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Application of a cognitive neuroscience perspective of cognitive control to late-life anxiety

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Abstract

Recent evidence supports a negative association between anxiety and cognitive control. Given age-related reductions in some cognitive abilities and the relation of late life anxiety to cognitive impairment, this negative association may be particularly relevant to older adults. This critical review conceptualizes anxiety and cognitive control from cognitive neuroscience and cognitive aging theoretical perspectives and evaluates the methodological approaches and measures used to assess cognitive control. Consistent with behavioral investigations of young adults, the studies reviewed implicate specific and potentially negative effects of anxiety on cognitive control processes in older adults. Hypotheses regarding the role of both aging and anxiety on cognitive control, the bi-directionality between anxiety and cognitive control, and the potential for specific symptoms of anxiety (particularly worry) to mediate this association, are specified and discussed.

Keywords

Late-life anxiety; Worry; Older adults; Cognitive control; Inhibition

1. Introduction

Although cognitive deficits in older individuals with depression have been the focus of numerous investigations, studies have only begun to investigate the relationship between anxiety and cognition. A small but growing literature has suggested there is a negative relationship between late-life anxiety and cognition. A recent critical review revealed weaker cognitive performance on effortful tasks among older adults with clinically significant anxiety symptoms compared with those with minimal or no symptoms (Beaudreau & O'Hara, 2008).

Recent theories (e.g., attention control theory; Eysenck, Derakshan, Santos, & Calvo, 2007) suggest that anxiety shifts cognitive resources away from goal-relevant information toward threat-focused information, and that this reallocation of resources leads to performance differences between anxious and non-anxious adults on cognitively demanding tasks. Converging evidence from multiple studies supports these theories by associating impaired

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cognitive control ability with self-reported anxiety (Beaudreau & O'Hara, 2009) and anxiety status in older individuals (Broomfield, Davies, MacMahon, Ali, & Cross, 2007; Mantella et al., 2007; see Price & Mohlman, 2007 for an alternative view). The term 'cognitive control' refers to processes associated with goal-directed behavior in a mechanistic definition of 'executive functions' (Miller & Cohen, 2001). The current review examines the relationship between late-life anxiety and cognitive control from cognitive neuroscience and cognitive aging perspectives. Independent roles for aging, anxiety and their interaction are proposed.

Notably, comorbidity of anxiety and depression is widespread in the older population (Hek et al., 2011). Depressive symptoms and episodes frequently coexist with clinically significant anxiety symptoms and generalized anxiety disorder (GAD) in older age (Mackenzie, Reynolds, Chou, Pagura, & Sareen, 2011; Richardson, Simning, He, & Conwell, 2011; Wolitzky-Taylor, Castriotta, Lenze, Stanley, & Craske, 2010). The pervasiveness of co-existing late-life anxiety and depression has led to interest in combinations of these symptoms, particularly major depressive disorder (MDD) with anxiety symptoms referred to as 'anxious depression.' This review therefore encompasses late-life investigations of cognitive control in adults with GAD and anxious depression.

Studies of late-life anxiety or anxious depression and cognition that focus on cognitive control typically examine how anxious older individuals deal with the interference associated with negative emotion. Interference is generally measured in studies of anxiety by incorporating emotional content into the standard Stroop paradigm (Stroop, 1935). Resultant effects reflect the impact of negatively valenced stimuli (MacLeod & Rutherford, 1992) and emotional conflict (i.e., incongruence of emotion words and faces vs. congruence; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006) on cognitive control. Although the literature has focused predominantly on Stroop interference associated with anxiety, the issue can be conceptualized as a more general problem of how an individual minimizes the interference caused by task-irrelevant information. A cognitive neuroscience framework may prove useful for elucidating the relationship of interference effects and cognitive control.

'Top-down processing' is a term often used interchangeably with 'cognitive control processing' to describe voluntary control of attention (Hirsch & Mathews, 2012). Deficient top-down processing has been shown to increase processing of threat information, and thus represents one possible contributor to states such as pathological worry (Hirsch & Mathews, 2012), including generalized anxiety disorder (GAD; MacLeod & Rutherford, 1992, 2004). Others have argued against such claims by suggesting that threat evaluation occurs before top-down processes could influence processing (Mogg & Bradley, 1998). Recent behavioral and imaging data suggest a role for both top-down and bottom-up processing of information during effortful tasks performed while in an anxious state (Reeck, LaBar, & Egner, 2012). Thus, complex interactions between both top-down and bottom-up processing appear to influence processing of threat-related information. Narrowing the focus of investigation to such factors allows for more precision in elucidating the relationship between late-life anxiety and cognition. For example, normal aging affects late-life cognitive processing even in the absence of anxiety, and therefore, any interactions with anxiety must be considered above and beyond the independent effects of aging.

2. Cognition in normal aging

Older adulthood gives rise to notable complexity and change in emotional processing (Scheibe & Carstensen, 2010) and cognitive functioning (Bosworth & Schaie, 1999). Older adults are believed to show greater emotional wellbeing and emotional stability, increased orientation to positive stimuli (Scheibe & Carstensen, 2010), and greater complexity and differentiation of emotional response to negative stimuli than their younger counterparts

(Beaudreau, MacKay, & Storandt, 2009). The extent to which these age-associated differences in emotional responses of healthy older adults applies to those with clinically significant anxiety or worry is unknown, although one recent study suggested that the age-related tendency toward a positivity bias dampens or reverses in the presence of anxiety (Price, Siegle, & Mohlman, 2012).

In contrast to positive changes associated with late-life emotional functioning, cognitive abilities decline with age. Older adults perform more poorly on a range of cognitive tasks compared with younger adults (Salthouse, 2010), with decrements corresponding to age-associated brain changes (Dennis, Kim, & Cabeza, 2008). Meta-analytic evidence suggests that age-related differences in simpler underlying processes, such as processing speed, explain some age deficits on cognitive control tasks (Verhaeghen, 2011). The impact of normal age-related cognitive changes in cognitive functioning coupled with anxiety or worry suggests that anxiety and aging pose a double jeopardy for reduced or impaired performance on measures of cognitive control.

Two cognitive aging theories propose direct mechanisms of age-associated cognitive control deficits: inhibition deficit theory (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007) and goal maintenance theory (Braver & Barch, 2002; Braver & West, 2008). Inhibition deficit theory (Hasher & Zacks, 1988) posits that age-related cognitive deficits result from impaired inhibitory control of the contents of working memory in older age. These inhibitory deficits lead to increased ‘mental clutter’ and deficits in working memory and other complex task performance relying upon working memory processing. This theory is supported by observations of greater influence of task irrelevant information on cognitive performance among older adults compared to younger adults (Zacks, Hasher, & Li, 2000).

Goal maintenance theory posits that age-related performance deficits on tasks of cognitive control occur due to a decline in the use of context, internal representations of task-sets, or goals; and that dopaminergic dysfunction in the prefrontal cortex (PFC; potentially associated with the updating of working memory representations) accounts for this specific age-associated cognitive deficit (Braver & Barch, 2002). These competing theories, along with general speed of processing accounts (Salthouse, 2010), suggest that the cognitive control deficits observed in late-life anxiety are due to a breakdown in inhibitory control (Banich et al., 2009), a breakdown in other control processing necessary for goal maintenance, or are explained by general slowing. The ability to distinguish anxiety-related deficits from age-related deficits, or to detect their interaction, necessitates the dissociation of performance on tasks designed to assess specific cognitive mechanisms. In addition, the goal maintenance framework provides a biologically plausible account of how cognitive control deficits could occur within the PFC.

Behavioral investigations of late-life anxiety and cognitive control focus on two different but related types of anxiety—clinically significant anxiety and trait anxiety. Investigations of these variants implicate unique age-related effects of anxiety on cognitive control. Neuroimaging studies using tasks designed to measure aspects of cognitive control processes further support an age by anxiety interaction.

3. Late-life anxiety and cognitive control

Behavioral studies of clinically significant anxiety and cognitive control generally implicate increased interference on the Stroop task. Although increased interference is expected for both emotional and non-emotional versions of the Stroop task (Banich et al., 2009), Stroop performance in anxious older adults varies both by the version (emotional vs. neutral) and anxiety severity and type. Table 1 provides an overview of the results from late-life anxiety studies of cognitive control. As expected, negative emotion conditions revealed greater

interference or reduced cognitive control compared with neutral emotion conditions in clinically anxious older adults. On the emotional Stroop task, older individuals with MDD with anxiety (vs. non-depressed and non-anxious controls; Broomfield et al., 2007) or high worry (vs. moderate or low worry; Price et al., 2012) demonstrated slower response times for negative words compared with neutral words. Overall, older individuals with clinical levels of anxiety, as determined by a *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text revision, American Psychiatric Association, 2000) diagnosis of GAD or MDD with anxiety, or based on elevated self-reported worry symptoms, may be predisposed to experience greater distraction to negative vs. neutral emotional stimuli.

Anxiety theories do not limit the prediction of cognitive control performance deficits to negative emotion conditions (Eysenck et al., 2007); therefore, such deficits are also expected on neutral cognitive control tasks. Higher levels of interference on the Stroop were associated with greater anxious arousal, but not associated with depressive symptoms in a sample of 102 community-dwelling older adults (Beaudreau & O'Hara, 2009). An analysis of 43 individuals with GAD indicated, however, that greater worry and greater trait anxiety were associated with *reduced* interference (Price & Mohlman, 2007). Anxious arousal and depressive symptoms were not significantly associated with Stroop performance in this sample. Differences noted between these two studies could be attributed to a restricted range of high anxious arousal scores on the Beck Anxiety Inventory (BAI; Beck & Steer, 1993) in the late-life GAD group, which could reduce the magnitude of correlations compared with a full range of BAI scores obtained from community-dwelling older adults in the former study. Alternatively, results have been proposed to indicate superior inhibitory control in the GAD patients due to the habitual use of emotional suppression as an emotion regulation strategy (Price & Mohlman, 2007). Studies using both diagnostic status (GAD vs. controls) and a dimensional approach (symptom severity regardless of group status) could also help resolve the different findings with the standard Stroop task. Further, a non-linear relationship between anxious arousal and Stroop performance could explain differences between these two studies, such that at lower levels, anxiety impedes cognitive control and at higher levels, it facilitates cognitive control.

Two experimental studies of trait anxiety in older individuals from the community (Fox & Knight, 2005; Lee & Knight, 2009) revealed age differences in cognitive control that arose during negative emotion conditions in both trait anxious and nonanxious groups (Lee & Knight, 2009). In particular, cognitive control was facilitated among older adults regardless of their trait anxiety while viewing angry faces, and among moderate trait anxious older adults while viewing sad faces. Neither of these associations occurred in a younger comparison group. Older adults also demonstrated less distraction from negative emotion faces than young adults during a cognitive control task. This is consistent with the positivity bias theory of aging (Scheibe & Carstensen, 2010). Furthermore, the fact that moderate (but not low or high) trait anxiety facilitated cognitive control suggests a potential non-linear association between the two variables. This is consistent with the classic Yerkes–Dodson model (1908) explicating an inverted U-shape association. This non-linear association, however, may only apply in the context of sad faces based on findings of facilitated attention in those with moderate levels of trait anxiety.

Results from this same study did not support the U-shaped association during exposure to negative emotion words. Specifically, Lee and Knight (2009) reported increased interference to negative emotion words during a dot-probe task in an older high trait anxiety group compared with low and moderate trait anxiety groups. In a different study (Fox & Knight, 2005), anxiety induction served to equalize interference for negative emotion words during dot probe task, and to reduce interference to negative emotion words during a Stroop task in high trait anxiety vs. low trait anxiety older adults; there was no moderate trait anxiety

comparison group. Perhaps anxiety induction serves to narrow attention during cognitive control, minimizing distraction in some negative emotion contexts, although the exact cognitive mechanism by which this occurs has yet to be determined.

In summary, studies using either diagnostic samples or clinical anxiety measures have provided fairly consistent evidence of increased interference in negative emotional contexts. Results from two studies using neutral cognitive control tasks produce mixed findings depending in part on the diagnostic status of the sample, the anxiety or worry measures examined, and whether diagnostic status or symptom severity were correlated with cognitive control. Future studies incorporating both anxious arousal and worry measures are needed to determine if one set of symptoms has a greater impact on cognitive functioning, or if the two symptoms interact to predict cognitive control in older adults.

4. Neurobiological evidence

Neuroimaging studies of cognitive control in older adults with anxiety disorders or anxious depression have provided a plausible biological explanation of observed behavioral findings between older anxious and nonanxious individuals, and between older and younger anxious adults. Regardless of the emotional content of the stimuli, regions of the dorsolateral prefrontal cortex (DLPFC) activate when attentional demands increase in the context of conflict arising from color incongruence or the emotional content of a word (Compton et al., 2003). This has led to the proposal that DLPFC regions are involved in top-down biasing toward task-relevant information regardless of the presence of emotional content; however, differences based on the emotional content arise in the more posterior regions of the DLPFC specific to the particular content being processed (Banich et al., 2000). Rostral anterior cingular cortex (ACC) and amygdala activation are closely linked to the presence of emotional disorders (Engels et al., 2007). The rostral ACC, hypothesized to inhibit amygdala activation, is less active in younger individuals reporting worry or anxiety-related arousal compared with individuals low on these two attributes (Engels et al., 2007) and it has a critical role resolving “emotional conflict” (Etkin et al., 2006). While small in number and sample size, emerging investigations suggest a revised view of the DLPFC and rostral ACC’s functional roles in anxious older adults.

Table 2 summarizes results of imaging investigations of late-life GAD and anxious depression during cognitive control tasks. In contrast to findings of increased PFC activation in younger adults trying to ignore distracting information, regional cerebral blood flow to the PFC did not increase during active thought suppression in late-life GAD but increased as expected in non-anxious older controls (Andreescu, Gross, et al., 2011). Decreased bilateral DLFPC activation has been reported in late-life GAD compared with healthy older controls during presentation of negative words on an emotional Stroop task (Price, Eldreth, & Mohlman, 2011). Decreased medial PFC activity was also observed in older adults with MDD and high anxiety compared with MDD low anxiety during a simple motor task (Andreescu, Wu, et al., 2011). In a recent review, Andreescu and Aizenstein (2012) proposed that older adults with GAD “failed to activate” the PFC during active thought suppression. Failure to activate the PFC, however, appears specific to thought suppression, emotional Stroop, and simple motor tasks given one investigation where older participants with GAD showed greater PFC activation than older controls during active worrying (Mohlman, Eldreth, Price, & Hanson, 2009).

Decreased ACC activation has been observed in younger adults during worry induction (Paulesu et al., 2010); this decreased activation is associated with the ability to regulate amygdala activity (Hariri, Mattay, Tessitore, Fera, & Weinberger, 2003) and emotions (Goldin, McRae, Ramel, & Gross, 2008; Ochsner & Gross, 2005). Consistent with these

studies, decreased rostral ACC activation was observed in older adults with anxious depression relative to non-anxious depression during a simple motor task (Andreescu, Wu, et al., 2011). Yet, older adults with GAD demonstrated *increased* ACC activation compared with late-life controls during a worry condition (Andreescu, Gross, et al., 2011; Mohlman et al., 2009). It is thus possible that older adults with GAD have particular difficulty regulating worry due to ACC dysfunction (Andreescu & Aizenstein, 2012). Overall, these studies suggest that while anxious young and middle-aged adults demonstrate increased functional efforts toward cognitive control of negative emotion, this process is disrupted in anxious older adults.

5. Discussion

Several observations and testable hypotheses emerge from the reviewed cognitive and emotional aging theories and behavioral and neuroimaging findings. First, age and anxiety independently affect cognitive control. A simple cognitive model of general slowing explains age-related cognitive control deficits on tasks with interfering irrelevant information (Verhaeghen, 2011; Verhaeghen & De Meersman, 1998); however, some age-related deficits on cognitive control tasks persist after accounting for general slowing, suggesting specific age-related deficits in control processes such as updating or dual tasking (Verhaeghen, 2011).

Affective neuroscience perspectives of anxiety suggest that cognitive control deficits arise from disturbances in goal maintenance due to disruption of the ability to inhibit task irrelevant information (Munakata et al., 2011). Price and Mohlman (2007) proposed that effective worriers have relative strengths in cognitive control in order to implement worry as an avoidance strategy. Nevertheless, assuming that worry is not necessarily under conscious control, and in light of theorized age-related deficits in inhibition or goal maintenance, worry is a potential pathway to impaired cognitive control in older adults. A recent formulation of worry (i.e., the contrast avoidance model of worry) suggests that worry operates to maintain a negative emotional state to avoid an extreme shift from positive to negative mood in anticipation of future feared situations (Newman & Llera, 2011). Hence, negative emotion states such as anxious arousal among high worriers could create internal distraction or increase the cognitive load of a task for older individuals even in the absence of an experimental paradigm of different emotion conditions or manipulation of mood states. The general nature of perceived threat among worriers, especially in GAD, would be expected to affect both cognitively effortful processes or tasks (high level appraisal) and unconscious or preattentive processing during even a neutral task (low level appraisal) in older anxious individuals.

Second, the directionality of late-life anxiety and cognitive control is not entirely clear. The presence of pre-existing cognitive control deficits could increase the risk of developing and maintaining anxiety. Alternatively, pervasive anxiety or worry could lead to impaired cognitive control, particularly in later life. One hypothesis is that anxiety and cognitive control deficits in older adults are mutually influential, with one exacerbating the other. The lack of longitudinal research limits the ability to draw definitive conclusions about directionality and causation. Cross-sectional evidence demonstrates that some but not all aspects of cognitive control are associated with rumination and anxiety in younger adults, with normal aging, and with worry and anxiety in older adults. Among these three groups, the aspects of cognitive control affected are not consistent. Developmental studies that follow anxious and non-anxious young or middle-aged adults over time tracking their cognitive control abilities in multiple domains are needed. Studies using experimental paradigms are also needed to dissociate the hypothesized components of cognitive control in normal aging compared with aging in the presence of anxiety and worry.

Third, it is unclear which variants or symptoms of late-life anxiety are most relevant to cognitive control. Common measures include worry severity, anxious arousal, trait anxiety, and diagnostic status (GAD or anxious depression). Although there may be situations in which worry severity facilitates cognitive control (Price & Mohlman, 2007) the mechanism for this finding is unclear given the cognitive neuroscience literature suggestive of brain activation inefficiency in late-life anxiety (Andreescu & Aizenstein, 2012; Mohlman et al., 2009). Direct comparisons within the same study and sample are needed on a range of anxiety and worry measures. Whether the behavioral and neuroscience evidence described here transfers to other types of late-life anxiety in which generalized worry is not a core feature (e.g., panic or phobias) deserves further examination. Future studies could determine if these associations are present due to anxiety in general or specific symptoms such as worry. Given that worry likely moderates anxiety symptoms or vice versa in older adults, models that take both of these symptoms into account simultaneously and those that also account for depressive symptoms will elucidate which of these symptoms, if not all, are driving the associations found in the relevant empirical literature.

Because depression is pervasive in late-life anxiety (Almeida et al., 2012; Byers, Yaffe, Covinsky, Friedman, & Bruce, 2010), models of cognitive control outcomes should adjust for depressive symptoms, examine interactions between anxiety and depressive symptoms, or compare anxious nondepressed individuals with those whom are characterized as having mixed anxiety and depression or depressive symptoms. The overlapping symptoms of worry and depressive rumination present in anxiety and depression (Hoyer, Gloster, & Herzberg, 2009) could be addressed by examining a potential common cognitive control mechanism as a predictor or outcome of these shared psychiatric features. The studies reviewed here demonstrate that in later life, clinically significant anxiety in depression leads to different behavioral and neuroimaging predictions than depression alone. Therefore, there is something unique about anxiety and cognitive control in older adults regardless of depressive status, with similar outcomes on cognitive control in anxious older adults regardless of their depressive status.

In addition, behavioral studies using a negative emotion paradigm with anxious older adults show increased interference in anxious younger and older adults on clinical measures of anxiety. This increased interference is generally found despite methodological differences among studies, including the selection of trait anxiety rather than traditional clinical self-report measures of anxiety or worry, a focus on community-dwelling older adults rather than clinical samples, use of different types of stimuli (neutral vs. emotional, faces vs. words), or the addition of anxiety induction. In some emotional contexts, such as with sad faces, a non-linear association between trait anxiety and cognitive control may be expected. Studies using continuous measurement of symptoms are needed to explicate non-linear trends.

Finally, relatively little attention has been paid to mechanisms of cognitive control deficits in geriatric anxiety. The causal, exacerbating, and maintaining role of cerebrovascular disease/white matter lesions in the PFC is hypothesized to produce executive function deficits in late-life depression (Alexopoulos et al., 1997). However, no such vascular hypothesis exists for late-life anxiety; a vascular hypothesis has the potential to advance understanding of pathophysiological mechanisms underlying late-life anxiety and cognitive control, the cognitive and biological mechanisms proposed in cognitive aging by goal maintenance theory (Braver & Barch, 2002) and the effects proposed in anxiety research by different types of inhibitory processes (Munakata et al., 2011). For example, the indirect competitive inhibition framework (Munakata et al., 2011) suggests that the interference effects identified in (emotional) Stroop paradigms are likely due to local competition among alternatives within cortical areas rather than ineffective top-down suppression of entire

cortical areas. Mechanistic theories such as these could be used to increase the precision of studying and ultimately understanding cognitive control as it relates to late-life anxiety.

6. Implications and conclusions

Mohlman (2005) proposed that executive dysfunction due to deficits in PFC functioning potentially moderates treatment outcome among older adults with GAD. In a recent study of neuropsychological predictors of treatment response in late-life GAD, Butters et al. (2011) found that healthy controls had better baseline cognitive control in addition to better neuropsychological performance on a number of measures. Notably, in the GAD group treated with 12-weeks of an SSRI (escitalopram), improvement on tasks of cognitive control (Stroop; Stroop, 1935) and memory recall was associated with clinically significant improvement in anxiety. This study implicates anxiety as a reversible cause of poor cognitive performance, which suggests that anxiety interventions might be effective for treating cognitive impairment.

In contrast, cognitive control deficits in later life, partially determined based on neuropsychological Stroop task performance, have been proposed to impact treatment outcome (Mohlman, 2005; Mohlman & Gorman, 2005). This reduced treatment response is especially relevant to older adults, given that their increased risk of medical conditions and cognitive impairment could negatively influence treatment outcome in GAD. Greater understanding of baseline cognitive control as a moderator of treatment outcomes for anxiety or worry could potentially identify which patients are likely vs. less likely to respond to specific interventions. Examining patterns of brain activation change following behavioral or pharmacological treatment could elucidate the degree to which treatment leads to enduring biological outcomes in addition to behavioral outcomes.

The reviewed behavioral and neuroimaging evidence of an association between late-life and anxiety and cognitive control suggests that treatments should address both aspects. Treatment of older anxious patients with cognitive control deficits could occur through several approaches. One approach would be to modify traditional treatments to increase support of cognitive control for those with such impairments, as incorporated in enhanced cognitive behavioral therapy (CBT), which allows for some modification for general sensory and cognitive slowing in older adults (Stanley et al., 2003). Cognitive remediation training has demonstrated preliminary support for improving executive functions and GAD symptoms in older adults (Mohlman, 2008). Behavioral therapies that reduce anxiety and simultaneously support cognitive control, such as problem-solving therapy (PST; Nezu, Nezu, & D'Zurilla, 2007) might provide an additional option. A preliminary study of an age-appropriate version of PST for depression showed promising results, indicating an advantage for PST over an active control condition (Alexopoulos et al., 2011).

Another approach, computerized attention bias modification training, targets selective attention by training anxious individuals to disengage their attention from threat stimuli, sometimes anxiety disorder specific and usually in the context of a dot-probe paradigm (Hakamata et al., 2010). This intervention shows promising results in terms of reducing anxiety, despite the lack of focus on reducing symptoms using explicit skills or techniques (Hakamata et al., 2010; Hallion & Ruscio, 2011). Use of cognitive training classes to teach older adults strategies to improve cognitive control is another option. Further, given recent evidence that cognitive control and other cognitive abilities improve after pharmacotherapy in late-life GAD (Butters et al., 2011), the efficacy of pharmacological treatments alone or behavioral treatments plus pharmacological treatments should be evaluated systematically to test for independent or synergistic benefits on both anxiety and cognitive control.

In addition to these therapeutic implications, experimental approaches, such as testing Stroop performance under different task variants (e.g. standard vs. emotional) and with differently characterized groups (i.e., anxious tendency vs. clinical diagnosis), could clarify mixed findings found among patients with late-life GAD. Several plausible interpretations could explain the relationship between anxiety and cognitive control on the Stroop task; therefore, it is useful to corroborate findings with performance on other non-Stroop tasks considered to tap the same behavior, or to examine other aspects of cognitive control. Specific recommendations include the Think/No Think test (Anderson & Green, 2001) to tap the inhibition of memory, and the n-back test (McElree, 2001) or the AX-CPT (Paxton, Barch, Racine, & Braver, 2008) to examine goal maintenance based on memory updating and use of context. Two modifications to the standard Stroop task, the switching Stroop (Eppinger, Kray, Mecklinger, & Oliver, 2007) and a modified Stroop (25% incongruent trials, 75% congruent trials: Kane & Engle, 2003) emphasize flexibility or goal maintenance and are also highly applicable to this research. Inclusion of a younger comparison group is recommended to dissociate age-related general slowing from anxiety related decrements in task performance.

Rather than investigating hypothesized aspects of cognitive control in isolation, it would be informative to assess a broad range of executive abilities in a well-specified single battery. Two examples might be the clinical/research neuropsychological battery under development by researchers at the University of California, San Francisco (Kramer et al., 2012) or the multidimensional battery of the NIH toolbox that includes brief measures assessing cognitive, emotional, motor, and sensory function (Gershon et al., 2012). Use of these broader batteries would allow researchers to rule out general decrements in executive abilities or other cognitive functions in association with late-life anxiety vs. those decrements specific to cognitive control. In summary, future studies should explore cognitive control in late-life anxiety by targeting goal maintenance and flexibility, expanding the focus to other tasks that converge on the same constructs, and examining other constructs that assess a wider range of performance.

Although preliminary evidence suggests deficits in aspects of cognitive control in late-life anxiety, the direction of the relationship has yet to be determined. Longitudinal studies and large-scale experimental investigations designed to dissociate aspects of cognitive control in anxious and nonanxious older adults are lacking. In spite of these limitations, cross-sectional evidence suggests an association between cognitive control deficits and anxiety in older adults that is corroborated by neuroimaging findings. Future investigations of cognitive control could provide a mechanistic framework with which to further develop our clinical understanding of late-life anxiety.

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Table 1

Summary of late-life anxiety and cognitive control studies.

Study	Participants	Task	Cognitive control[a]
Beaudreau and O'Hara (2009)	102 community-dwelling older adults, varying levels of anxious arousal and depression	Stroop Color and Word Test	Elevated anxious arousal < cognitive control independent of depressive symptoms
Broomfield et al. (2007)	19 MDD with anxiety[b] vs. 20 controls	eStroop (negative words)	MDD with anxiety < controls
Fox and Knight (2005)	31 high vs. 37 low TA	eStroop (negative words); dot probe (negative words)	Negative words eStroop: high TA > low TA following anxiety induction Dot probe: high TA = low TA regardless of anxiety induction
Lee and Knight (2009)	13 high vs. 13 moderate vs. 18 low TA older adults	Dot probe	High TA < moderate/low TA for supraliminal negative words Moderate TA < high/low TA sad faces All old < all young angry faces
Mantella et al. (2007)	19 GAD vs. 68 MDD vs. 40 controls	EXIT battery; Trails B	EXIT: GAD, MDD < controls Trails B: GAD, MDD < controls
Mohlman, Price, and Vietri (2008)	35 GAD vs. 28 controls; GAD waitlist (n = 15) vs. posttreatment (n = 12)	Dot probe	GAD = controls Anxiety words: GAD posttreatment > GAD waitlist
Price et al. (2011) [c]	16 GAD vs. 12 controls	Stroop; eStroop (negative vs. neutral words)	Stroop: GAD = controls eStroop: GAD < controls
Price and Mohlman (2007)	43 GAD vs. 14 controls	Stroop	GAD only > with greater worry severity GAD = controls
Price et al. (2012)	20 high vs. 19 moderate vs. 21 low worry	eStroop	Negative words: high worry < low worry Positive words: high worry > low and moderate worry

Note: GAD: generalized anxiety disorder; MDD: major depressive disorder; TA: trait anxious.

[a] More, less, or not statistically different levels of cognitive control denoted with >, <, or =.

[b] Moderate to severe anxiety based on mean BAI score for MDD group. Results also hold when anxiety covaried in the analysis.

[c] fMRI data presented separately in Table 2.

Table 2

Summary of neuroimaging studies in late-life anxiety.

Study	Participants	Tasks	Activation/results
Andreescu and Aizenstein (2012)	7 GAD vs. 11 controls from a previously published study[a]	Worry induction/suppression	Regulatory relationship between subgenual ACC and amygdala delayed during worry suppression in GAD vs. controls
Andreescu et al. (2009)	4 MDD high anxiety vs. 4 MDD low anxiety	POP	MDD high anxiety > MDD low anxiety in sustaining effort of dorsal ACC, posterior cingulate, and PFC during non-emotional cognitive control
Andreescu, Gross, et al. (2011)	7 GAD vs. 10 controls	Worry induction/suppression	GAD > controls for rostral ACC rCBF during worry induction GAD < controls for left lateral PFC rCBF during worry suppression
Andreescu, Wu, et al. (2011)	11 MDD high anxiety vs. 8 MDD low anxiety from a previously published study[b]	Finger tapping	MDD high anxiety < MDD low anxiety for rostral ACC, medial PFC and OFC
Price et al. (2011) [c]	16 GAD vs. 12 controls	eStroop	GAD < controls for dorsolateral PFC during negative vs. neutral words (Stroop) GAD > controls for amygdala during negative vs. neutral words (Stroop)—due to decreased amygdalar activation in controls
Mohlman et al. (2009)	20 GAD vs. 16 age-matched controls	Worry induction	GAD > controls for left PFC, left insula, bilateral amygdala, right ACC

Note: GAD: generalized anxiety disorder; controls: older, non-anxious controls; ACC: anterior cingulate cortex; rCBF: regional cerebral blood flow; PFC: prefrontal cortex; OFC: orbital frontal cortex; MDD: major depressive disorder; POP: preparing to overcome prepotency task/switching with congruent and incongruent trials; all results based on blood-oxygen-level-dependent (BOLD) signals from functional imaging except for Andreescu, Gross, et al. (2011) perfusion MRI.

[a] Data from Andreescu, Gross, et al. (2011).

[b] Data from Andreescu et al. (2009).

[c] Study also reported in Table 1.