Hartley, A., Miller, A., Marshuetz, C., & Koeppe, R. A. (2000). Age differences in the frontal lateralization of verbal and spatial working memory revealed by PET. *Journal of Cognitive Neuroscience*, 12(1), 174-187. doi: 10.1162/089892900561814.
- Rosenkranz, J.A., Moore, H., Grace, A.A., (2003). Prefrontal cortex regulates lateral amygdala neuronal plasticity and responses to previously conditioned stimuli. *The Journal of Neuroscience*, 23, 11054-11064.
- Rosvold, H. E., Mirsky, A.F., Sarason, I., Bransome, E.D., & Beck, L.H. (1956). A continuous performance test of brain damage. *Journal of Consulting psychology*, 20, 343-350.
- Salovey, P., & Mayer, J. D. (1990.). Emotional intelligence. Imagination, Cognition, and Personality, 9, 185-211.
- Sambataro, F., Murtya, V. P., Callicotta, J. H., Tana, H.-Y., Das, S., & al., e. (2010). Age-related alterations in default mode network: Impact on working memory performance. *Neurobiology of Aging*, 31(5), 839-852. doi: 10.1016/j.neurobiolaging.2008.05.022

- Samanez-Larkin GR, Levens SM, Perry LM, Dougherty RF, Knutson B (2012). Frontostriatal white matter integrity mediates adult age differences in probabilistic reward learning. *J Neurosci* 32: 5333–5337. doi: 10.1523/JNEUROSCI.5756-11.2012.
- Sarter, M., Givens, B., & Bruno, J.P. (2007). The cognitive neuroscience of sustained attention: where top-down meets bottom-up. *Brain Research Reviews*, 35, 146-160.
- Schneider, W. & R. M. Shiffrin. (1977). Controlled and automatic human information processing: Detection, search, and attention. *Psychological Review*, 84, pp1-66.
- Segal, Z. V., Williams, J. M. G., & Teasdale, J. D. (2002). Mindfulness-based cognitive therapy for depression: A new approach to preventing relapse. New York: Guilford Press.
- Stroop, J.R. (1935): Studies of interference in serial verbal reactions. *J Exp Psychol Gen* 18: 643-662.
- Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society of London B*, 298, 199-209.
- Shallice, T. (1988). *From neuropsychology to mental structure*. Cambridge: Cambridge University Press.
- Smallwood, J., & Schooler, J. (2006). The restless mind. *Psychological Bulletin*, 132, 946-958.
- Smallwood, J., McSpadden, M., & Schooler, J. W. (2007). The lights are on but no one's home: Meta-awareness and the decoupling of attention when the mind wanders. *Psychonomic Bulletin and Review*, 14, 527-533.
- Smallwood, J. Davies, J., Heim, D., Finnigan, F., Sudberry, M., O'Connor, R., & Obonsawin, M. (2004). Subjective experience and the attentional lapse: Task engagement and disengagement during sustained attention. *Consciousness and Cognition*, 12, 452-484.
- Smith, S. (2002). Fast robust automated brain extraction. *Human Brain Mapping*, 17(3), 143-155. doi: 10.1002/hbm.10062
- St. Jacques PL, Bessette-Symons B, Cabeza R. Functional neuroimaging studies of aging and emotion: Fronto-amygdalar differences during emotional perception and episodic memory (2009). *Journal of the International Neuropsychological Society*, 15:819–825
- Tamber-Rosenau, B. J., Esterman, M., Chiu, Y.-C., & Yantis, S. (2011). Cortical mechanisms of cognitive control for shifting attention in vision and working memory. *Journal of*

*Cognitive Neuroscience*, 23, 2905-2919.

- Tang, Y. Y., Ma, Y., Wang, J., Fan, Y., Feng, S., Lu, Q., . . . Posner, M. I. (2007). Short-term meditation training improves attention and self-regulation. *Proceedings of the National Academy of Sciences USA*, 104, 17152-17156. doi: 10.1073/pnas.0707678104
- Taylor, V. A., Grant, J., Daneault, V., Scavone, G., Breton, E., Roffe-Vidal, S., . . . Beauregard, M. (2011). Impact of mindfulness on the neural responses to emotional pictures in experienced and beginner meditators. *NeuroImage*, 57, 1524-1533. doi: 10.1016/j.neuroimage.2011.06.001
- Teasdale, J. T., Segal, Z. V., Williams, J. M. G., Ridgeway, V. A., Soulsby, J. M., & Lau, M. A. (2000). Prevention of relapse/recurrence in major depression by mindfulness-based cognitive therapy. *Journal of Consulting and Clinical Psychology*, 68, 615– 623.
- Uddin LQ, Kelly AMC, Biswal BB, Castellanos FX, Milham MP. 2009. Functional connectivity of default mode network components: Correlation, anticorrelation, and causality. *Hum Brain Mapp* 30: 625-37.
- Unsworth, N., Redick, T. S., Spillers, G. J., & Brewer, G. A. (2012). Variation in working memory capacity and cognitive control: Goal maintenance and microadjustments of control. *Quarterly Journal of Experimental Psychology*, 65, 326-355.
- Velanova, K., Lustig, C., Jacoby, L. L., & Buckner, R. L. (2007). Evidence for frontally mediated controlled processing differences in older adults. *Cerebral Cortex*, 17, 1033-1046.
- Verhaeghen, P., Marcoen, A., Goossens, L. (1992). Improving memory performance in the aged through mnemonic training: A meta-analytic study. *Psychology and Aging*, 7, 242-251.
- Way, B. A., Cresswell, J. D., Eisenberger, N. I., & Lieberman, M. D. (2010). Dispositional mindfulness and depressive symptomatology: correlations with limbic and self-referential neural activity during rest. *Emotion*, 10, 12-24.
- Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., . . . Group, A. S. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *Journal of the American Medical Association*, 296, 2805-2814.
- Williams LM, Brown KJ, Palmer D, Liddell BJ, Kemp AH, Olivieri G, et al. (2006). The mellow years? Neural basis of improving emotional stability with age. *Journal of Neuroscience*, 26(24):6422–6430.

- Woolrich, M. W., Ripley, B., Brady, J., & Smith, S. (2001). Temporal autocorrelation in univariate linear modeling of fMRI data. *NeuroImage*, *14*, 1370-1386. doi: 10.1006/nimg.2001.0931
- Xiong, G.L. & Doraiswamy, M. (2009). Does meditation enhance cognition and brain plasticity? *Annals of the New York Academy of Sciences*, *1172*, 63-69. doi: 10.1196/annals.1393.002
- Zeidan, F., Johnson, S. K., Diamond, B. J., David, Z., & Goolkasian, P. (2010). Mindfulness meditation improves cognition: Evidence of brief mental training. *Consciousness and Cognition*, *19*, 597-605. doi: 10.1016/j.concog.2010.03.014