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Emotion and Cognition Across Age: Insights from Studies on Affect, Repetitive Thinking, Stress and Inflammation

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Psychological Science

by

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PUBLICATIONS

Kircher, J. A., Charles, S. T., Sin, N. L., & Almeida, D. M. (2023). Chronic pain and affective experiences associated with daily stressors and uplifts. *International Journal of Applied Positive Psychology.* 1-16. doi: 10.1007/s41042-023-00101-w.

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ABSTRACT OF THE DISSERTATION

Emotion and Cognition Across Age: Insights from Studies on Affect, Repetitive Thinking, Stress and Inflammation

by

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Doctor of Philosophy in Psychological Science

University of California, Irvine, 2024

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Negative emotional states are frequently associated with declines in cognitive performance. However, the mechanisms and pathways underlying the relationship between emotion and cognition are not well understood. In a three-study series, this dissertation examined associations between affect, perceived stress, and cognitive functioning and how unconstructive repetitive thinking (URT), and inflammatory markers may underlie the association between emotion and cognition. The first two studies focused on the association between fluctuations in momentary affective experiences and cognitive functioning. Study 1 examined how high arousal negative and positive emotional states relate to working memory across different age groups. Findings indicated that both high negative and positive affect were linked to poorer working memory performance, with younger adults experiencing more pronounced negative effects when positive affect increased. Study 2 explored the impact of momentary unconstructive repetitive thinking (URT), such as worry and rumination, on cognitive function throughout the day. Contrary to expectations, greater URT was associated with improved working memory, especially in younger adults, although this relationship was moderated by negative affect, which suppressed

the cognitive benefits of URT. Study 3 investigated the effects of chronic perceived stress on cognitive performance and its potential mediation by inflammatory cytokines among adults in midlife. Results revealed that higher perceived stress was directly related to poorer cognitive function and elevated levels of certain inflammatory markers; however, inflammation did not mediate the perceived stress–cognition link. These studies underscore the nuanced interactions between affective states, stress, and cognitive performance, highlighting age-related differences and the complex role of physiological stress responses in cognitive aging. Overall, in moments when positive and negative affect were heightened, cognitive function worsened, but only for younger and middle-aged adults. Across younger and middle-aged adults, moments of increased URT were related to better cognitive performance; and, when negative affect was accounted for during moments of greater URT, cognition was more affected by momentary URT. The momentary relationships between affect and age on cognition, as well as greater URT and better cognition, provide notable contributions to the area of emotion and cognition research focused on understanding the differences in state versus trait emotional processes. The findings demonstrate that cognition is sensitive to both state and trait emotional processes, which has important implications for understanding when and how cognitive function improves or when interference occurs.

GENERAL INTRODUCTION

Associations between stress, negative affect, and cognitive well-being are well documented. Research consistently shows that negative emotions and stress can have both short-term and long-term adverse effects on cognitive function (Aggarwal et al., 2014a; Boals & Banks, 2012; Öhman et al., 2007; Ihle et al., 2020; Palmer, 2013). Experiencing high levels of negative affect and stress is associated with deficits in cognitive functions such as processing speed, memory, and executive functioning (Aggarwal et al., 2014a; Kim et al., 2015; Munoz et al., 2015).

Psychological Theories Related to Stress and Cognition

Two prominent theories posit that stress influences short-term cognition by increasing the mental effort needed to process information in working memory, a phenomenon similar to the concept of cognitive load. The concept of cognitive load is built on the premise that people have limits to the amount and capacity of information they can process at any given time (Conway et al., 2003; Kalyuga, 2011; Klepsch et al., 2017). Working memory allows the mind to focus, sustain attention, and actively manipulate information. Working memory has a limited capacity, and an increase in cognitive load further reduces working memory capacity.

Environmental stimuli can increase cognitive load, such as noises distracting people from tasks or needing to divide attention to complete two tasks simultaneously. Internal processes can also increase cognitive load, such as one's motivation, expectations, or psychological stress (Schmeichel & Demaree, 2010; Storbeck & Maswood, 2016; Sweller, 2010). Highly arousing emotions are posited to increase cognitive load because the cognitive processing required to regulate emotions will compete with the cognitive resources needed for memory, attention, and learning (Plass & Kalyuga, 2019). Models that use concepts similar to cognitive load describe psychological pathways through which perceived stress influences cognitive functioning (Kalyuga, 2011; Klepsch et al., 2017; Moreno, 2010).

Psychosocial Stress Process Model

The Psychosocial Stress Process model (Wheaton, 1983; Wheaton, 1997) posits that chronic stress disrupts cognitive processes through increased cognitive demand. The model describes how negative automatic and effortful coping responses to stress can worsen cognitive functioning, a coping response to stress akin to the more recent concept of cognitive load. When managing chronic stress, negative affect (e.g., anxiety, depression, or anger) is a frequent and impulsive response. Thought patterns become interrupted, creating negative cognitive processes such as worry, negative intrusive thoughts, and a fixation on negative memories. Managing involuntary negative thoughts requires cognitive effort, and in turn, these cognitive pathways contribute to the maintenance of chronic stress.

Cognitive Model of Depression

LeMoult and Gotlib (2019) used the Psychosocial Stress Process model as a foundation to develop a more complex model that describes specific types of cognitive emotion regulation processes that interfere with cognitive processes. The Cognitive Model of Depression emphasizes the role of intrusive thoughts and motivations on cognition. Although this model was originally derived to explain the effects of depression on cognitive functioning, it offers a framework that can be applied to describe the cognitive effects of heightened negative affective states (e.g., unhappy, frustrated, or angry) and perceived stress (LeMoult and Gotlib; 2019). Experiencing heightened negative affect (i.e., depression, anger) has long been a predictor of interferences in cognition across ages (Aggarwal et al., 2014; Korthauer et al., 2018; Storbeck & Clore, 2007; Storbeck et al., 2015; Zahodne et al., 2014).

Unconstructive Repetitive Thinking as a Psychological Mechanism

Critical to both the Psychosocial Stress Process and Cognitive Model of Depression are ruminative and intrusive thoughts. Rumination and repetitive negative are considered by both models as key psychological pathways linking perceived stress and cognitive functioning (Du et al., 2018; Scott et al., 2015). Unconstructive repetitive thinking (URT) is a construct describing frequent and unwanted thought patterns. Experiencing chronic stress requires increased engagement in emotion regulation, leading to more effortful cognitions (Compas et al., 1997; Compas et al., 1991; Joorman & Quinn, 2014). Cognition may be negatively affected by URT because it depletes attentional resources, which has negative downstream effects on cognitive performance (Stawski et al., 2006). URT also interferes with one's ability to engage in proper coping behaviors, one of which is emotion regulation. The psychological pathway of URT will be assessed as part of the first study in the current proposal.

Stress and Cognitive Function via Physiological Changes

URT and other aspects of rumination may not only affect short-term memory, but also results in constant physiological arousal (Christ et al., 2020; Pedersen et al., 2011; Sladek et al., 2020). This arousal may then lead to physiological changes that also influence cognitive functioning (Ando' et al., 2020). Physiological processes may be involved in both gradual and long-term effects of stress on cognition. The classic stress process, put forth by Selye (1951), provides a strong basis for the physiological effects of stress (McEwen 1998a; McEwen 1998b; McEwen & Sapolsky, 1995). The most current understanding of the relationship between stress and cognition is that glucocorticoids compromise areas of the brain essential to memory and executive function (Crosswell et al., 2021). Most notably, studies assessing acute or chronic stress through cortisol find a relationship with cognitive functioning rooted in functional changes in the brain (de Souza-Talarico et al., 2011; James et al., 2023).

Cortisol, a main glucocorticoid, becomes elevated during periods of chronic stress, which over time can result in higher levels of inflammatory profiles. Increased circulating inflammation can result in alterations to hippocampal functioning, which leads to impairments with memory, processing speed, and executive function (Cohen et al., 2012; Kim et al., 2015; Smyth et al., 2013). Glucocorticoids (i.e., cortisol) activate inflammatory responses which can be identified through measuring biomarkers of inflammation pro-inflammatory cytokines (Gu et al., 2012; Piazza et al., 2010; Rohleder, 2019).

Addressing Gaps

The links between lower cognition and chronic stress are well-established, but fewer studies have examined affective processes and underlying inflammatory mechanisms connecting higher levels of stress and negative emotions with poorer cognition (Baum et al., 1999; Gaydosh et al.; Gouin & Kiecolt-Glaser, 2011; Marin et al., 2011; Öhman et al., 2007; Sliwinski et al., 2006). To address this, study one investigated how momentary negative and positive affect relate to momentary tasks of cognition, and how that varies across younger, middle-aged, and older adults. Results showed that during moments of heightened negative and positive affect, cognitive task performance declined, but this effect was not significant among older adults. To further examine whether emotions were related to working memory, I analyzed how momentary reports of URT related to cognition, and whether negative emotions were underlying that association. I found that among young and middle-aged adults, moments of increased URT related to better cognitive function. Moreover, this effect was not caused by negative emotions; instead, it was suppressed by them. Finally, I was interested in how inflammation may be tied to the emotional processes involved in cognition. In the third study, I examined whether the link between perceived stress and cognitive function was explained by pro-inflammatory cytokines. Perceived stress was a significant predictor of both poorer cognitive task performance, as well as increased levels of the pro-inflammatory cytokine TNF-α. However, perceived stress did not impact cognitive function through an inflammatory pathway. Taken together, the results suggest that heightened negative affective states are significantly related to cognitive interference, as well as physiological indicators of stress (i.e., inflammation). These studies offer deeper insights into how affective processes impact cognition in both a momentary and cross-sectional context.

CHAPTER 2

Study 1. Heightened Cognitive Arousal Related to Greater Response Time Problems for Younger Adults

ABSTRACT

High arousal negative emotional states are often related to poorer working memory. Findings for high arousal positive states (e.g., excitement or joyful), however, are more mixed, with some studies indicating that higher arousal is linked to better cognitive task performance. The purpose of this study was to examine how reports of negative and positive affect throughout the day are associated with working memory, and how this relationship varies by age. It was hypothesized that moments of high negative or positive affect would be associated with poorer performance on cognitive tasks. Additionally, age was hypothesized to moderate the relationship between affect and cognition, such that when older age is coupled with heightened negative or positive affect, cognitive performance will be worse across all momentary tasks. Data from the Effects of Stress on Cognitive Aging, Physiology, and Emotion (ESCAPE) study consisted of five assessments throughout the day across 14 days among 260 community residents ranging from 25-65 years old (Mage = 46.5). At each assessment, participants completed the n-back adapted for mobile phones and reported the current affect. Across all ages, higher levels of reported negative and positive affect at each assessment were related to worse momentary working memory ($\gamma_{NegativeAffect}$ = -.0004, SE = .0002, p = .02; $\gamma_{PositiveAffect}$ = -0.0003, SE = .0002, p = .04) and younger age was related to worse working memory as levels of positive affect increased.

INTRODUCTION

When examining the role of affect in cognitive processes, researchers often find that higher levels of affect, regardless of its valence, are related to poorer cognitive function (Forgas, 2008; Payne & Schnapp, 2014). Two domains sensitive to fluctuations in negative and positive affect include working memory and processing speed. Studies examining the relationship between heightened affective states and cognitive difficulty often use traditional laboratory-based measures to capture an individual's cognitive performance (Labouvie-Vief et al., 2009; Levine & Pizarro, 2004; Levine & Edelstein, 2010; Schmeichel & Demaree, 2010; Sladek et al., 2020; Shankar & Park, 2016). Using traditional survey-based methods to capture affect and cognition does not allow researchers to understand how the relationship between affect and cognition may function at the daily level. Negative and positive affect are relatively stable over time; however, there are often wide daily fluctuations in individual affect (Genet & Siemer, 2012; Hulur et al., 2015; Sliwinski et al., 2006; Stawski et al., 2013). Solely observing trait-level positive and negative affect fails to capture how within-person variation in affect contributes to cognitive function. Capturing momentary state-level affect in relation to momentary cognitive performance could provide a more nuance and real-world understanding of the connections between affect and cognitive function.

In recent years, researchers have begun using both daily diaries and ecological momentary assessment to further understand how fluctuations in daily affect relate to cognitive processes (Brose et al., 2014; Stawski et al., 2019). However, prior research has yet to clearly identify whether intraindividual differences in negative and positive affect relate to cognitive performance, and how this varies by age. Moreover, few studies have gone beyond daily diary and examined momentary assessments of affect in relation to momentary performance on cognitive tasks. The current study investigated how momentary reports of negative and positive affect related to performance on momentary tasks of processing speed and working memory among adults ranging in age from 25 to 65 years.

Affective Processes and Cognition

Affective processing and cognition share a well-established connection, such that mood states are interdependent with cognitive processes (Hogan et al., 2013; Matthews & Campbell, 2010; Storbeck & Clore, 2007). Having high amounts of negative affect (e.g., anger, sadness) can interfere with cognitive function. More specifically, negative affect is related to the depletion of executive function (Philippot & Agrigoroaei, 2017; Zahodne et al., 2014; Yang et al., 2017). A recent review of emotion and working memory performance among healthy adults found a robust link between negative affective states, (e.g., anxiety or depression) and declines in working memory abilities. Moreover, verbal and spatial working memory were consistently affected by negative emotion. Xie and colleagues (2023) conducted a meta-analysis to research the hypothesis that negative emotion is related to aspects of working memory. Across 13 experiments, when negative mood was induced, participants fared worse on tasks of working memory recall compared to those in neutral emotional states.

Since affective states can change throughout one's day, cognitive processes may be sensitive to those fluctuations in negative and positive affect (Trilla et al., 2021; Rocke et al., 2009). Studies demonstrating the relationship between affect and cognition are most commonly laboratory based, thus the trait-based assessments are cross-sectional and consider between-person relationships with affect and cognition. In a study examining daily variability in working memory and daily negative affect, working memory performance was poorer on days with higher negative affect compared to lower negative affect reports (Brose et al., 2012). A more recent study using momentary assessment revealed higher momentary negative affect is associated with lower working memory capacities, which leads to interferences in higher-order cognitions such as problem-solving (Garrison & Schmeichel, 2020). Though research on daily negative affect and cognitive processes is not consistent. Self-rated changes in memory were not related to daily fluctuations in negative affect among a sample of older adults (Stawski et al., 2013).

Despite the substantial amount of literature on the relationship between positive affect and cognitive performance, it remains unclear how positive affect contributes to within-person fluctuations of cognitive performance on an intra-individual, or within-person level. Studies examining inter-individual differences find that mild amounts of positive affect are predictive of better cognitive performance (Bell et al., 2022), and most researchers suspect that the reason for this interference is that positive affect may interfere with cognition when it elicits heightened physiological arousal (i.e., quicker heartrate; Gerber et al., 2008; Madrid & Patterson, 2014; Nealis et al., 2015).

When considering positive affect, some findings are similar to that of negative affect, but other studies indicate that some degree of positive affect is beneficial to cognitive skills (Papatoniou et al., 2012). Studies examining positive affect and cognitive task performance, however, are typically laboratory based using mood induction or assessing trait positive affect. For example, Figueira and colleagues (2018) found that positive affect was a positive influence on working memory and facilitated better maintenance of goal-relevant information in the working memory. Conversely, another study induced positive mood states and found that performance on the Running Memory Span, a measure of working memory capacity, is negatively impacted by positive dispositions. The mixed findings highlight a need to better assess the connection positive affect has with cognitive process, especially in the context of momentary affective states.

Intraindividual Differences in Affect and Cognition Across Age

Reports of positive and negative affect tend to differ across ages. Among young and middle-aged adults, positive affect remains stable and may increase in older adulthood; while negative affect generally tends to decrease with older age (Charles & Carstensen, 2010; Charles et al., 2001). While emotion across age remains relatively stable, within-person differences are recognized and variability across age appears to differ. Yet, little research has investigated within-person differences by age as it pertains to momentary affect and cognition (Carstensen et al., 2000). Cognitive function tends to decline as people age, and since heightened emotions can impair cognitive processes, it may become increasingly challenging to engage in cognitive tasks effectively as one gets older (Karlamangla et al., 2014; Campbell et al., 2020).

Current Study

The purpose of this study was to examine how momentary affect, negative and positive, is associated with performance on momentary cognitive tasks including processing speed and working memory. Another aim of this study was to consider how the relationship between affective processes and cognitive performance throughout the day varies by age. For all ages, I hypothesized that working memory performance would be lower during moments of heightened negative affect. Moments of heightened negative affect are also predicted to be associated with slower processing speed. For positive affect, I predicted that performance on all three cognitive measures will be poorer during times of increased positive affect. Older age was expected to moderate the hypothesized main effects of momentary affect by exacerbating the negative relationship between heightened negative and positive affect and momentary cognitive task performance.

METHOD

Study Design and Procedures

The present study used data from The Effects of Stress on Cognitive Aging, Physiology and Emotion (ESCAPE) project (Scott et al., 2015). ESCAPE data is publicly accessible and can be requested through the Center for Open Science at https://osf.io/4ctdv/. The longitudinal study began in 2003 and was approved by the ethical review board of The Albert Einstein College of Medicine of Yeshiva University. The project used a measurement burst design that allowed for the investigation of intra-individual differences over short periods of time (e.g., minutes, hours, days) and longer intervals (e.g., months, years). In total, four waves of data were collected including a baseline assessment and follow-up waves at 9-, 18-, and 27-months post-baseline. After the conclusion of each wave, participants received up to $160 in compensation based on their compliance rate.

Participant eligibility for the study included: 25 – 65 years of age, English-speaking, ambulatory, able to operate the study smartphone (i.e., free of visual impairments that would interfere), and a resident of Bronx County, New York. Participants were also ineligible if they were unable to answer the smartphone surveys throughout their day for reasons such as having work or personal commitments that interfere with engaging in the study, and if they scored 25 or lower on the mini-mental state examination (an indicator of dementia). Systematic probability sampling was used for recruitment to gather a racially and economically diverse sample. A sampling pool was created using the New York City Registered Voter Lists (RVL). Then, individuals from RVL were sorted into 10-year age groups denoting one sampling block, and each sampling block included 450 possible participants. Participants were first contacted by mail with a letter introducing the study's aims and how they were identified. Follow-up telephone calls were made within two weeks of sending letters to build rapport, assess for exclusion criteria, and enroll participants in the study.

During each wave, participants were given a study smartphone to complete a two-week measurement burst. Training sessions guided them in operating the smartphone surveys and tasks. Before the measurement burst began, participants visited the lab where they completed cognitive performance tasks and baseline surveys asking about demographics, physical and mental health, as well as potential psychosocial moderators (e.g., stress, feelings). The same measures were completed again at the conclusion of the study wave. Over the course of 14 consecutive days, participants responded to an alarm to complete ecological momentary assessments once in the morning, five times throughout the day, and once at bedtime – resulting 70 in momentary observations. To assist with compliance and answer any questions, research assistants made follow-up phone calls after day one and again after the first week. After the measurement burst, participants visited the lab to return their smartphones and complete end-of-study questionnaires.

Participants

Due to attrition across the three waves of data collection, only the first wave of data collected from ESCAPE were used resulting in a total of 260 adults with the average age of 46 years (range: 25 – 65). The sample is mostly female ($N = 172$, 65%), primarily Black or African American racial/ethnic identity (N = 167, 63%), 70% have at least some college education and on average an annual income of $40,000. Half of the participants were employed (N = 132, 50%) and many in the sample were single (N = 178, 67%).

Baseline Measures

Demographics

Information on participants' gender (male/female), age, race and ethnicity, education, income, work status and marital status were gathered. Participants were able to select more than one race/ethnicity including Caucasian, Black or African American, Hispanic/White, Hispanic/Black, Asian, or other. Education was assessed with five categories ranging from grade school or less to graduate or professional degree, and annual income was reported through eight categories starting from <$4,999 to $150,000 or greater. Work status was reported as either employed; retired; unemployed and looking for work; unemployed and not looking for work and marital status as married to first spouse; remarried; divorced; separated; never married; not married but living with someone; and other.

Ecological Momentary Assessments

Affect

Affect was captured via smartphone before cognitive assessments. Positive and negative affect were rated with alternating positive and negative words at five separate times throughout the day. Using items chosen based on Diener and Emmons (1984). The four items comprising positive affect, include happy, enjoyment/fun, joyful, and pleased. The negative affect items include tense, depressed, angry, unhappy, and frustrated. Participants were prompted on their screens with the various affective descriptors and asked to rate how well each of the items described how they felt "right now". Responses were answered using a sliding bar on the screen ranging from 0 (not at all) to 100 (extremely).

Cognition

Through each of the 14 days, cognition was assessed five different times using a smartphone. Participants completed three tasks in a fixed order which tested: processing speed, visual working memory and spatial working memory (Scott et al., 2015; Sliwinski et al., 2018). Figures 1.1, 1.2, and 1.3 provide visuals of the ambulatory cognitive tasks.

Processing Speed. In each of the 16 consecutive trials, participants examine three symbol pairs on the top of the smartphone screen and compare it to the two symbol pairs located at the bottom of the screen (see Figure 1.1). To assess processing speed, participants must decide as quickly as possible which pair of symbols at the bottom match up with any of the three symbol pairs on the top of the screen. Each assessment included a total of 16 symbol comparison trials. Processing speed is scored using 'throughput', a composite response measure calculated by dividing the percent correct (correct response per minute) with average reaction time (Thorne, 2006). Higher scores represent better processing speed.

Working Memory. Participants completed two momentary working memory tasks. The first task is a modified version of the N-back paradigm using a 2-back condition for their second cognitive task (see Figure 1.2; (Scott et al., 2015; Verhaeghen & Basak, 2005). Three standard playing cards in boxes first appear face-up on the phone screen. Participants determine if the first and third cards match, and then the cards are turned face-down. The left most card then disappears, as the other two cards move one box to the left. A new card is then presented face-up in the right most spot. Finally, participants decide whether the cards in the first and third boxes match. A total of 12 trials were completed. Scores for the n-back tasks were calculated using throughput, a composite measure of the proportion of correct responses per minute with average reaction time (Thorne, 2006). Higher scores represent better working memory performance.

For the second task, a location dot memory task has participants memorize the location for three red dots (see Figure 1.3). The three red dots are presented on a 5x5 grid for three seconds, then a visual distractor exercise is completed for eight seconds and after participants are asked to recall the location of the three red dots. This task was performed across two trials. To score the dot memory task, Euclidean distance is calculated based on the distance of the location of the incorrect dot compared to the correct grid location (Sliwinski et al., 2018). Higher scores indicate less accurate placement of the dot and worse working memory performance.

Analytic Plan

The total sample consisted of 260 people. Demographic variables were coded into categories for the analysis. Since much of the sample were Black/African American (63%) with other categories comprising fewer than 10% of the sample the categories for racial/ethnic identity were collapsed into three categories: White, Black/African American, and "Other" which includes "Non-White Hispanic" and "Asian". The categories for education were reduced from six to five because participants who responded that they completed grade school or less (.5%) were combined with the participants who completed some high school (5.4%). For income, participants could respond to eight options, one of which was "decline to answer". The observations under "decline to answer" ($N = 22$, 8.5%) were removed from the variable for final analysis. When reporting work status, participants had the following options: employed, retired, unemployed and looking for work, or unemployed and not looking for work. For parsimony, work status was dichotomized into "working" (employed, 50.51%) and "not working" [includes: retired (14.09%), unemployed and looking for work (27.18%), unemployed and not looking for work (8.21%)]. Additionally, marital status was dichotomized into "partnered" [includes married to first spouse (22.99%), remarried (8.74%), not married but living with someone (8.98%)] and “not partnered” [includes divorced (9.82%), separated (4.73%), never married (35.61%), widowed (2.78%), “other” (6.36%)].

To test our hypotheses, SAS version 9.6 (PROC MIXED) was used with residual (restricted) maximum likelihood (REML) estimation for the analysis. Separate models were analyzed for each of the three cognitive outcomes (processing speed and working memory (n-back, dot memory). Level 1 continuous covariates and predictors were grand-mean centered. Level 2 predictors in our models were person-mean centered. Multi-level models examined how momentary reports of affect and repetitive thinking (within-person level 1 variables) relate to momentary performance on processing speed and working memory tasks. This procedure also allowed for the investigation of interactive effects between affect and cognition, as well as moderation effects of age. Each model adjusted for age, gender, racial/ethnic identity, income, education, work status, and marital status.

RESULTS

The participant characteristics, as well as the bivariate correlations for the variables of interest are presented in Table 1.1. Most participants identified as Black, female, and single. Most respondents had at least some college education (70%), and 50% of participants fell between an annual income of $20,000 and $60,000 dollars.

Three momentary cognitive measures: processing speed, working memory, and spatial working memory, were used as separate outcomes. For each outcome, a three multi-level model was conducted to estimate the main effects of the predictors and covariates. Then, a second model included interactions for both negative and positive affect with age. The main effects and interaction effects models for the processing speed task can be viewed on Table 1.2, Table 1.3

for the first working memory task (n-back) on Table 1.4, and Table 1.5 includes results for the dot memory task of working memory.

Negative Affect

Momentary negative affect was first tested as a predictor of momentary processing speed (i.e., symbol search). Momentary negative affect was not significantly associated with processing speed ($\gamma = -0.00$, $t(220) = -1.63$, $p = .10$). However, trait negative affect was related to overall worse processing speed across the measurement point ($\gamma = -0.0006$, $t(220) = -2.68$, $p < .01$).

Next, momentary negative affect was tested as a predictor of working memory, looking first at the n-back task performance. Lower performance on momentary tasks of working memory (N-back) was related to moments of greater negative affect ($\gamma = -0.0004$, $t(221) = -2.43$, $p = .02$). Similarly, trait negative affect was significantly related to lower levels of working memory ($\gamma = -0.003$, $t(221) = -3.23$, $p < .01$).

Although trending in the expected direction for dot memory (second working memory task), the association between momentary negative affect and momentary working memory was not significant ($\gamma = -0.001$, $t(221) = -1.67$, $p = .09$). Similar to the result for processing speed and the first working memory task (n-back), poorer performance on the dot memory task was related to higher levels of trait negative affect ($\gamma = -0.01$, $t(221) = -3.06$, $p < .01$).

Positive Affect

Momentary positive affect was not associated with momentary performance on processing speed ($\gamma = 0.000$, $t(220) = 1.47$, $p = .14$), but higher trait positive affect was significantly related to worse momentary processing speed ($\gamma = -0.001$, $t(220) = -2.23$, $p = .03$).

In moments of higher positive affect, performance on the n-back (working memory) was significantly lower compared to moments of average or lower positive affect ($\gamma = -0.003$, $t(221)$

= -2.03, *p* =.04). In contrast, trait positive affect was unrelated to the n-back (working memory) (γ = -0.001, *t*(221) = -1.54, *p* =.12).

Momentary dot memory performance (working memory) was unrelated to momentary positive affect (γ = -0.00, *t*(221) = -0.56, *p* =.57), and unrelated to trait positive affect (γ = -0.006, *t*(221) = -1.59, *p* =.11).

Age

Across all three models, older age was associated with poorer cognitive performance (processing speed: γ = -0.002, *t*(222) = -6.28, *p* < .0001; working memory (N-back): γ = -0.011, *t*(222) = -8.18, *p* < .0001; spatial working memory (dot memory): γ = -0.02, *t*(223) = -3.11, *p* < .01).

Moderation of Negative Affect

Age did not moderate the effect of momentary negative affect on working memory for the n-back (γ = 0.000, *t*(221) = 0.70, *p* =.48) or dot memory task (γ = -0.000, *t*(221) = -0.47, *p* =.64). Results showed a significant moderation effect of age on momentary negative affect and processing speed task performance (γ = -7.22E-6, *t*(221) = -2.31, *p* =.02).

The significant interaction was probed in two ways. First, the interaction was probed as a categorical-by-categorical interaction. Age was divided into three categories including younger (25 to 40 years), middle-aged (41 to 53 years), and older adults (54 to 65 years). Then, negative affect was also separated into groups representing low, medium, and high levels of negative affect. The mean differences in slopes were statistically significant (see Figure 1.4). I next probed the continuous-by-continuous interaction by examining the mediator (age) at +1 and -1 standard deviation from the mean, as well as at the mean (See Figure 1.5) *M* = 46.49, *SD* = 11.02). Heightened negative affect led to poorer processing speed, for younger adults (*b* = -

0.00013, t(259), -3.68, *p* < .001) and middle-aged adults (*b* = -0.00007, t(259), -2.83, *p* < .01), but not older adults (*b* = -0.00002, t(259), -0.41, *p* = .69).

Moderation of Positive Affect

Age did not significantly moderate the relationship between momentary positive affect and processing speed (γ = -0.000, *t*(220) = -0.75, *p* =.45). The association between positive affect and performance on the dot memory task (working memory) did not vary based on age (γ = 0.000, *t*(221) = 1.06, *p* =.29).

Age significantly moderated how increased momentary positive affect related to the n-back task for working memory (γ = 3.6E-5, *t*(221) = 2.57, *p* =.01). The interaction effect was probed to understand how age adjusts the relationship between positive affect and working memory. I probed the interaction first as a categorical-by-categorical interaction, and then as the original continuous-by-continuous interaction. Age was separated into younger (25 to 40 years), middle-aged (41 to 53 years), and older adults (54 to 65 years), and negative affect was separated into groups representing low, medium, and high levels. Figure 1.6 depicts the pattern in mean differences on the n-back task based on age groups and levels of positive affect. To probe the continuous-by-continuous interaction, I examined the mediator (age) at +1 and -1 standard deviation from the mean, as well as at the mean (See Figure 1.7) *M* = 46.49, *SD* = 11.02). Heightened positive affect led to poorer processing speed, for younger adults (*b* = -0.00013, t(259), -3.68, *p* < .001) and middle-aged adults (*b* = -0.00007, t(259), -2.83, *p* < .01), but not older adults (*b* = -0.00002, t(259), -0.41, *p* = .69).

Exploratory Analyses

Based on the significant interactions observed between age, affect, and cognition, exploratory analyses were conducted to ascertain whether specific types of negative and positive affect exhibit stronger associations with age and cognitive function. Pearson correlations were conducted to explore the relationships between the five negative affect items: tense, angry, depressed, frustrated, and unhappy. Age was significantly negatively correlated with anger (r = - .04, $p < .01$), and frustration (r = - .03, $p < .01$). All five negative affect items were significantly correlated with processing speed and working memory. Correlations between cognition and feeling angry and depressed were strongest (See Table 1.5). Four positive affect items were included in the measure: happy, pleased, enjoyment/fun, and joyful. Pearson correlations, provided in Table 1.6, demonstrate that for all four items, higher positive affect was significantly correlated with older age. Pleased, enjoyment/fun, and joyful had stronger correlations with processing speed and the n-back working memory task, compared to the correlations with happy.

DISCUSSION

The purpose of this study was to understand how differences in state-level negative and positive affect relate to cognitive performance on a momentary basis. Additionally, I investigated how the interaction between momentary affect and age is associated with differences in performance on cognitive tasks for processing speed and working memory. Age was hypothesized to moderate affect and cognition, such that older age combined with heightened affect (negative and positive) will result in poorer performance on all cognitive tasks, compared to younger adults with heightened affect.

Findings provide additional evidence that affective factors are related to differences in cognition. In line with previous inferences, our results support the theory that elevated negative affect, both trait and state, is associated with detrimental effects on cognitive task performance (Payne & Schnapp, 2014; Stawski et al., 2019). I also found that momentary increases in positive affective states are associated with declines in cognitive function. This result maintains the idea that elevated affective states, regardless of valence, may interfere with temporary cognitive processes (Dreisbach, 2006).

Negative Affect

Greater trait negative affect was related to poorer performance across all three momentary cognitive tasks. This finding is generally consistent with prior literature linking increased negative affect with poorer cognitive function (Gillet et al., 2013; Hulur et al., 2015; Negative affect could be related to poorer cognitive function through related factors such as lifestyle or health habits that ultimately lead to cognitive impairments (Korthhauer et al., 2018).

In moments when participants experienced increased levels of negative affect, their cognitive performance on repeated assessments of processing speed and working memory (dot memory) appeared to be unaffected. However, in moments of heightened negative affect, individuals performed significantly worse on the N-back working memory task compared to moments when they reported lower levels negative affect. While the null relationship between momentary negative affect and processing speed and working memory (dot memory) did not fall in line with the hypotheses, both estimates were approaching significance (γ = -1.63, p = 0.10; γ = -1.67, p = 0.09) which are the same direction (i.e., negative relationship) as the estimate for the N-back test for working memory. It is likely that the non-significant results between negative affect and the dot memory task stem from the measure lacking within-person variability (Sliwinski et al., 2018).

Examining the direct effect of momentary affect and cognitive task performance across adults is a quickly developing area; though, there are contextual factors to consider within this dataset. To better understand the types of negative affect most associated with momentary cognitive performance, the discrete negative affect items were tested in the models. In Table 1.5, the correlations between the separate items for negative affect and the momentary cognitive measures can be viewed. All negative affect items (angry, tense, depressed, frustrated, and unhappy) were all significantly negatively correlated with cognition; however, the correlations were not large and only modestly significantly correlated with each other.

Positive Affect

Trait-level positive affect was significantly related to worse performance on tasks of processing speed, but not with either working memory tasks (N-back and dot memory). When individuals reported increased moments of positive affect, their performance on the N-back working memory task decreased. This was not the case for momentary performance on processing speed and the dot memory task. Elevated momentary positive affect was a significant predictor of poorer working memory (N-back) contributing to novel EMA research on affective processes and cognition (Pupillo et al., 2022). While the significant finding for processing speed performance was in line with my hypotheses, the literature does not necessarily align with the results (Yang et al., 2013). Positive affect has not consistently predicted cognitive performance in one direction or the other (Dreisbach, 2006). These mixed findings are perhaps due to the types of positive emotions measured.

Some research suggests that positive affect may have different influences on cognitive processes, based on valence and arousal levels (Bagozzi, 1994; Luo et al., 2023; Pedersen et al., 2011). One way of explaining how affect impacts an individual is based on arousal and that positive affect ranges from low (e.g., relaxed, calm) to high (e.g., excited, happy). Based on the potential that positive may relate to cognitive processes differently based on arousal levels, I explored which discrete emotions within positive affect may be driving the significant relationship. I suspected that high arousal emotions are the ones responsible for significant findings. Based on exploratory correlations (see Table 1.6), happy has the weakest correlation with age, which is consistent with literature finding that happy falls into the low-arousal category (Cudo et al., 2018).

Age Moderating Affect and Cognition

One aim of the present study was to understand how momentary affective processes related to momentary cognitive function across ages including younger to older adults (range of 25 to 65 years). The results showed that age significantly moderated the relationship between momentary negative affect and processing speed, as well as momentary positive affect and working memory (N-back). Probing the interaction showed that the effect between heightened negative affect and poorer processing speed was only significant among younger and middle-aged adults. It was also the case that younger and middle-aged adults with greater momentary positive affect performed worse on working memory tasks, compared to older adults. Some research has demonstrated that intraindividual differences in positive affect are not as strong among older adults (Rocke et al., 2009). However, when considering intraindividual variation in cognitive functioning, there could be age-based variation not captured within this sample. In this sample, older adults showed significantly less variability in PA and NA than young adults.

Implications

There are both theoretical and practical implications surrounding the findings within this study. The inconsistencies in the findings between negative and positive affect, and types of momentary working memory tasks reveal that there is more to understand regarding the links between momentary affective states and cognitive processes. With positive affect especially, measuring both perceived and objective affective arousal level, may be a necessary factor in understanding how changes in momentary affect lead to cognitive interference.

Limitations and Future Directions

While this study provides valuable insight into how cognitive performance can vary through intra-individual differences in affect and age, it is important to recognize the limitations. Despite having repeated measures, the analyses were cross-sectional and correlational. Given that, I are prevented from drawing any causal predictions for the factors related to variability in momentary cognition. Future research assessing how cognitive function varies on an intra-individual level should focus on including momentary assessments of affective processes. Employing longitudinal research on low and high arousal emotions among a population of adults beyond ages 65 may reveal more about the specific ages at which affect may become more or less of an interference to cognition.

The bi-directional nature of emotions and cognition should also be considered for future research. Prior research provides evidence for intraindividual variability in cognitive performance which may also then account for changes in emotions, especially momentary affective states. Another limitation of this study was that physiological measures related to affective states, such as cortisol or pro-inflammatory cytokines, were not available to analyze within this sample. Additional studies should evaluate the underlying psychological and physiological pathways linking negative affect and cognitive function, especially on a momentary basis. It could be that the negative affect is creating interference through a difference mechanism such as rumination.

Conclusion

This study aimed to understand how momentary fluctuations in negative and positive affect related to performance on cognitive tasks of working memory and processing speed. Additionally, the moderating role of age was investigated, and it was found that younger to middle-aged adults experienced the most cognitive interference based on heightened negative and positive affect. The findings revealed that elevated negative affect was associated with poorer cognitive performance across tasks, while momentary increases in positive affect were linked to declines in working memory. Age was found to moderate these relationships, with younger and middle-aged adults being more susceptible to the effects of negative affect on processing speed, and younger adults experiencing greater interference from positive affect on working memory. Additional research is needed to gain a deeper insight into the potential pathways explaining the links between heightened affect and cognition.

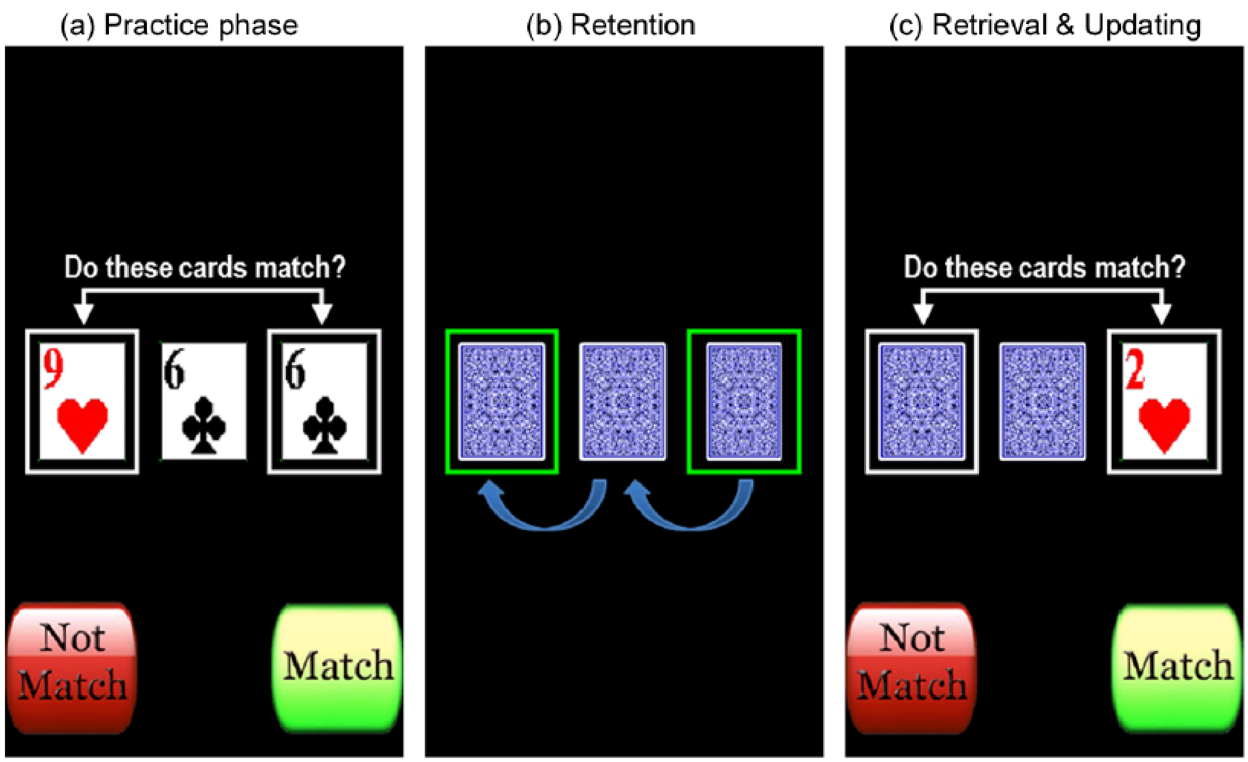
Figure 1.1

Symbol Search Test

Note. An example of one trial from the symbol search test. The test measures processing speed by asking participants to decide as quickly as possible which of the two pairs at the bottom of the screen match a symbol pair at the top of the screen.

Figure 1.2

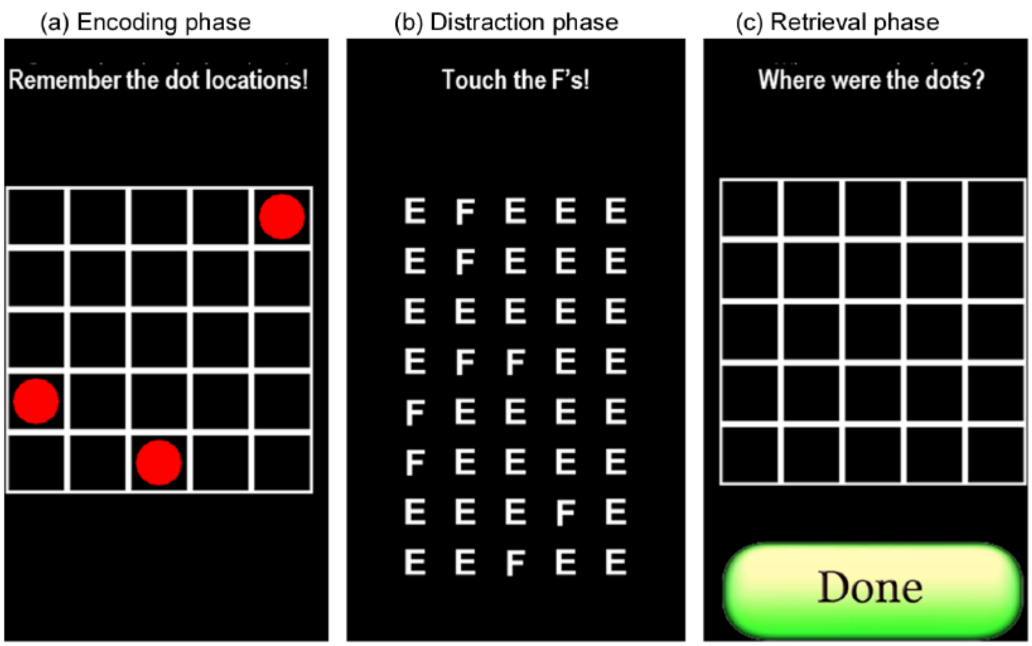
Modified N-Back Paradigm



Note. An example of the n-back test completed by participants. In the practice phase (a) participants decide if the two cards match while they are facing up. Next, cards are shifted from right to left and the new target cards are now face down (b). Participants then go through retrieval and updating (c) where they determine if the new target card matches the facedown card presented two phases prior.

Figure 1.3

Dot Memory Task



Note. One example of the dot memory test for spatial working memory. Participants are shown three red dots for three seconds (a), then asked to engage in a distraction phase (b), and the retrieval phase (c) asks participants to recall where the three dots were located.

Table 1.1

Study 1 Descriptives and Correlations

Variable	*N*	*M (SD)* % or [range]	1	2	3	4	5	6	7	8	9	10	11	12
1. Age	260	46.49 (11.09) [25 - 65]	1											
2. Gender	260		0.02	1										
Male	91	35												
Female	169	65												
3. Racial/Ethnic Identity[1]	260		**-0.12**	-0.08	1									
White	22	8.46%												
Black	165	63.46%												
Other	73	28.08%												
4. Income[2]	236	3.83 (1.69) [1 - 8]	0.08	0.08	-0.11	1								
5. Education[3]	260	3.3 (1.14) [1 – 5]	0.09	-0.01	**-0.15**	**0.34**	1							
6. Work Status	158		**-0.17**	-0.08	0.00	**0.28**	**0.15**	1						
Working	130	50.4%												
Not Working	128	49.6%												
7. Partnered	259		**0.18**	**0.13**	0.08	**0.45**	0.12	0.01	1					
Yes	81	32.1%												
No	178	67.2%												
8. Negative Affect[4]	260	23.07 (15.85) [0 – 100]	-0.05	-0.04	0.10	**-0.19**	0.04	-0.02	0.00	1				
9. Positive Affect [4]	260	61.18 (18.40) [0 – 100]	**0.14**	0.08	-0.03	0.04	-0.18	-0.07	-0.02	**-0.50**	1			
10. Processing Speed[5]	259	0.23 (.05)	**-0.40**	-0.03	0.11	**0.16**	**0.16**	**0.20**	-0.06	-0.10	**-0.13**	1		
11. N-back Working Memory6	260	0.7 (.25)	**-0.50**	0.08	0.04	0.05	0.03	0.11	-0.07	**-0.14**	-0.06	**0.63**	1	
12. Dot Memory Working Memory[6]	260	-1.84 (.91)	**-0.15**	**0.17**	-0.05	**0.26**	**0.27**	0.04	0.08	**-0.21**	-0.03	**0.45**	**0.37**	1

Note. *N* is used to represent the number of respondents for each variable, % stands for the percentage of the sample, M and SD denote mean and standard deviation. Significant correlation values are bolded. [1]White represents non-Hispanic White/Caucasian and "Other" includes Hispanic-White, Hispanic-Black, and Asian. [2]Annual income was treated as a continuous variable; income was reported with eight categories between <$4,999 to $150,000 or greater. [3]Education was measured using five categories ranging from completion of grade school or less, to a graduate or professional degree. [4]Value accounts for the person-level variables averaged across 14 days. [5]Processing speed was measured using a symbol search test and was reverse-coded, the mean value is for the average error score across 14 days. [6]The mean value represents average performance across 14 days.

Table 1.2

Main & Interactive Effects of Momentary Affect and Age on Processing Speed with Covariates

Parameters	*γ*	*SE*	*t*	*p*	95% CI Lower	95% CI Upper
Intercept	0.2128	0.01313	16.21	<.0001	0.1870	0.2387
Beep	-0.00112	0.000280	-4.00	<.0001	-0.00167	-0.00057
Day	0.001795	0.000110	16.32	<.0001	0.001580	0.002011
Age	-0.00199	0.000317	-6.28	<.0001	-0.00261	-0.00136
Gender	-0.00009	0.006955	-0.01	0.9901	-0.01379	0.01362
Racial/Ethnic Identity	-0.01874	0.01309	-1.43	0.1537	-0.04454	0.007058
Education	-0.03378	0.01574	-2.15	0.0330	-0.06479	-0.00276
Work Status	0.002895	0.007088	0.41	0.6833	-0.01107	0.01686
Partnered	-0.01186	0.008084	-1.47	0.1438	-0.02779	0.004072
Income	0.006077	0.002373	2.56	0.0111	0.001401	0.01075
Main Effects	***γ***	***SE***	***t***	***p***	**95% CI Lower**	**95% CI Upper**
Negative Affect[1]	-0.00047	0.000211	-2.23	0.0265	-0.00089	-0.00006
Momentary Negative Affect	0.000042	0.000029	1.47	0.1409	-0.00001	0.000099
Positive Affect[1]	-0.00066	0.000247	-2.68	0.0079	-0.00115	-0.00018
Momentary Positive Affect	-0.00005	0.000033	-1.63	0.1041	-0.00012	0.000011
Interaction Effects	***γ***	***SE***	***t***	***p***	**95% CI Lower**	**95% CI Upper**
Negative Affect *Age	-7.22E-6	3.125E-6	-2.31	0.0208	-0.00001	-1.1E-6
Positive Affect * Age	-1.93E-6	2.567E-6	-0.75	0.4519	-6.96E-6	3.101E-6

Note. [1]Person-level average of momentary negative and positive affect across 14 days. Day and Beep are included in the models to account for practice effects.

Table 1.3

Main & Interactive Effects of Momentary Affect and Age on Working Memory (N-back) with Covariates

Parameters	***γ***	***SE***	***t***	***p***	**95% CI**	
					Lower	**Upper**
Intercept	0.6112	0.05722	10.68	<.0001	0.4984	0.7239
Beep	-0.00579	0.001545	-3.75	0.0002	-0.00882	-0.00276
Day	0.01604	0.000574	27.91	<.0001	0.01491	0.01716
Age	-0.01123	0.001373	-8.18	<.0001	-0.01393	-0.00852
Gender	0.04837	0.03029	1.60	0.1117	-0.01132	0.1081
Racial/Ethnic Identity	-0.03017	0.05696	-0.53	0.5969	-0.1424	0.08207
Education	-0.1653	0.06848	-2.41	0.0166	-0.3002	-0.03031
Work Status	-0.00541	0.03084	-0.18	0.8609	-0.06618	0.05536
Partnered	-0.03515	0.03518	-1.00	0.3188	-0.1045	0.03417
Income	0.01230	0.01032	1.19	0.2345	-0.00804	0.03264
Main Effects	***γ***	***SE***	***t***	***p***	**95% CI**	
					Lower	**Upper**
Negative Affect[1]	-0.00346	0.001072	-3.23	0.0014	-0.00557	-0.00135
Momentary Negative Affect	-0.00044	0.000182	-2.43	0.0151	-0.00080	-0.00009
Positive Affect[1]	-0.00141	0.000916	-1.54	0.1245	-0.00322	0.000393
Momentary Positive Affect	-0.00032	0.000156	-2.03	0.0419	-0.00062	-0.00001
Interaction Effects	***γ***	***SE***	***t***	***p***	**95% CI**	
					Lower	**Upper**
Negative Affect *Age	0.000012	0.000017	0.70	0.4846	-0.00002	0.000045
Positive Affect * Age	0.000036	0.000014	2.57	0.0102	8.487E-6	0.000063

Note. [1]Person-level average of momentary negative and positive affect across 14 days. Day and Beep are included in the models to account for practice effects.

Table 1.4

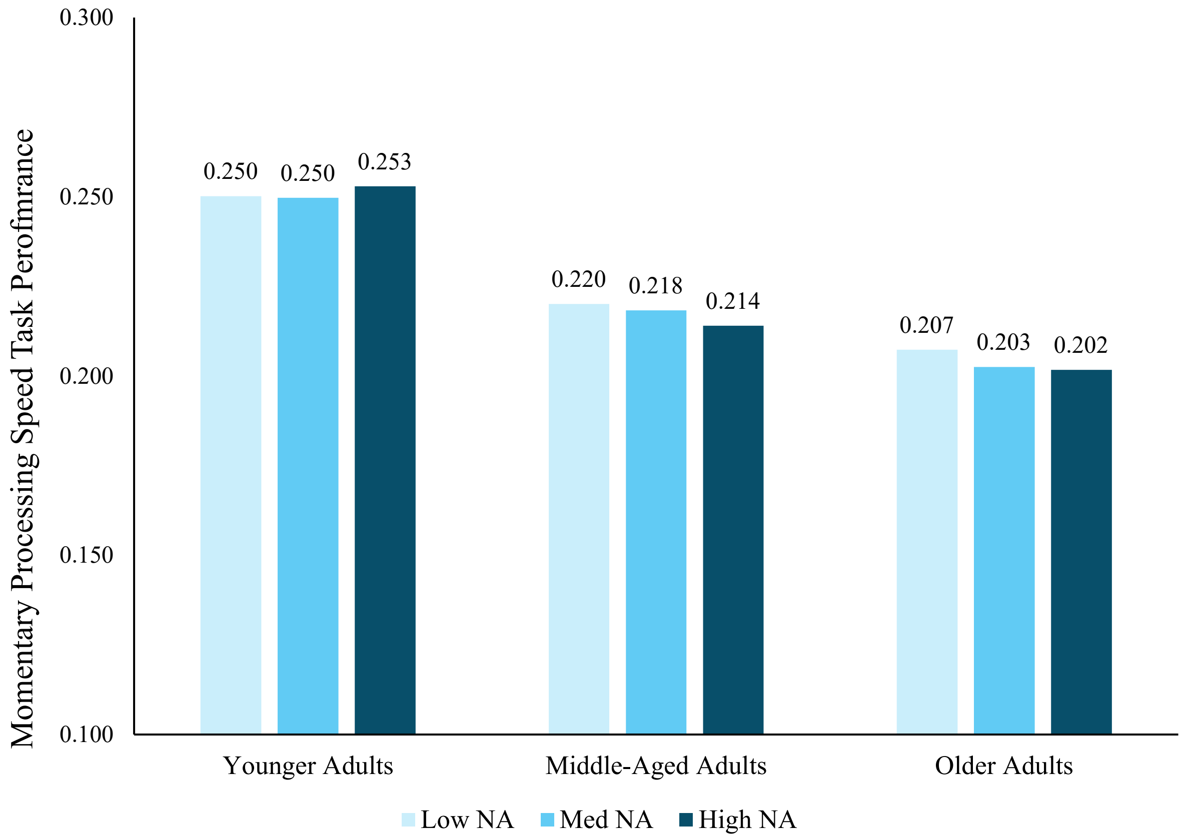
Main & Interactive Effects of Momentary Affect and Age on Working Memory (Dot Memory Task) with Covariates

Parameters	*γ*	*SE*	*t*	*p*	95% CI Lower	95% CI Upper
Intercept	-2.13410	0.22290	-9.57	<.0001	-2.5735	-1.6948
Beep	-0.04335	0.00662	-6.55	<.0001	-0.05633	-0.03038
Day	0.01611	0.00245	6.58	<.0001	0.01131	0.02091
Age	-0.01662	0.00535	-3.11	<.001	-0.02716	-0.00609
Gender	0.36510	0.11790	3.10	<.001	0.1328	0.5974
Racial/Ethnic Identity	0.02180	0.22180	0.10	0.92	-0.4153	0.4589
Education	-0.60590	0.26670	-2.27	0.02	-1.1314	-0.08042
Work Status	-0.15060	0.12010	-1.25	0.21	-0.3872	0.08600
Partnered	-0.02495	0.13700	-0.18	0.86	-0.2948	0.2449
Income	0.11060	0.04020	2.75	0.01	0.03143	0.1899
Main Effects	*γ*	*SE*	*t*	*p*	95% CI Lower	95% CI Upper
Negative Affect[1]	-0.01276	0.00418	-3.06	<.001	-0.02098	-0.00453
Momentary Negative Affect	-0.00130	0.00078	-1.67	0.09	-0.00282	0.00023
Positive Affect[1]	-0.00569	0.00357	-1.59	0.11	-0.01273	0.00135
Momentary Positive Affect	-0.00038	0.00067	-0.56	0.57	-0.00169	0.00093
Interaction Effects	*γ*	*SE*	*t*	*p*	95% CI Lower	95% CI Upper
Negative Affect *Age	-0.00003	0.00007	-0.47	0.64	-0.00018	0.00011
Positive Affect * Age	0.00006	0.00006	1.06	0.29	-0.00005	0.00018

Note. [1]Person-level average of momentary negative and positive affect across 14 days. Day and Beep are included in the models to account for practice effects.

Figure 1.4

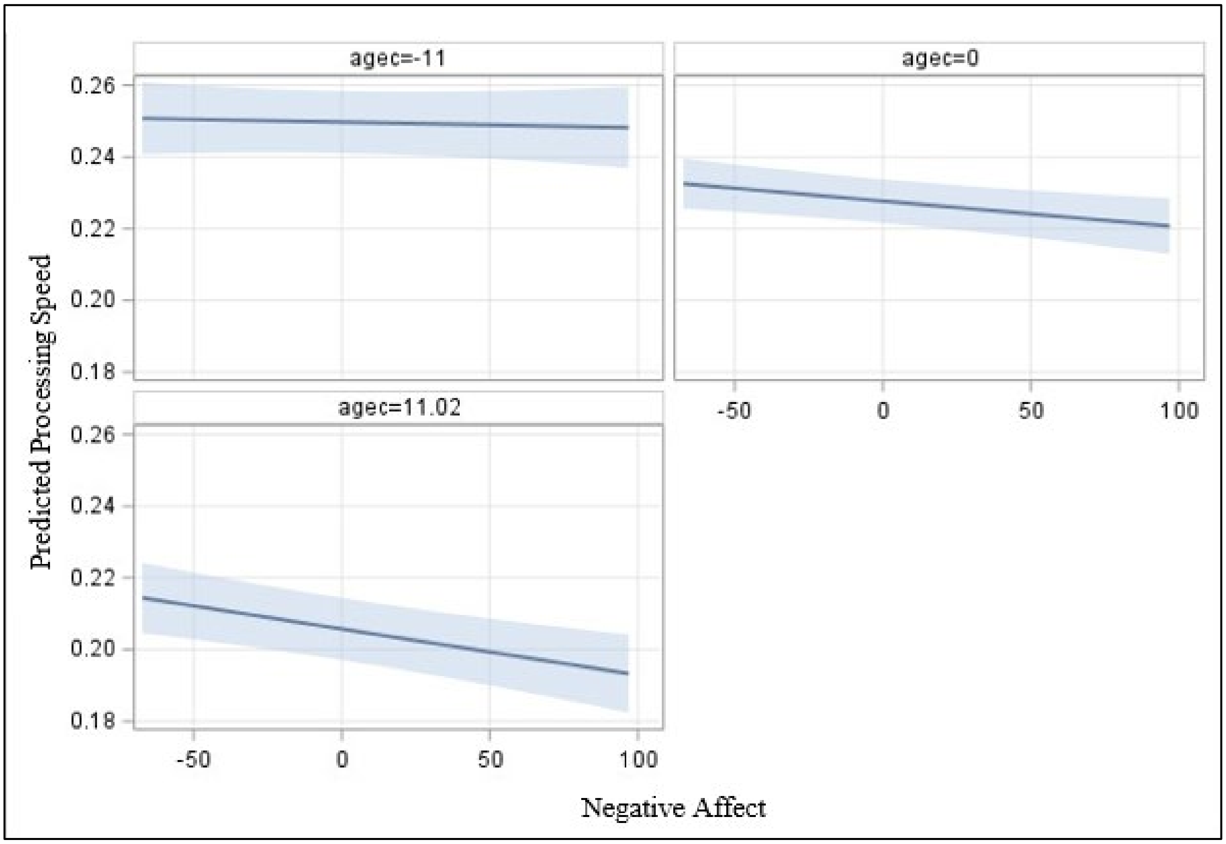
Mean Differences in Processing Speed Based on Negative Affect and Age



Note. The differences between each group were statistically significant ($p < .0001$). Younger adults ranged in ages 25 to 40 years old, middle-aged adults ranged from 41 to 53, and older adults were between the ages 54 and 65 years.

Figure 1.5

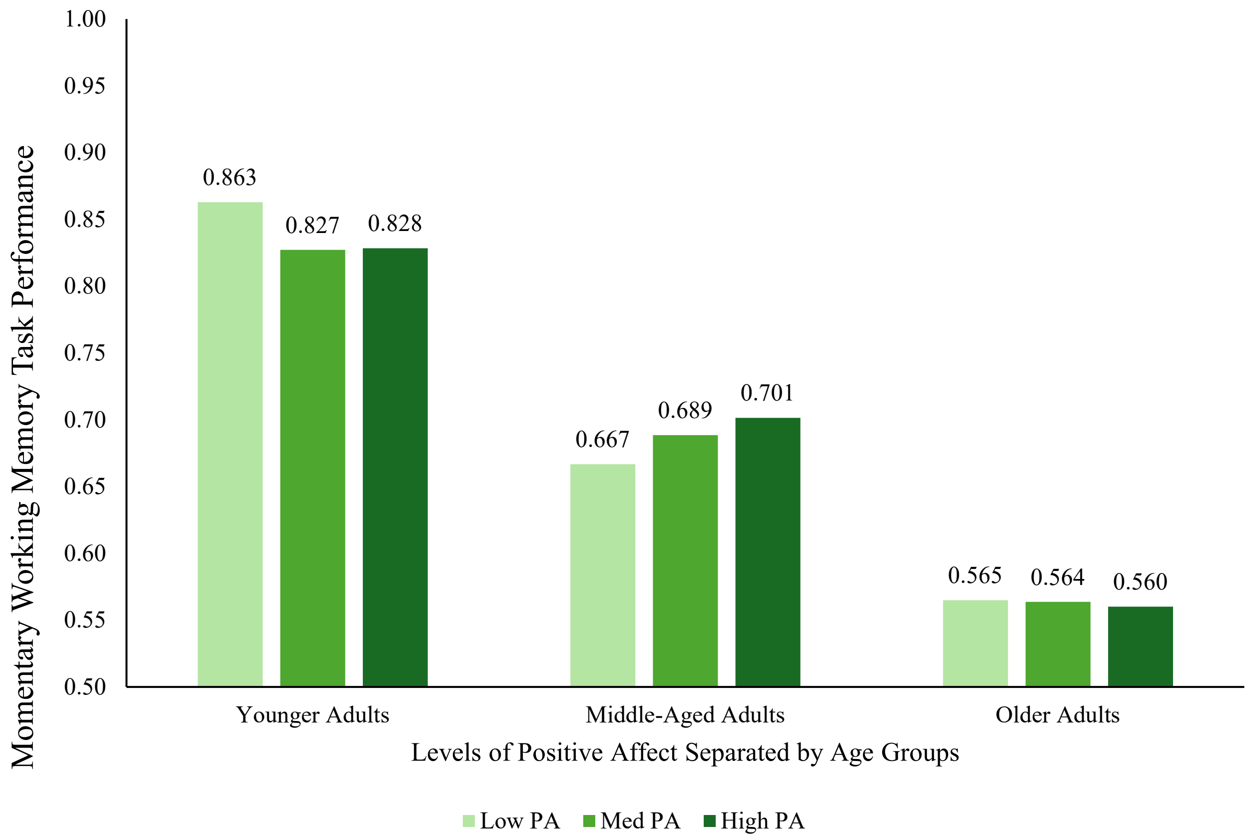
Probing of Simple Slopes for the Interaction between Negative Affect and Age on Processing Speed



Note. 95% Confidence Intervals displayed. Agec = Age mean- centered, probed at +1 standard deviation above the mean (+11.02), -1 below the mean (-11.02), and at the mean (0). The slopes for -1 below (younger) and at the mean (middle-aged) were significantly different from zero.

Figure 1.6

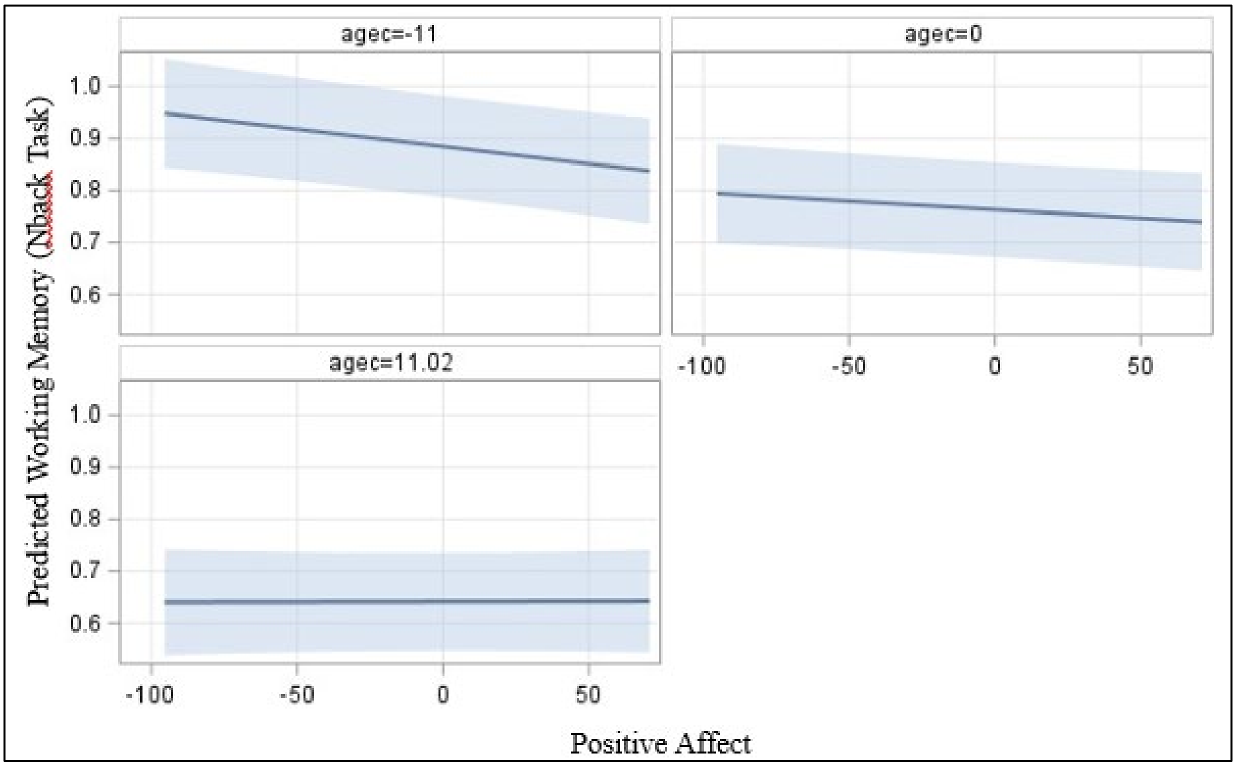
Differences in Momentary Working Memory (N-back) Based on Positive Affect and Age



Note. The differences between each group were statistically significant ($p < .0001$). Younger adults ranged in ages 25 to 40 years old, middle-aged adults ranged from 41 to 53, and older adults were between the ages 54 and 65 years.

Figure 1.7

Probing of Simple Slopes for the Interaction between Positive Affect and Age on Working Memory (N-back Task)



Note. 95% Confidence Intervals displayed. Agec = Age mean- centered, probed at +1 standard deviation above the mean (+11.02), -1 below the mean (-11.02), and at the mean (0). The slopes for -1 below (younger) and at the mean (middle-aged) were significantly different from zero.

Table 1.5

Exploratory Correlations between Negative Affect Items, Momentary Cognitive Tasks, and Age

Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Age	1									
Average NA	**-0.02**	1								
Tense	-0.01	0.58	1							
Angry	**-0.04**	0.61	0.63	1						
Depressed	0.001	0.70	0.56	0.64	1					
Frustrated	**-0.03**	0.62	0.67	0.68	0.68	1				
Unhappy	-0.003	0.65	0.60	0.65	0.74	0.77	1			
Processing Speed[1]	-0.31	-0.08	**-0.05**	**-0.08**	**-0.08**	**-0.04**	**-0.06**	1		
WM (N-back)[1]	-0.36	-0.09	**-0.05**	**-0.04**	**-0.09**	**-0.05**	**-0.08**	0.44	1	
WM (Dot Memory)[1]	-0.12	-0.13	**-0.10**	**-0.12**	**-0.11**	**-0.08**	**-0.09**	0.26	0.19	1

Note. [1]Represents averaged momentary performance on processing speed and working memory tasks. Bolded correlations are significant.

Table 1.6

Exploratory Correlations between Positive Affect Items, Momentary Cognitive Tasks, and Age

Variables	1	2	3	4	5	6	7	8	9
Age	1								
Average PA	**0.15**	1							
Happy	**0.07**	0.66	1						
Pleased	**0.12**	0.67	0.83	1					
Enjoyment/Fun	**0.10**	0.69	0.79	0.79	1				
Joyful	**0.12**	0.70	0.80	0.80	0.85	1			
Processing Speed[1]	-0.31	-0.11	**-0.04**	**-0.07**	**-0.08**	**-0.08**	1		
WM (N-back)[1]	-0.36	-0.06	**-0.03**	**-0.05**	**-0.04**	**-0.05**	0.443	1	
WM (Dot Memory)[1]	-0.12	-0.03	-0.00	**-0.02**	**-0.02**	**-0.02**	0.26	0.19	1

Note. [1]Represents averaged momentary performance on processing speed and working memory tasks. Bolded correlations are significant.

CHAPTER 3

Study 2. Momentary Unconstructive Repetitive Thinking, Cognitive Performance, and Age

ABSTRACT

Repetitive thought is often described as the process of thinking repeatedly, frequently, or attentively, which is related to interferences in cognitive function. Unconstructive repetitive thinking (URT) is one type of repetitive thinking posited to deplete attentional resources, resulting in downstream effects on cognition. Studies examining the effects of URT on cognitive performance often use laboratory-based study designs. This study aimed to investigate how reports of URT throughout the day are linked to scores on momentary cognitive tasks of processing speed and working memory. I hypothesized that reports of greater engagement in URT will be related to worse momentary cognitive function. Age is expected to moderate this relationship such that older age will interact with heightened URT resulting in worse cognitive performance compared to those younger in age. Data from the Effects of Stress on Cognitive Aging, Physiology, and Emotion (ESCAPE) study included 245 community residents ranging from 25 to 65 years old (Mage = 46.5) completing five assessments throughout the day across 14 days. Contrary to the hypothesis, I found that greater URT was related to improved working memory (N-back: $\gamma = .005$, SE = .001, $p < .001$), but not processing speed. Higher momentary negative affect was associated with poorer working memory. However, instead of serving as a pathway between URT and cognition, negative affect was suppressing the positive relationship between increased URT and improved working memory. Probing these interactions revealed that URT and cognition were related for younger and middle-aged adults, but not for older adults.

INTRODUCTION

Strong affective states may be related to thoughts that impair one's ability to concentrate on a task at hand which adds to our cognitive load (Lee Pe et al., 2013; Zahodne et al., 2014). Both trait and daily negative affect are often associated with lower performance on working memory tasks, perhaps because negative affect is often related to unconstructive repetitive thinking (URT) – negative ruminative thoughts about oneself or the environment. When an individual engages in excessive URT, it leads to increased cognitive load due to the demand for constant updating of the working memory (Battista et al., 2023; Lee Pe et al., 2013). URT requires attentive, repetitive, and frequent engagement in repetitive thought (Segerstrom et al., 2003).

Researchers also find that repetitive negative thinking predicts subjective cognitive decline, a risk factor for objective declines in memory and executive function (Schlosser et al., 2020). Studies supporting these findings often use traditional laboratory-based measures to capture an individual's cognitive performance. But traditional methods prevent researchers from understanding how cognitive function may fluctuate day-to-day or within days. In recent years, researchers have begun using both daily diaries and ecological momentary assessment to further understand how affect relates to differences in cognitive processes throughout the day. However, few studies have examined how momentary assessment of URT and negative affect influence momentary cognitive task performance. The current study investigated how cognitive function would vary throughout multiple times a day, based on the momentary experiences of URT and negative affect across adults.

Rumination is the engagement in repetitive thinking, or perseverative cognitions, about negative events from the past. Thus, unconstructive repetitive thinking (URT) can be considered the umbrella construct that subsumes processes of rumination and perseverative cognitions. URT is also generally associated with negative affective states. Though studies often refer to the construct as "rumination", URT is recognized as a factor related to cognitive functioning, but findings remain mixed regarding the specific cognitive processes that may be affected. Cognition may be negatively influenced by URT because it depletes attentional resources, which has negative downstream effects on cognitive performance (Stawski et al., 2006).

A meta-analysis evaluating associations between rumination and executive functions found that across 34 studies, rumination was related to poorer inhibition and set-shifting, but not working memory (Yang et al., 2017). Among adults with depression undergoing a clinical intervention, improvements in working memory occurred when rumination about negative information was significantly reduced (Jopling et al., 2020). Researchers also find that repetitive negative thinking predicts subjective cognitive decline, a risk factor for objective cognitive decline, including memory and executive function (Schlosser et al., 2020). Repetitive thinking is unconstructive when it interferes with one's ability to successfully cope with stress or stress-related disorders such as depression and anxiety (Spinhoven et al., 2018).

LeMoult and Gotlib (2019) proposed The Cognitive Model of Depression, which emphasizes the role of intrusive thoughts and motivations on cognition. While this model was originally derived to explain the effects of depression on cognitive functioning, it offers a framework that can be applied to describe the cognitive effects of ruminative thinking (LeMoult and Gotlib; 2019). Recurring and unconstructive thoughts are common among individuals with depressive symptoms (i.e. negative affect), and these individuals have related deficits in processing speed, attention, working memory, and executive (Abramovitch et al., 2021; Köhler et al., 2010; Krogh et al., 2014). Rumination and repetitive thinking are considered by the model as key psychological pathways linking negative affect and cognitive functioning (Du et al., 2018; Scott et al., 2015).

Prior research has mainly focused on how cognition is impacted by emotion and thought processes such as repetitive thinking in laboratory settings (Brinker et al., 2013; Korthauer et al., 2017; Linnenbrink et al., 1999; Thomsen et al., 2004). While some researchers have employed ecological momentary assessment and daily diary methods in the context of transient cognitive function, their aims do not specifically address the relationship between repetitive thoughts and cognitive task performance on an intra-individual level (Cerino et al., 2021; Genet & Siemer, 2012).

Current Study

The first aim was to examine how momentary URT relates to performance on momentary processing speed and working memory task. The next aim was to better understand if negative affect is an underlying mechanism between URT and cognitive function. Furthermore, how these relationships vary by age was investigated. I hypothesized that working memory (N-back and dot memory tasks) and processing speed skills would be poorer in moments when higher URT is reported. Also, I hypothesized that age would moderate the relationship between URT and cognition. Such that, older adults who reported high URT will do worse on all three cognitive tasks compared to younger adults with higher URT.

METHOD

Study Design and Procedures

The Effects of Stress on Cognitive Aging, Physiology and Emotion (ESCAPE) provided data for this study and can be publicly accessed by researchers through the Center for Open Science registration: https://osf.io/4ctdv/ (Scott et al., 2015). Approved by the ethical review board of The Albert Einstein College of Medicine of Yeshiva University, ESCAPE used a measurement burst approach to examine intra-individual variations over short timeframes (e.g., minutes, hours, days) and longer intervals (e.g., months, years). Data collection occurred over four waves, starting with a baseline assessment and follow-ups at 9-, 18-, and 27-months post-baseline. Participants received up to $160 for participating, depending on their adherence to the study protocol.

Participants were Bronx County, New York, residents aged 25 to 65 years who were fluent in English, able to move independently, and capable of using the study smartphone without impairments such as visual difficulties. Exclusion criteria included an inability to respond to smartphone surveys during the day due to work or personal commitments, or a score of 25 or lower on the Mini-Mental State Examination (a dementia indicator). A systematic probability sampling method was employed to obtain a racially and economically diverse cohort. A sampling pool was created using the New York City Registered Voter Lists (RVL) and RVL data was sorted into age groups spanning 10 years each, forming sampling blocks of 450 potential participants. Initial contact with potential participants was made via a letter outlining the study's purpose and participant selection process. Follow-up phone calls were made within two weeks of sending the letters to establish rapport, check eligibility, and recruit participants.

During each wave, participants were provided with a study smartphone for a two-week measurement burst period. Training sessions familiarized participants with the smartphone surveys and tasks. Prior to starting the measurement burst, a lab visit was required where participants completed the baseline cognitive tasks, as well as surveys inquiring about demographics, physical and mental health, and potential psychosocial moderators. These assessments were repeated at the end of each wave. Over the course of 14 consecutive days, participants responded to alerts to complete ecological momentary assessments once in the morning, five times throughout the day, and once at night, resulting in 70 momentary observations. Research assistants conducted follow-up phone calls after day one and at the end of the first week to assist with compliance and answer any questions. At the end of each measurement burst, participants returned to the lab to hand in their smartphones and complete the final questionnaires.

Participants

The first wave of data collected from ESCAPE included a total of 260 adults who averaged 46 years old (range: 25 – 65), mostly female (N = 172, 65%) and primarily of Black or African American racial/ethnic identity (N = 167, 63%). The sample is well-educated with 70% having at least some college education, and on average they have an annual income of $40,000. Roughly half the participants were employed (N = 132, 50%) and most participants were not partnered (N = 178, 67%). If data were missing on momentary measurements for the predictor or outcome variables, then participants were excluded from analyses. One participant had missing data for one of the cognitive tasks, but 15 individuals (5.7%) were missing reports for URT during the survey beeps. Due to this missing data, a sample total of 245 participants were included in the study.

Baseline Measures

Demographics

Information on participants' gender (male/female), age, race and ethnicity, education, income, work status and marital status were gathered. Participants were able to select more than one race/ethnicity including Caucasian, Black or African American, Hispanic/White, Hispanic/Black, Asian, or other. Education was assessed with five categories ranging from grade school or less to graduate or professional degree, and annual income was reported through eight categories starting from <$4,999 to $150,000 or greater. Participants were either “employed”, “retired”, “unemployed and looking for work”, or “unemployed and not looking for work”. Marital statuses included “married to first spouse”, “remarried”, “divorced”, “separated”, “never married”, “not married but living with someone” and “other”.

Momentary Measures

Affect

Before cognitive function was tested, negative affect was reported. Negative affect was rated five separate times throughout the day. The items chosen for each negative affect was based on Diener and Emmons (1984). The following five items were included: tense/anxious, depressed, angry, unhappy, and frustrated. When participants were notified to respond, they were prompted on their screens with the various affective descriptors and asked to rate how well each of the items described how they felt “right now”. Responses were answered using a sliding bar on the screen ranging from 0 (not at all) to 100 (extremely).

Unconstructive Repetitive Thinking

Also, before the cognitive assessments, are questions about unconstructive repetitive thinking. Participants were notified by an alarm five times throughout the day to complete a Momentary Thought Questionnaire asking if they are experiencing recurring, unwanted, and negative thoughts. The Momentary Thought Questionnaire was developed for the ESCAPE study to measure URT (Scott et al., 2015). The questionnaire originally included four items asking: “In the past 5 minutes… 1. Overall, which of these bests describes (positive or negative descriptors) the thoughts you had? 2. Were you experiencing a train of thought that you couldn’t get out of your head? 3. Were you thinking about personal problems or worries? 4. Were you preoccupied with thoughts of something about to happen or that might happen in the future?". Participants rated thoughts experienced in the 5 minutes prior to completing the other smartphone surveys. A visual analog slider scale for valence ranging from unpleasant (0) to pleasant (100) was used (higher scores represent greater URT).

Cognitive Assessments

Three cognitive tasks were presented on a smartphone in a fixed order testing processing speed first, and then two working memory tasks: the dot memory task and a modified N-back. Refer to Figures 1-3 for visuals of the ambulatory cognitive tasks. individuals complete the location dot memory task, where they had to memorize the location for three red dots (see Figure 3). First, the three red dots are presented on a 5x5 grid for three seconds, then a visual distractor exercise was completed for eight seconds and after participants were asked to recall the location of the three red dots. This task was performed across two trials and measured. The dot memory task is scored by calculating the Euclidean distance between the location of the incorrectly placed dot and the correct grid location (Siedlecki, 2007; Sliwinski et al., 2018). Higher scores reflect less accurate dot placement and poorer working memory performance.

Processing Speed. Participants compare three symbol pairs on the top of the smartphone screen with two symbol pairs located at the bottom of the screen (see Figure 1) and must decide as quickly as possible which pair of symbols at the bottom match with one of the three symbol pairs above. Each assessment included a total of 16 symbol comparison trials. Processing speed is evaluated using 'throughput,' a composite measure obtained by dividing the percentage of correct responses per minute by the average reaction time (Thorne, 2006). Higher throughput scores indicate better processing speed.

Working Memory. This study included two tasks of working memory. First, individuals complete the location dot memory task, where they had to memorize the location for three red dots (see Figure 3). First, the three red dots are presented on a 5x5 grid for three seconds, then a visual distractor exercise was completed for eight seconds and after participants were asked to recall the location of the three red dots. This task was performed across two trials and measured. The dot memory task is scored by calculating the Euclidean distance between the location of the incorrectly placed dot and the correct grid location (Siedlecki, 2007; Sliwinski et al., 2018). Higher scores reflect less accurate dot placement and poorer working memory performance.

Second, a modified version of the n-back paradigm using a 2-back condition was administered to participants (see Figure 2; (Scott et al., 2015; Verhaeghen & Basak, 2005). Three standard playing cards in boxes first appear face-up on the phone screen. Participants determine if the first and third cards match, and then the cards are turned face-down. The left most card then disappears, as the other two cards move one box to the left. A new card is then presented face-up in the right most spot. Finally, participants decide whether the cards in the first and third boxes match. A total of 12 trials were completed. Scores for the n-back tasks were determined using throughput, a composite metric representing the proportion of correct responses per minute to the average reaction time (Thorne, 2006). Higher throughput scores indicate improved working memory performance.

Analytic Plan

The total sample consisted of 260 people; however, listwise deletion reduced the total to 245 participants for analysis due to 15 missing cases on the URT measures (5.7% of full sample, $N = 260$). After conducting sensitivity analysis to consider differences based on racial and ethnic identity, no significant differences were found. Therefore, I collapsed race/ethnic identity into three categories: White, Black/African American, and “Other” which includes Non-White Hispanic and Asian. Education categories were condensed from six to five groups by merging participants who reported completing grade school or less (0.5%) with those who had some high school education (5.4%). Regarding work status, participants could choose from employed, retired, unemployed and seeking work, or unemployed and not seeking work. For simplicity, work status was grouped into two categories: "working" (employed) and "not working" (retired, unemployed and seeking work, or unemployed and not seeking work). Similarly, marital status was divided into "partnered" (married to first spouse, remarried, or living with a partner) and "not partnered" (divorced, separated, never married, widowed, or other).

I first assessed whether momentary levels of URT related to cognitive performance across the day. The secondary aim was to test whether age moderated the momentary relationship between URT and cognition. SAS version 9.6 (PROC MIXED) and residual (restricted) maximum likelihood (REML) estimation was used to analyze the research questions. A total of three models were used – each with a separate outcome variable: processing speed, and the two working memory tasks. Predictors in the three models were centered, with momentary predictors centered at the person mean. Multi-level models examined how momentary reports of URT (within-person level 1 variables) relate to momentary performance on processing speed and working memory tasks. This procedure also allowed for the investigation of interactive effects between URT and age on cognitive performance. The covariates included in each model were age, gender, racial/ethnic identity, income, education, work status, and marital status.

RESULTS

Descriptive statistics of the participants as well as bivariate correlations of the covariates and main study variables are provided in Table 2.1. Included participants were mostly female, single, and of Black racial/ethnic identity. Most participants had at least some college education (70%), and income for half of the participants was on average between an annual income of $20,000 and $60,000 dollars.

Processing speed and working memory were assessed using three momentary tasks and each was treated as a separate outcome. Separate models were conducted to estimate the main effects of covariates and URT. The interactions for age and URT were included in a second model. The main effects and interaction effects models can be viewed on Table 2.2 for processing speed, Table 2.3 for the n-back working memory task, and Table 2.4 for the dot memory (working memory) task.

Unconstructive Repetitive Thinking

Processing Speed

URT was first tested as a predictor of processing speed. Table 2.2 provides the main effects for momentary URT. Contrary to my hypothesis, higher momentary URT was related to better processing speed ($\gamma = 0.0006$, $t(206) = 2.67$, $p < .01$). Trait URT (averaged momentary URT) was not associated with processing speed ($\gamma = -0.003$, $t(206) = -1.63$, $p = .11$).

Negative Affect. In a second model, momentary negative affect was tested as a mediator of URT and cognitive function (steps shown in Table 2.2). The direct relationship between negative affect and processing speed was tested first. In moments of heightened negative affect processing speed worsened ($\gamma = -0.00014$, $t(205) = -4.53$, $p < .0001$). Trait negative affect was not significantly associated with processing speed ($\gamma = -0.00$, $t(205) = -0.97$, $p = .34$). When momentary negative affect was entered into the model with URT, rather than mediating the relationship, negative affect suppressed the effect of URT on processing speed. The effect size of URT increased from 0.0006 to 0.0011.

Working Memory (N-back Task)

Table 2.3 displays the main effects for URT and the N-back. Parallel to processing speed, moments of heightened URT related to poorer working memory on the N-back task (γ = 0.003563, $t(206) = 2.99$, $p < .01$). Trait URT (averaged momentary URT) was not associated with the working memory N-back task (γ = -0.01156, $t(206) = -1.52$, $p = .13$).

Negative Affect. Table 2.3 presents estimates for the main effects and mediation analysis of negative affect on URT and cognition. Moments of heightened negative affect were significantly related to lower performance on the n-back task (γ = -0.00042, $t(206) = -2.41$, $p = .02$). Trait negative affect was also related to poorer working memory (N-back: γ = -0.00314, $t(206) = -2.27$, $p =.03$). Interestingly, the suppression effect of negative affect on URT found for processing speed remained consistent for working memory using the N-back task. When momentary negative affect was added to the model, the effect size for momentary URT increased from 0.003563 to 0.004959.

Working Memory (Dot Memory Task)

The estimates for main effects and the mediation analysis of negative affect on URT and cognition are provided.in Table 2.4. Unlike the other working memory measure, momentary URT was unrelated to performance on the dot memory task (γ = -0.00755, $t(207) = -1.50$, $p = .13$). However, greater trait URT was associated with poorer dot memory performance (γ = -0.08434, $t(207) = -2.86$, $p <.01$).

Negative Affect. Momentary negative affect was not significantly related to performance on the dot memory task (γ = -0.00093, $t(206) = -1.26$, $p = .21$). Trait negative affect was also unrelated to the dot memory task(γ = -0.00455, $t(206) = -0.84$, $p = .40$). Estimates for the main effects of each step can be viewed in Table 2.4.

Age as a Moderator

Across all momentary outcomes, older age was associated with worse cognitive performance (processing speed: γ = -0.002, $t(222) = -6.28$, $p < .0001$; N-back/working memory: γ = -0.011, $t(222) = -8.18$, $p < .0001$; dot memory/working memory: γ = -0.02, $t(223) = -3.11$, $p < .01$). Refer to Tables 2.2, 2.3, and 2.4 for the estimates.

The relationship between momentary URT and processing speed did not vary based on age (γ = -0.00003, $t(206) = -1.58$, p =.11). Age was also not a significant moderator of momentary URT and performance on the dot memory task (γ = -0.00087, $t(206) = -1.87$, p =.06). However, the association between momentary URT and N-back performance (working memory) did vary significant by age (γ = -0.00042, $t(206) = -3.82$, $p < .0001$).

The interaction was probed by examining both the categorical-by-categorical interaction as well as the original continuous-by-continuous interaction. Three categories were created for age divided into younger (25 to 40 years), middle-aged (41 to 53 years), and older adults (54 to 65 years). URT was then broken into three levels including low, medium, and high scores. The mean differences in each of the slopes for N-back task performance were significantly different based on age and URT (see Figure 2.4). The continuous-by-continuous interaction was probed next by inspecting age at +1, -1, and 0 standard deviations from the mean. (See Figure 2.5; M = 46.49, SD = 11.02). Heightened URT led to improved working memory on the N-back task for younger adults (b = 0.007, t(242), 4.28, $p < .001$) and middle-aged adults (b = 0.003, t(242), 2.72, $p < .01$), but not older adults (b = -0.0004, t(242), -0.20, p = .84).

Exploratory Analyses

Although there was no significant main effect of momentary URT on the dot memory task, since momentary URT was related to the other working memory task (N-back), the interaction between URT and age was probed. Figure 2.6 shows the mean differences in scores on the dot memory task based on age groups and URT levels. Probing the continuous-by-continuous interaction with age at +1, -1, and 0 standard deviations from the mean (see Figure 2.7), showed that middle-aged (b = -0.01, t(242), -2.00, p = .05) and older adults (b = -0.00002, t(242), -2.01, p = .04) appear to have poorer working memory during moments of higher URT, but not younger adults (b = -0.005, t(242), -0.78, p = .44).

Exploratory correlation analyses were also conducted to assess whether specific URT questions revealed any significant patterns with negative affect, age, and cognitive tasks (shown on Table 2.6).

DISCUSSION

The primary aim of this study was to understand how intraindividual differences in URT related to momentary cognitive performance on processing speed and working memory tasks. Another objective for this study was to assess whether the relationship between momentary URT and cognitive function is explained based on levels of negative affect. Moreover, the role of age in adjusting the relationships between momentary URT and cognitive task performance was investigated.

The most noteworthy finding was that during moments of increased URT, cognitive performance on processing speed and working memory tasks were benefited. This significant and positive association between momentary URT, processing speed, and working memory remained robust across all ages. The finding that greater URT is associated with better working memory appears inconsistent with the literature, which typically links negative affect to poorer cognitive performance. However, mediation analyses revealed that negative affect did not help explain the relationship between moments of higher URT and improved working memory. Working memory capacity represents the extent to which an individual can maintain goal-relevant information during times of distraction (Conway et al., 2003; Schmeichel & Demaree, 2010). The better one's emotion regulation is during times of cognitive interference (e.g., stressful events), the more working memory capacity is preserved or potentially improved. The findings from this study fall in line with the working memory capacity framework (Plass & Kalyuga, 2019; Turner & Engle, 1989).

The relationship between greater URT and improved working memory was not explained by momentary negative affect. Rather, negative affect acted as a suppressor on the positive relationship between momentary URT and working memory. One meta-analysis on the associations between rumination and executive functions found that rumination, most related to negative affective processes, was related to poorer inhibition and set-shifting but not working memory (Yang et al., 2017). However, among adults with depression undergoing a clinical intervention, improvements in working memory occurred when rumination about negative information was significantly reduced (Jopling et al., 2020). This study demonstrates that URT and negative affect should be considered related constructs, but not related as a pathway for cognitive interference.

Age Moderates Unconstructive Repetitive Thinking and Working Memory

A secondary aim to the study was to assess whether the relationship between momentary URT and cognitive function varied by age. Age significantly interacted with URT in predicting working memory. Before probing the interaction, it was theorized that older adults with greater levels of URT would demonstrate the worst working memory. Yet, it was revealed that it was younger adults' whose cognitive performance was most impacted by higher levels of URT. Age also had a significant negative correlation with URT meaning that older adults tended to perseverate less frequently compared to younger adults (see Table 2.1). It appears that older adults who perseverate more frequently, are not afforded a benefit to their working memory capacity as it occurs in younger and middle-aged adults.

Implications

The finding that momentary URT is linked to better processing speed and working memory was robust. When considering URT as a beneficial factor toward working memory performance, the idea of working memory capacity captures this phenomenon. Rather than the negative emotion associated with URT taking over the cognitive interference, engaging in repetitive thinking is exercising working memory capacity. Despite the positive correlation between each URT item and higher negative affect, the relationship between URT and cognition is not as clear. Findings on the links between affective processes and objective cognition function remain mixed (c.f. study 1). As Segerstrom and colleagues (2003) discussed, repetitive thought is not always maladaptive and may be beneficial when it can be engaged in constructively. The fourth item asking about valence in URT, which was removed from the measure, demonstrated that respondents had on average a neutral to positive valence in their repetitive thoughts.

Limitations and Future Directions

One major limitation of this study is that it is unclear whether the EMA reports for state negative affect are directly related to the thoughts and feelings associated with URT inquiries. Future research should inquire more about the types of thoughts participants are having when experiencing increased URT. The age range of this study is both a strength and a limitation.

While there was a wide range of ages (25 to 65 years old), this study lacked data examining the ages of older adults. It is possible these effects could differ across even older ages. It appears that younger age, rather than older age, interacts with momentary heightened levels of URT leading to worse working memory performance compared to younger adults with lower levels of momentary URT. Future studies should continue to explore those age differences and work to understand what factors underlie that relationship.

Conclusion

The findings from this study extend current knowledge on how unconstructive repetitive thinking is related to cognitive function. I examined the relationship between intraindividual differences in URT and momentary cognitive performance, while also investigating the potential role of negative affect and age in this relationship. The most prominent finding was the positive association between increased URT and enhanced cognitive performance on processing speed and working memory tasks, which remained consistent across all age groups. Surprisingly, momentary negative affect did not account for this relationship, acting instead as a suppressor. This suggests that while URT and negative affect are related constructs, they do not necessarily operate as pathways for cognitive interference. Moreover, age was found to moderate the relationship between URT and working memory, with younger adults experiencing the greatest influence on cognitive performance in moments of higher URT. These findings highlight the complex interplay between URT, negative affect, age, and cognitive function, underscoring the need for further research to fully understand these relationships.

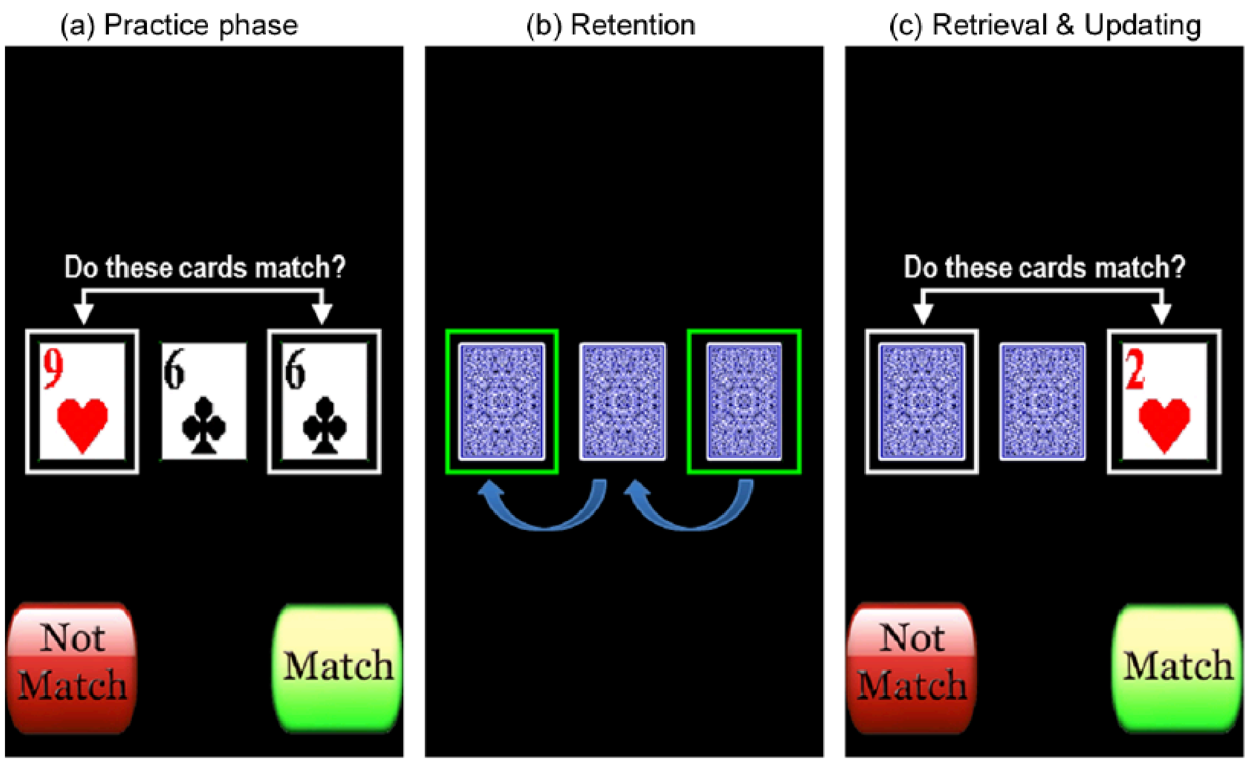
Figure 2.1

Symbol Search Task

Note. An example of one trial from the symbol search test. The test measures processing speed by asking participants to decide as quickly as possible which of the two pairs at the bottom of the screen match a symbol pair at the top of the screen.

Figure 2.2

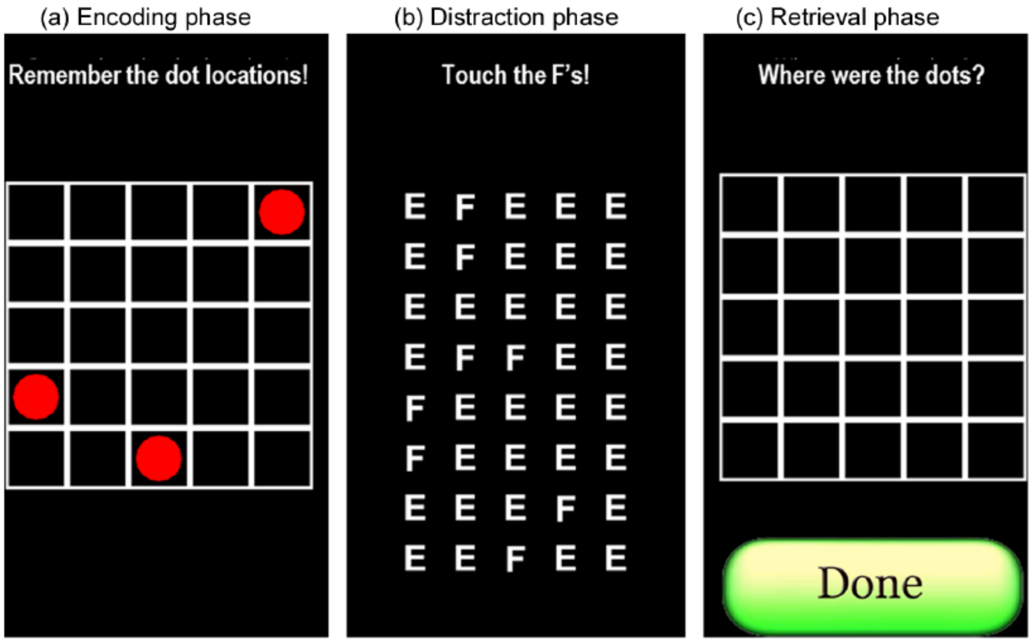
Modified N-Back Paradigm



Note. An example of the n-back test completed by participants. In the practice phase (a) participants decide if the two cards match while they are facing up. Next, cards are shifted from right to left and the new target cards are now face down (b). Participants then go through retrieval and updating (c) where they determine if the new target card matches the facedown card presented two phases prior.

Figure 2.3

Dot Memory Task



Note. One example of the dot memory test for spatial working memory. Participants are shown three red dots for three seconds (a), then asked to engage in a distraction phase (b), and the retrieval phase (c) asks participants to recall where the three dots were located.

Table 2.1

Descriptives and Correlations

Variable		*N*	*M (SD)* % or [range]	1	2	3	4	5	6	7	8	9	10	11	12
1. Age		245	46.49 (11.09) [25 - 65]	1											
2. Gender		260		0.02	1										
	Male	91	35%												
	Female	169	65%												
3. Racial/Ethnic Identity[1]		260		**-0.12**	-0.08	1									
	White	22	8.46%												
	Black	165	63.46%												
	Other	73	28.08%												
4. Income[2]		236	3.83 (1.69) [1 - 8]	0.08	0.08	-0.11	1								
5. Education[3]		260	3.3 (1.14) [1 – 5]	0.09	-0.01	**-0.15**	**0.34**	1							
6. Work Status		158		**-0.17**	-0.08	0.00	**0.28**	**0.15**	1						
	Working	130	50.4%												
	Not Working	128	49.6%												
7. Partnered		259		**0.18**	**0.13**	0.08	**0.45**	0.12	0.01	1					
	Yes	81	32.1%												
	No	178	67.2%												
8. Negative Affect[4]		260	(15.85)	-0.05	-0.04	0.10	**-0.19**	0.04	-0.02	0.00	1				
9. Unconstructive Repetitive Thinking [4]		245	3.61 (2.02) [0 – 10]	**-0.04**	**-0.05**	**0.09**	**-0.19**	**0.05**	**0.03**	0.01	**0.75**	1			
10. Processing Speed[5]		259	0.23 (0.05)	**-0.31**	**-0.02**	**0.09**	**0.14**	**0.13**	**0.17**	**-0.04**	**-0.08**	**-0.05**	1		
11. N-back Working Memory[6]		260	0.7 (0.25)	**-0.36**	**0.06**	**0.03**	0.01	0.01	**0.09**	**-0.05**	**-0.09**	**-0.04**	**0.44**	1	
12. Dot Memory Working Memory[6]		260	-1.84 (0.91)	**-0.12**	**0.11**	**-0.04**	**0.17**	**0.17**	**0.03**	**0.06**	**-0.13**	**-0.15**	**0.26**	**0.19**	1

Note. *N* is used to represent the number of respondents for each variable, % stands for the percentage of the sample, M and SD denote mean and standard deviation. Correlations values are based on Pearson correlations, *p < .05, **p < .001, ***p < .0001. [1]White represents non-Hispanic White/Caucasian and "Other" includes Hispanic-White, Hispanic-Black, and Asian. [2]Annual income was treated as a continuous variable; income was reported with eight categories between <$4,999 to $150,000 or greater. [3]Education was measured using five categories ranging from completion of grade school or less, to a graduate or professional degree. [4]Value accounts for the person-level variables averaged across 14 days. [5]Processing speed was measured using a symbol search test and was reverse-coded, the mean value is for the average error score across 14 days. [6]The mean value represents average performance across 14 days.

Table 2.2

Main & Interactive Effects of Momentary Unconstructive Repetitive Thinking, Negative Affect, and Age on Processing Speed with Covariates

Parameters	***γ***	***SE***	***t***	***p***	**95% CI** **Lower**	 **Upper**
Intercept	0.2128	0.01313	16.21	<.0001	0.1870	0.2387
Beep	-0.00112	0.000280	-4.00	<.0001	-0.00167	-0.00057
Day	0.001795	0.000110	16.32	<.0001	0.001580	0.002011
Age	-0.00199	0.000317	-6.28	<.0001	-0.00261	-0.00136
Gender	-0.00009	0.006955	-0.01	0.9901	-0.01379	0.01362
Racial/Ethnic Identity	-0.01874	0.01309	-1.43	0.1537	-0.04454	0.007058
Education	-0.03378	0.01574	-2.15	0.0330	-0.06479	-0.00276
Work Status	0.002895	0.007088	0.41	0.6833	-0.01107	0.01686
Partnered	-0.01186	0.008084	-1.47	0.1438	-0.02779	0.004072
Income	0.006077	0.002373	2.56	0.0111	0.001401	0.01075
Main Effects	***γ***	***SE***	***t***	***p***	**95% CI** **Lower**	 **Lower**
Step 1						
Momentary URT	0.000576	0.000215	2.67	0.0075	0.000154	0.000997
URT*	-0.00286	0.001757	-1.63	0.1056	-0.00632	0.000608
Step 2						
Momentary URT	0.001050	0.000239	4.39	<.0001	0.000581	0.001519
URT[1]	-0.00121	0.002457	-0.49	0.6243	-0.00605	0.003639
Momentary Negative Affect	-0.00014	0.000032	-4.53	<.0001	-0.00021	-0.00008
Negative Affect[1]	-0.00031	0.000322	-0.97	0.3354	-0.00095	0.000324
Interaction Effects	***γ***	***SE***	***t***	***p***	**95% CI** **Lower**	 **Lower**
URT *Age	-0.00003	0.000020	-1.58	0.1141	-0.00007	7.522E-6

Note. [1]Represents average value across study days. The main effects and interaction effects were entered in after accounting for the main effects.

Table 2.3

Main & Interactive Effects of Momentary Unconstructive Repetitive Thinking, Negative Affect, and Age on Working Memory (N-back Task) with Covariates

Parameters	γ	SE	t	p	95% CI Lower	95% CI Upper
Intercept	0.2128	0.01313	16.21	<.0001	0.1870	0.2387
Beep	-0.00112	0.000280	-4.00	<.0001	-0.00167	-0.00057
Day	0.001795	0.000110	16.32	<.0001	0.001580	0.002011
Age	-0.00199	0.000317	-6.28	<.0001	-0.00261	-0.00136
Gender	-0.00009	0.006955	-0.01	0.9901	-0.01379	0.01362
Racial/Ethnic Identity	-0.01874	0.01309	-1.43	0.1537	-0.04454	0.007058
Education	-0.03378	0.01574	-2.15	0.0330	-0.06479	-0.00276
Work Status	0.002895	0.007088	0.41	0.6833	-0.01107	0.01686
Partnered	-0.01186	0.008084	-1.47	0.1438	-0.02779	0.004072
Income	0.006077	0.002373	2.56	0.0111	0.001401	0.01075
Main Effects	**γ**	**SE**	**t**	**p**	**95% CI Lower**	**95% CI Lower**
Step 1						
Momentary URT	0.003563	0.001190	2.99	0.0028	0.001230	0.005895
URT*	-0.01156	0.007604	-1.52	0.1301	-0.02655	0.003436
Step 2						
Momentary URT	0.004959	0.001324	3.74	0.0002	0.002363	0.007555
URT[1]	0.005109	0.01052	0.49	0.6278	-0.01564	0.02585
Momentary Negative Affect	-0.00042	0.000176	-2.41	0.0160	-0.00077	-0.00008
Negative Affect[1]	-0.00314	0.001382	-2.27	0.0241	-0.00587	-0.00042
Interaction Effects	**γ**	**SE**	**t**	**p**	**95% CI Lower**	**95% CI Lower**
URT *Age	-0.00042	0.000110	-3.82	0.0001	-0.00064	-0.00020

Note. [1]The main effects and interaction effects were entered in after accounting for the main effects.

Table 2.4

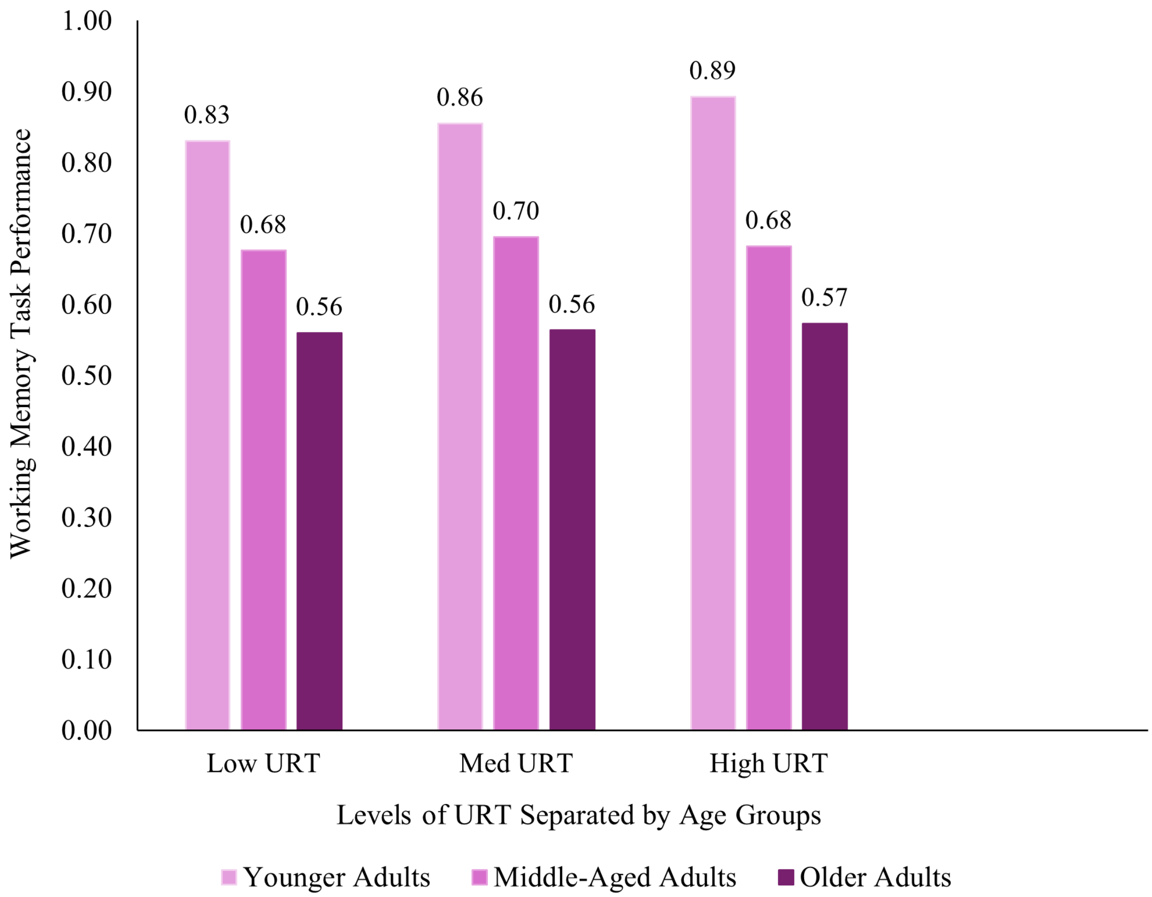
Main & Interactive Effects of Momentary Unconstructive Repetitive Thinking, Negative Affect, and Age on Working Memory (Dot Memory Task) with Covariates

Parameters	*γ*	*SE*	*t*	*p*	**95% CI** Lower	**95% CI** Upper
Intercept	0.2128	0.01313	16.21	<.0001	0.1870	0.2387
Beep	-0.00112	0.000280	-4.00	<.0001	-0.00167	-0.00057
Day	0.001795	0.000110	16.32	<.0001	0.001580	0.002011
Age	-0.00199	0.000317	-6.28	<.0001	-0.00261	-0.00136
Gender	-0.00009	0.006955	-0.01	0.9901	-0.01379	0.01362
Racial/Ethnic Identity	-0.01874	0.01309	-1.43	0.1537	-0.04454	0.007058
Education	-0.03378	0.01574	-2.15	0.0330	-0.06479	-0.00276
Work Status	0.002895	0.007088	0.41	0.6833	-0.01107	0.01686
Partnered	-0.01186	0.008084	-1.47	0.1438	-0.02779	0.004072
Income	0.006077	0.002373	2.56	0.0111	0.001401	0.01075
Main Effects	*γ*	*SE*	*t*	*p*	**95% CI** Lower	**95% CI** Lower
Step 1						
Momentary URT	-0.00755	0.005044	-1.50	0.1344	-0.01744	0.002336
URT*	-0.08434	0.02948	-2.86	0.0047	-0.1425	-0.02622
Step 2						
Momentary URT	-0.00444	0.005619	-0.79	0.4291	-0.01546	0.006572
URT[1]	-0.06012	0.04122	-1.46	0.1462	-0.1414	0.02115
Momentary Negative Affect	-0.00093	0.000741	-1.26	0.2090	-0.00238	0.000522
Negative Affect[1]	-0.00455	0.005404	-0.84	0.4003	-0.01521	0.006100
Interaction Effects	*γ*	*SE*	*t*	*p*	**95% CI** Lower	**95% CI** Lower
URT *Age	-0.00087	0.000465	-1.87	0.0616	-0.00178	0.000042

Note. [1]The main effects and interaction effects were entered in after accounting for the main effects.

Figure 2.4

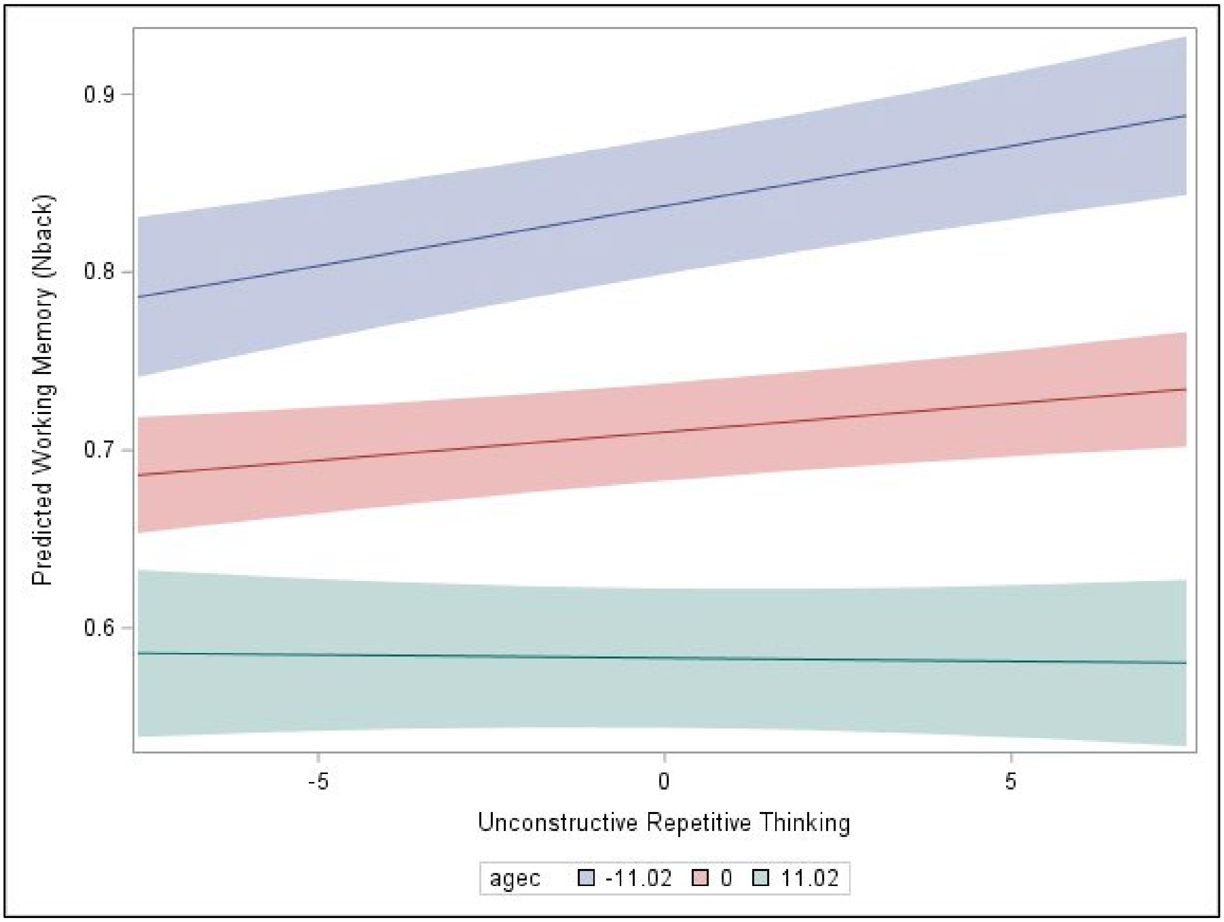
Mean Differences in Working Memory (N-back Task) Based on Unconstructive Repetitive Thinking and Age



Note. The differences between each group were statistically significant ($p < .0001$). Younger adults ranged in ages 25 to 40 years old, middle-aged adults ranged from 41 to 53, and older adults were between the ages 54 and 65 years.

Figure 2.5

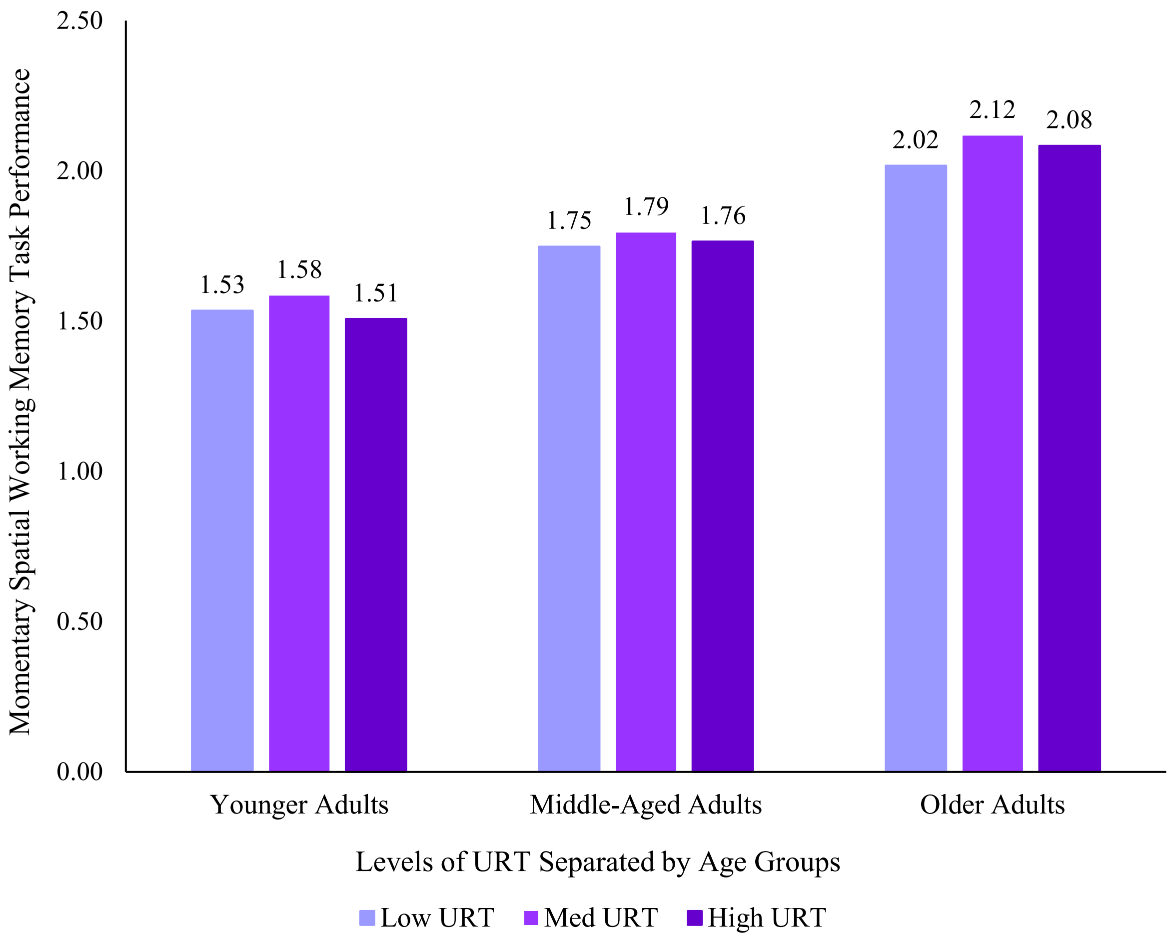
Probing of Simple Slopes for the Interaction between Unconstructive Repetitive Thinking and Age on Working Memory (N-back Task)



Note. 95% Confidence Intervals displayed. Agec = Age mean- centered, probed at +1 standard deviation above the mean (+11.02), -1 below the mean (-11.02), and at the mean (0). The slopes for -1 below (younger) and at the mean (middle-aged) were significantly different from zero.

Figure 2.6

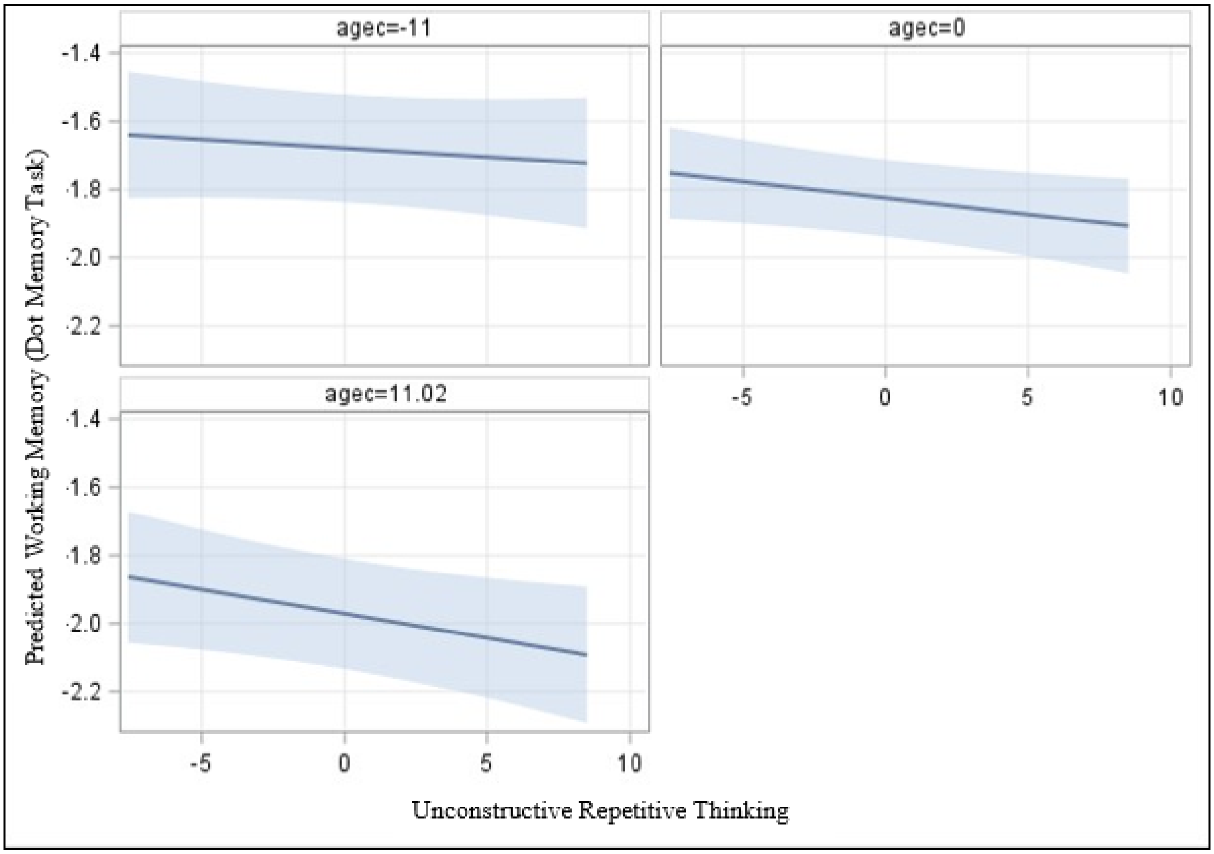
Exploring Mean Differences in Working Memory (Dot Memory Task) Based on Unconstructive Repetitive Thinking and Age



Note. The differences between each group were statistically significant ($p < .0001$). Younger adults ranged in ages 25 to 40 years old, middle-aged adults ranged from 41 to 53, and older adults were between the ages 54 and 65 years.

Figure 2.7

Exploratory Probing of Simple Slopes for the Interaction between Unconstructive Repetitive Thinking and Age on Working Memory (Dot Memory Task)



Note. 95% Confidence Intervals displayed. Agec = Age mean- centered, probed at +1 standard deviation above the mean (+11.02), -1 below the mean (-11.02), and at the mean (0).

Table 2.5

Exploratory Correlations between Age, Negative Affect, Unconstructive Repetitive Thinking, and Cognitive Measures

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1. Age	1													
2. Negative Affect[1]	-0.02	1												
3. Tense	-0.02	0.92	1											
4. Angry	-0.07	0.91	0.84	1										
5. Depressed	0.01	0.94	0.78	0.84	1									
6. Frustrated	-0.04	0.96	0.88	0.83	0.87	1								
7. Unhappy	-0.01	0.96	0.82	0.82	0.93	0.93	1							
8. URT_Valence of Thoughts[2]	**0.08**	**-0.60**	-0.57	-0.49	-0.53	-0.60	-0.62	1						
9. URT_Thoughts about Future[2]	**-0.05**	**0.63**	0.63	0.54	0.57	0.60	0.60	-0.38	1					
10. URT_Train of Thought[2]	**-0.02**	**0.70**	0.68	0.64	0.67	0.65	0.67	-0.45	0.88	1				
11. URT_Personal Worries[2]	**-0.02**	**0.78**	0.76	0.69	0.73	0.75	0.75	-0.49	0.81	0.83	1			
12. Processing Speed[3]	-0.31	-0.08	-0.06	-0.10	-0.10	-0.05	-0.08	-0.04	-0.03	-0.07	-0.05	1		
13. Working Memory_Nback[3]	-0.36	-0.09	-0.05	-0.05	-0.11	-0.08	-0.11	-0.02	-0.02	-0.05	-0.05	0.44	1	
14. Working Memory_SS[3]	-0.12	-0.13	-0.13	-0.16	-0.14	-0.10	-0.12	0.00	-0.13	-0.16	-0.15	0.26	0.19	1

Note. Bolded correlations were significant at $p < .0001$. [1]Negative affect represents the average value across the study days (14). [2]Item on unconstructive repetitive thinking (URT) measure that asks about how positively or negatively valanced their thoughts were in the moment. [3]Value represents the average processing speed and working memory task scores across the study days.

CHAPTER 4

Study 3. The Effect of Pro-Inflammatory Cytokines on Perceived Stress and Cognitive Function in Mid to Later Life

ABSTRACT

Chronic stress is often associated with poorer cognition among middle-aged and older adults. Inflammatory processes may underlie this relationship, and older adults are at higher risk for experiencing greater inflammatory profiles. In the current study, I hypothesized that greater perceived stress is related to lower cognitive function, and that higher levels of inflammation account for this link among a group of healthy middle-aged and older adults. Participants (N= 980) with an average age of 54.21(12.41; Range: 34 - 84) completed the cognitive and biomarker projects in the second wave of the Midlife in the United States Study (MIDUS II). Inflammation was measured through three pro-inflammatory cytokines (TNF-α, C-reactive protein and interleukin-6) and a composite of cognition included measures of memory and executive function. Hierarchical multiple regression analysis revealed a significant direct effect of perceived stress on cognition (path c, β= -0.09, $p < .001$, $R^2_{adj} = .29$,)), and a significant relationship between perceived stress on TNF-α (path a, β= -0.05, $p = .03$; $R^2_{adj} = 0.07$**)**, but not on IL-6 (path a, β= -0.02, $p = .46$) or CRP: β= -0.01, $p = .68$). None of the cytokines were related to cognition (path b), but higher perceived stress was predictive of higher inflammatory levels. Future research should focus on understanding how inflammation may work as a mediator over time accounting for prolonged heightened perceived stress.

INTRODUCTION

Stress is associated with both short- and long-term adverse effects on cognitive functioning (Aggarwal et al., 2014; Boals & Banks, 2012; Ihle et al., 2020; Ohman et al., 2007; Palmer, 2013). Higher levels of stress are related to interferences in several cognitive processes including areas of working memory, processing speed, and executive functioning (Aggarwal et al., 2014a; Kim et al., 2015; Munoz et al., 2015). Yet, much of the literature linking higher stress to poorer cognitive function is based on assessments in response to laboratory stressors. Less often studied is how perceived stress, or the cognitive appraisals of how stressed one feels, relates to differences in cognitive function outside of the laboratory. Dysregulation of the HPA-axis is one reason stress is posited to negatively impact cognitive function (Korten et al., 2016; Lupien et al., 2007).

A marker of HPA-axis function is inflammation, typically measured through pro-inflammatory cytokines, and increased levels of systemic inflammation have been linked to lower cognitive function (Leonardo & Fregni, 2023). For this reason, inflammation may also function as an underlying pathway between perceived stress and cognitive function. Examining the underlying pathways between psychological and physiological stress could provide further insight into how greater perceived stress leads to lower cognitive function. The current study assessed whether inflammation helps explain the relationship between perceived stress and cognitive function in a sample of healthy adults in mid to later-life.

Perceived Stress and Cognition

Short-term effects of stress on cognition regularly occur when individuals view stressors as uncontrollable and overwhelming, appraisals resulted in high perceived stress. Researchers have used academic performance (i.e., exam grades) as a proxy for cognitive performance, and consistently find a robust correlation between higher perceived stress and lower exam grades (Frazier et al., 2019; Pettit & DeBarr, 2011; Spivey et al., 2020; Talib & Zia-ur-Rehman, 2012; Varghese et al., 2015). Moreover, when objective cognitive tasks have been used to measure cognitive function, higher levels of perceived stress are more likely to be associated with poorer executive function and working memory (Frazier et al., 2019; Varghese et al., 2015). A psychological framework that helps support the relationship between perceived stress and cognitive function is one that considers the emotional processes of stress associated with cognitive dysfunction.

Cognitive Model of Depression and its Application to Perceived Stress

LeMoult and Gotlib (2019) use the Cognitive Model of Depression to describe specific types of cognitive emotion regulation processes that interfere with cognitive processes. Although this model was originally developed to explain the effects of depression on cognitive functioning, it offers a framework that can be applied to describe the cognitive effects of perceived stress (LeMoult and Gotlib; 2019). High perceived stress is common among individuals with depressive symptoms, and these individuals have related deficits in processing speed, attention, working memory, and executive (Abramovitch et al., 2021; Köhler et al., 2010; Krogh et al., 2014). The types of cognitive functioning affected by stress processes are specified within the Cognitive Model of Depression. Executive functioning, memory, attention, and processing speed are often disrupted when cognitive control is lost (Jopling et al., 2020). To expand on this model, factors such as inflammation levels should be considered to help understand how perceived stress influences cognitive processes.

Inflammatory Processes and Stress

When individuals experience on-going psychological stress, for instance being a caregiver for a family member with dementia, their inflammatory responses remain elevated over time (Gouin et al., 2012). Cortisol is a glucocorticoid hormone secreted by the hypothalamic-pituitary-adrenal (HPA) axis, and an increase in production occurs when the body responds to stress (Charles et al., 2020; Sladek et al., 2020). When cortisol is released, its anti-inflammatory properties work to regulate inflammatory responses (Miller et al., 2007). Immunological functioning relies on inflammatory reactions adapting to one's environment, especially during times of heightened stress. The Glucocorticoid Cascade Hypothesis (GCH; Sapolsky et al., 1986) posits that chronic stress results in the dysregulation of glucocorticoids, leading to paradoxically increased and sustained inflammatory responses. If chronic stress persistently activates the HPA axis then cortisol becomes less effective at controlling inflammation (Knight et al., 2021).

C-reactive protein and interleukin-6 (CRP and IL-6) are two pro-inflammatory cytokines known to be biomarkers of exaggerated inflammation among individuals with chronic stress (Cunningham et al., 2009; Leonard, 2018; Wirtz & von Känel, 2017). Persons with high perceived stress often have increased levels of inflammation, which is connected to poorer cognitive functioning (Allison & Ditor, 2014; Black, 2002; Krogh et al., 2014). Increased IL-6 and CRP levels are correlated with poorer cognitive functioning in the domains of memory and processing speed (Iob et al., 2020; Leonard, 2018; Miller et al., 2007; Oitzl et al., 2010; Wilson et al., 2002). Examining how inflammation underlies the relationship perceived stress and cognitive function is necessary to better understand the biopsychosocial determinants of cognition (Benson et al., 2017; Black, 2002; Duivis et al., 2013). Evidence connecting systemic inflammation and cognitive impairment among young, middle-aged and older adults is emerging (Brydon et al., 2008; Lin et al., 2018; Marsland et al., 2015). However, given that chronic illnesses such as dementia or Alzheimer's are more common in later life, older adults may be especially vulnerable to the physiological effects of stress on cognition (Gaydosh et al., 2019; Giuntella et al., 2021; Goldman et al., 2018).

Current Study

The current study examined whether inflammation, measured by pro-inflammatory cytokines TNF-α, and a composite of CRP and IL-6, may underlie the relationship between perceived stress and cognitive functioning in a sample of healthy middle-aged and older adults. I hypothesized that higher perceived stress will be associated with poorer cognitive performance, and that this relationship will be explained by inflammation. Heightened levels of perceived stress will predict higher level of inflammation which in turn will lead to poorer cognitive task performance. In addition, a main effect linking higher perceived stress to cognitive performance is expected.

METHOD

Procedures and Participants

The present study used data from Midlife in the United States (MIDUS I), a National Longitudinal Study of Health and Wellbeing. MIDUS I was first conducted between 1995 and 1996 and included 7,108 participants (Radler, 2014). Selection criteria for MIDUS were being non-institutionalized, English-speaking, living in the continental U.S., and being aged 25 through 75 years old. The primary aim of MIDUS I was to study behavioral, psychological, and social factors related to physical and mental health and wellbeing. MIDUS was repeated from 2004 to 2006 (MIDUS II), and included a total of 5,555 returning and newly recruited participants (Ryff et al., 2007; Ryff & Almeida, 2009). In the second and continuing waves, a subsample of MIDUS II participants were invited to partake in cognitive and biomarker sub-projects (Ryff et al., 2010). Only participants who completed the cognitive project were eligible for the biomarker project, resulting in a total of 1,255 participants included in this study.

The cognitive project was designed to study cognitive performance of young, middle-aged, and older adults from a large-scale national sample (Ryff & Lachman, 2009). Participants completed a comprehensive cognitive battery administered over the phone which included tasks for multiple domains of cognition (i.e., memory, processing speed, and executive function). The purpose of the MIDUS II biomarker project was to identify biopsychosocial pathways contributing to mental, physical and cognitive health outcomes (Ryff et al., 2010). Biomarkers of stress and inflammation were collected through fasting blood draw, 12-hour urine, and saliva samples. The biomarkers collected assessed immune, cardiovascular, musculoskeletal, antioxidant, and metabolic processes. Participants were also evaluated for psychosocial factors including perceived stress, included in this study.

Measures

Stress

The Perceived Stress Scale (PSS; Cohen et al., 1983) is a 14-item measure of the perception of stress through appraisals of how stressful situations are in one's life. The PSS asks people how unpredictable, uncontrollable, and overloaded they feel by their life, but also includes questions about levels of stress currently experienced during the past month. For example, participants were asked, "In the last month… how often have you been upset because of something that happened unexpectedly? and, "how often have you felt nervous or stressed?" Responses for each item range from 0 (Never) to 4 (Very Often). Scores for the PSS can range from 0 to 40, with higher scores representing greater perceived stress.

Inflammatory Biomarkers

The three inflammatory biomarkers included in this study include pro-inflammatory cytokines C-Reactive Protein (CRP), tumor-necrosis factor-alpha (TNF-α) interleukin-6 (IL-6). Circulating levels of IL-6, a pro-inflammatory cytokine related to systemic inflammation, were collected as an inflammatory measure (Elliot & Chapman, 2016; Ryff et al., 2010). The enzyme-linked immunosorbent assay (ELISA; R & D Systems; Minneapolis, MN) was used to measure concentrations of IL-6 from blood serum. CRP, synthesized in the liver and other tissues, is produced when stimulated by IL-6 and other pro-inflammatory cytokines (e.g., TNF-α). CRP was measured from blood serum using a particle enhanced immunonephelometric assay (BNII nephelometer from Dade Behring, Deerfield, IL). Laboratory intra- and inter-assay coefficients for the biomarkers were in acceptable ranges of variance.

To reduce skewness in the distributions, a base-10 logarithm transformation was performed on IL-6 and CRP. Research examining CRP suggests that levels exceeding 10.0mg/L are reflective of acute inflammation resulting from a current infection or injury; therefore, researchers often discard those cases. Following this, cases of CRP levels of 10.0mg/L were not included (Elliot & Chapman, 2015; O'Connor et al., 2009).

Cognitive Tests

The Brief Test of Adult Cognition by Telephone (BTACT) assesses multiple domains of cognitive functioning including memory, processing speed, and executive function (Lachman et al., 2014; Tun & Lachman, 2006, 2008). The psychometric properties of the BTACT are strong (Lachman et al., 2014), with convergent validity for the measures included ranging from .42 to .54 ($p < .001$). The BTACT includes seven subtests. These seven subtests create a composite score for overall cognitive functioning with two dimensions accounted for including episodic memory and executive function.

Word List Immediate Recall. Participants listen to a list of 15 words being spoken aloud. Once all 15 words are spoken, participants immediately recall the set of words. A participant's score represents the total number of words recalled accurately. The 15 words were compiled from the Rey Auditory Verbal Learning Test (Lezak et al., 2004; McMinn et al., 1988).

Digits Backward. The Digit-Span Backward is a test of working memory, developed for the Wechsler Adult Intelligence Scale-III (Ryan & Lopez, 2001; Wechsler, 1997). First, participants are read aloud strings of numbers ranging from two to eight numbers. Then, they are instructed to repeat the string of number back, but in reverse order. Scores are calculated based on the number of the longest number set correctly repeated backward (i.e., 0 – 8).

Category Fluency. Participants are asked to verbally name as many animals as they can in 60 seconds, as a test of executive function. The total number of distinct animals named represents a participant's score (DiBlasio et al., 2021; Drachman & Leavitt, 1972).

The Stop and Go Switch Task. This is a measure of executive function involving the dimensions of attention and task switching, as well as inhibition (Tun & Lachman, 2008). Participants complete two mixed-task conditions – a normal condition and reverse condition. Next participants are instructed to say "stop" every time they are read aloud the word red and "go" when they hear green for the normal condition. In the reverse condition, participants are told to say "go" for red and "stop" for green.

Number Series. Measuring inductive reasoning, which falls under executive function, Number Series requires participants to identify number patterns. Participants are presented with a series of five numbers and then tasked with deciding what the sixth number would be in the series. A score of 0 – 5 can be earned, depending on how many correct number series trials are completed (DiBlasio et al., 2021; Salthouse & Prill, 1987).

Backward Counting. Starting from 100, participants count backwards aloud, and as quickly and precisely as possible, for a 30 second period. Since participants must be able to rapidly generate a non-automatic sequence of familiar items (i.e., numbers), this measure tests processing speed. Participants are scored based on the total number correctly counted (Hughes et al., 2018).

Word List Delayed Recall. Assessing memory retrieval, Word List Delayed Recall requires participants to recall the Rey Auditory Verbal Learning Test – a list of 15 words presented roughly 15 minutes earlier in the cognitive battery (Lezak et al., 2004). Scores are treated the same, ranging from 0 to 15 based on how many words were remembered correctly.

Baseline and Covariate Measures

Demographics. As part of the MIDUS II self-administered questionnaires, participants reported their date of birth, gender (male or female), marital status (married or not married), as well as their racial and ethnic identity. The categories for racial and ethnic identity include White, Black and/or African American, Native American or Alaska Native Aleutian Islander/Eskimo, Asian, Native Hawaiian or Pacific Islander, or other. Participants were also asked whether they are of Spanish, Hispanic, or Latino descent, which includes Mexican, Mexican American, Chicano, Puerto Rican, Cuban, or other Spanish Origin.

To assess socioeconomic status, participants reported their highest level of education, as well as their household income and work status (working or not working). Education was treated as a continuous variable in the model. The variable consists of 12 categories ranging from no school or some grade school to having completed a doctoral degree. Total household income was calculated based on wages, pension, social security, and other government assistance for all household members. A standardized z-score was calculated to create a composite score for household income.

Body Mass Index. Chronic levels of inflammation are associated with higher body mass index (BMI); therefore, research often statistically adjusts for BMI in research assessing pro-inflammatory cytokines (Kantor et al., 2013; Knight et al., 2021). BMI was calculated using the participant's height and weight.

Analytic Plan

SAS version 9.4 was used for all analyses in this study. To participate in the biomarker project, participants were required to have completed both the survey and cognitive projects, which resulted in a total sample of 1,255 (see flow chart in Figure 3.1). The three datasets including the survey, cognitive, and biomarker projects were merged into one dataset and cleaned and screened for missingness and normality. Following the suggestion of prior inflammation research, cases of CRP and IL-6 falling above 10.0mg/L were removed from analysis ($N_{\text{CRP}} = 3$, $N_{\text{IL-6}} = 2$). Otherwise, no significant outliers were identified across the predictors and covariates, and data did not require transformation. There was < 1% of missing data for the predictors of perceived stress, for TNF-α, CRP and IL-6. Since the missing data was lower than 20% for each variable, listwise deletion was employed to handle missing data within the models used for analyses.

As described above, seven measures assessing the domains of memory, processing speed, memory, and executive function were computed into an overall composite *z*-score. No multicollinearity was demonstrated between the pro-inflammatory cytokines, so each was treated as a separate predictor. Proc Reg was used to test the hypotheses through hierarchical multiple regression analyses. Each model fit produced parameter estimates then used to compute the direct and indirect effects between the predictor (perceived stress), mediators (TNF-α, CRP, IL-6). Figure 3.2 depicts the hypothesized mediation model.

RESULTS

Table 3.1 provides the sample demographics and descriptive statistics. Participants had an average age of 55, were primarily white (91.5%), married, had some college, and roughly half the sample was employed (50.4%). Correlation analyses (see Table 1) revealed that older age was significantly related to higher levels of perceived stress ($r = .10$), TNF-α ($r = .25$) and IL-6 ($r = .12$), and to lower levels of cognitive performance ($r = -.43$).

Mediation Analyses

Table 3.2 presents the coefficients and confidence intervals for each pathway tested in the mediation model (refer to Figure 3.2). The initial overall model with covariates and perceived stress was significant ($F(7, 930) = 55.63$, $p < .0001$), and the main effects of the included covariates were as expected. Older age predicted lower cognition, but higher education, being white, married, and employed all significantly predicted better cognition (see Table 3.2).

To test whether inflammation mediated the link between perceived stress and cognition, first the direct effect of perceived stress on cognitive function was tested. Perceived stress was a significant predictor of lower cognitive performance [path c, ($\beta = -.10$, $t(1) = -3.40$, $p < .001$, 95% CI = (-.14, -.04)]. Next, I tested the relationship between perceived stress and each cytokine (path a). Perceived stress had a direct effect on TNF-α [($\beta = -.05$, $t(1) = -2.13$, $p = .03$, 95% CI = (-.01, -.00)], but not on CRP [($\beta = -.01$, $t(1) = -.41$, $p = .68$, 95% CI = (-.06, .04)], or IL-6 [($\beta = .02$, 95% CI = (-.03, .08); $t(1) = .74$, $p = .46$]. Finally, I evaluated whether entering inflammation in the model would significantly reduce the direct effect of perceived stress (path b). None of the individual cytokines significantly mediated the effect of perceived stress on cognition (see Table 3.2).

DISCUSSION

The purpose of the current study was to assess whether inflammation is an underlying pathway for the relationship between perceived stress and cognitive function among a group of adults in mid- to later life. I hypothesized that higher perceived stress would lead to poorer cognitive function and that this relationship is mediated by pro-inflammatory cytokines (TNF-α, CRP, IL-6). Despite the finding that inflammation did not significantly explain the association between perceived stress and cognition, this study provides further support for the link between perceived stress and cognitive function. Additionally, findings also demonstrated that perceived stress is associated with inflammation.

Perceived Stress and Cognitive Function

The finding that higher perceived stress is related to poorer cognitive function is consistent with previous studies (Agorastos & Chrousos, 2021; Allison & Ditor, 2014; Black & Garbutt, 2002; Rohleder, 2019). People who experience high levels of perceived stress exhibit cognitive deficits including inattention, lower processing speed, and impaired memory. Although this finding that greater perceived stress is related to lower cognitive function is not novel, this is one of few studies to examine this effect using a sample of middle-aged and older adults (34 to 84 years; Aggarwal et al., 2014; Oken et al., 2011; Turner et al., 2017) Older age is associated with both greater levels of systemic inflammation and declines in overall cognitive function (Menza et al., 2010; Sin et al., 2015). Findings indicate that older adults with higher levels of perceived stress are more susceptible to declines in their cognitive functioning than their less-stressed peers (Aggarwal et al., 2014b). Prior studies have found that when perceived stress is maintained at high levels, or when perceived stress increases over time, older adults experience deficits in memory, attention, processing speed, and executive function. For example, in a longitudinal study of Chinese-American older adults, performance on memory and processing speed tasks was lower among participants with high levels of perceived stress over two years (Chen et al., 2019).

Perceived Stress, Inflammation, and Cognitive Function

The hypothesized relationship between higher perceived stress and greater systemic levels of inflammation was based on the Glucocorticoid Cascade Hypothesis. In this hypothesis, the hypothalamic-pituitary-adrenocortical axis (HPA) becomes dysregulated due to the downstream effects of chronic stress (O'Brien, 1997; Sapolsky et al., 1986) leading to higher circulating levels of inflammation. In the present study, perceived stress was significantly related to inflammation, but only the pro-inflammatory cytokine of TNF-α. Since research generally finds that CRP and IL-6 are related to higher reported stress perceptions, the mixed results in this study are likely due to lack statistical variation in the CRP and IL-6 variables. Using measures of inflammation and perceived stress from only one timepoint could also be decreasing the predictive value of these variables. Additionally, cross-sectional research examining perceived stress and inflammation does not necessarily capture systemically elevated inflammation which is associated with sustained activation of the physiological stress systems. (Karlamangla et al., 2014; Seeman, 1997; Teunissen et al., 2003; Wilson et al., 2002). Inflammation levels would likely be better predicted using repeated measurements of inflammatory biomarkers over time (Acabchuk et al., 2017; Hannibal & Bishop, 2014).

Limitations and Strengths

The first limitation to note in this study is that data and subsequent analyses were cross-sectional. It was important that this study first established the correlational links between perceived stress, inflammation, and cognitive function across middle-aged and older adults. Additionally, this study used a large sample of healthy older adults, demonstrating that cognitive function is related to perceived stress outside of pathological aging (e.g., dementia or Alzheimer's). Despite the cross-sectional data not allowing for a true mediation to be tested, the analyses provide robust support for the direct association between perceived stress and cognition, as well as perceived stress and inflammation. Another methodological limitation is that the sample consistently primarily of white adults, which prevents the findings from this study from extending to other races and ethnicities. The sample, although representative of the age group within the United States time point in which data were collected (Ryff, 2010; Ryff & Lachman, 2009), does not represent the more ethnically diverse older adults that the United States will have in the future.

Future Directions

These findings provide avenues for future research involving additional psychophysiological processes to consider. First, assessing additional biomarkers of physiological stress (e.g., cortisol levels) for mediation effects alongside those of inflammation could illuminate how the physiological pathways ultimately connect to cognitive function. The rationale for this direction stems again functioning from the Glucocorticoid Cascade Hypothesis (GCH). The GCH has implications for cognitive, as there is some evidence of hippocampal cell damage due to prolonged glucocorticoid secretion stemming from chronic stress (Conrad, 2008; Sapolsky, 1999). Though less widely studied than the short-term effects of perceived stress and cognitive functioning, some studies demonstrate the long-term effects of perceived stress on cognition using longitudinal data (Aggarwal et al., 2014). Future research should utilize multiple timepoints of perceived stress data as well as inflammatory biomarkers to predict the pathways leading to deficits in cognitive function.

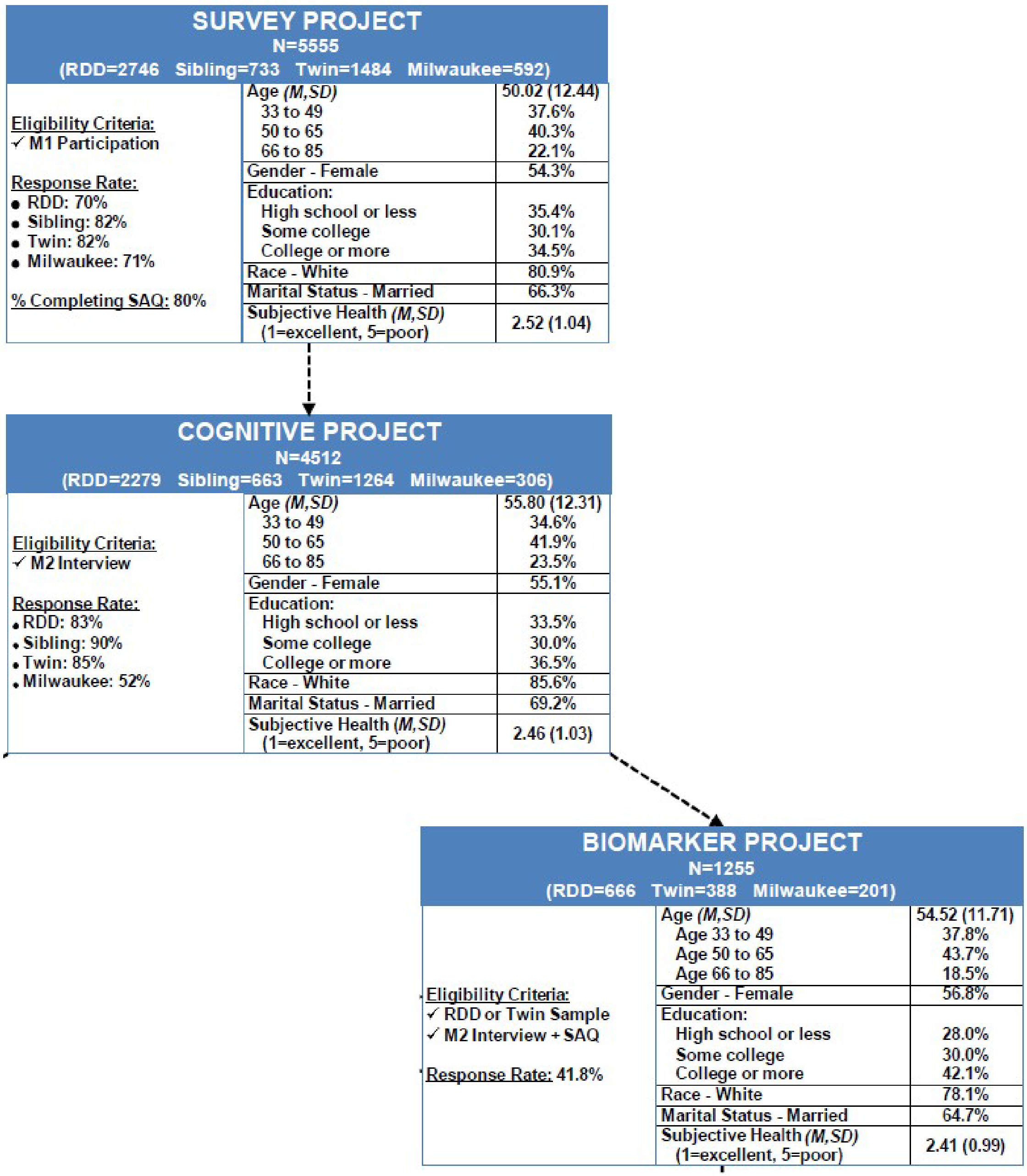
Furthermore, findings highlight the potential for future research to investigate the bi-directional relationship between inflammation and perceived stress. Chronic health diseases related to cognitive outcomes, and both the risk for developing chronic illness and levels of inflammation increase with age (Black & Garbutt, 2002; Chung et al., 2019; Greenberg et al., 2014; Gorelick, 2010; Krogh et al., 2014; Piazza et al., 2018; Sapolsky, 1999). Future research should continue to disentangle these relationships, considering both psychological and physiological pathways

Conclusion

Using a sample of healthy middle-aged to older adults, this study demonstrated that higher levels of perceived stress are significantly associated with lower cognitive performance assessed through a standardized composite measure of memory and executive function. An underlying pathway between perceived stress and cognition through inflammation was not supported in this study. Despite these null effects, findings reveal that even among healthy middle-aged to older adults, experiencing heightened perceived stress is related to poorer cognitive function. This study helps to advance the fields understanding of underlying mechanisms in the relationship between stress and cognition.

Figure 3.1

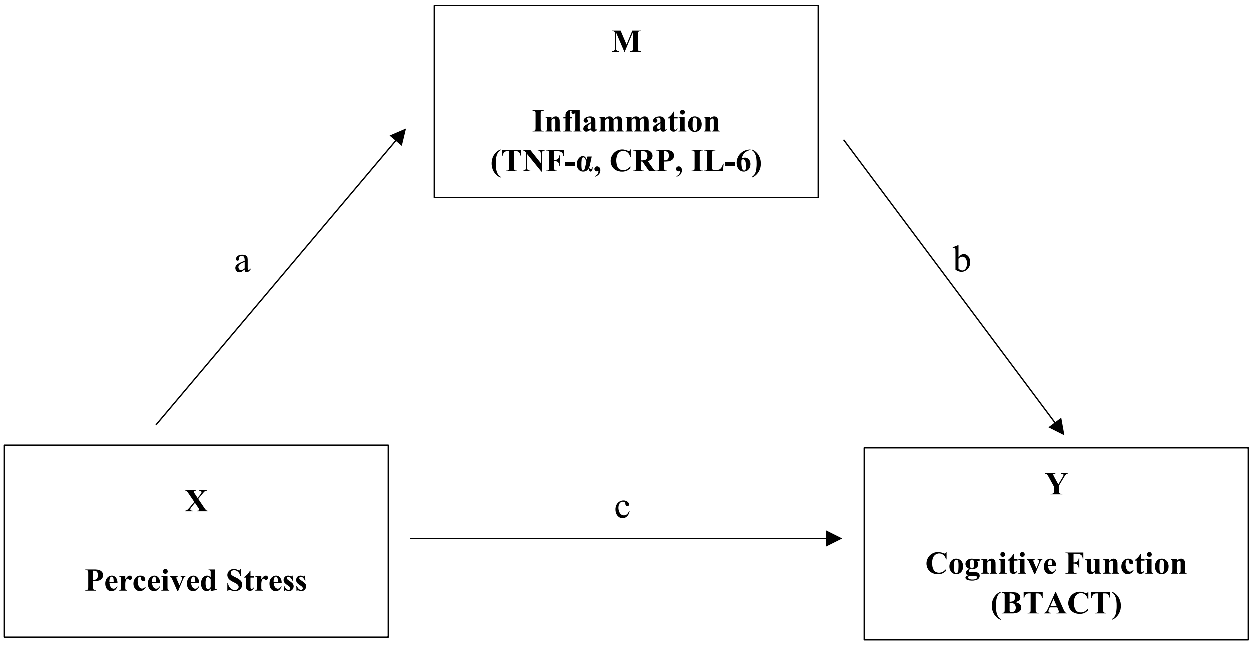
MIDUS 2 Sample Flow Across Projects



Note. The daily diary and neuroscience projects were removed from the flowchart since those projects were not included in this study.

Figure 3.2

Mediation Model of Perceived Stress, Inflammation, and Cognitive Function



Note. Each pro-inflammatory cytokine (TNF-α, CRP, IL-6) will be tested in separate mediator models. Path a to b represents the indirect effect of X on Y after controlling for M. Path c represents the direct effect of perceived stress on cognition.

Table 3.1

Study 3 Descriptives and Correlations

Variable	*N*	*M (SD)* % or [range]	1	2	3	4	5	6	7	8	9	10	11	12
1. Age	1233	54.53 (11.69) [34 - 84]	1											
2. Gender	1233		0.00	1										
Male	536	43.47%												
Female	697	56.53%												
3. Racial/Ethnic Identity[1]	1037		0.05	-0.02	1									
White	949	91.51%												
Other	88	8.49%												
4. Education[2]	1037	7.4 [1 – 12]	-0.14	-0.10	0.05**	1								
5. Work Status	1036		-0.50	-0.13	-.02	0.18	1							
Working	702	50.4%												
Not Working	334	49.6%												
6. Married	1037		-0.09	-0.15	-0.11	0.06	.06	1						
Yes	753	72.61%												
No	284	27.39%												
7. BMI[3]	1004	27.88 (5.53)	0.11	0.06	0.06	0.00	-0.08	0.01	1					
8. Perceived Stress	1228	22.24 (6.34) [0 – 50]	-0.19	0.07	-0.05	-0.09**	-0.01	-0.04	0.10**	1				
9. TNF-α[4]	1227	0.23 (0.05)	0.25	-0.06*	0.01	-0.12**	-0.17	-0.02	0.18	-0.05	1			
10. CRP[4]	1233	0.7 (0.25)	-0.02	0.14	-0.01	-0.08*	-0.03	0.01	0.26	0.06*	0.18	1		
11. IL-6[4]	1232	-0.01 (.99)	0.12	0.06*	0.01	-0.07*	-0.17	-0.03	0.19	0.08**	0.25	0.42	1	
12. BTACT[5]	970	0.15 (0.92)	-0.43	-0.02	0.12	0.42	0.31	0.10	-0.03*	-0.06	-0.15	-0.06	-0.12**	1

Note. *N* is used to represent the number of respondents for each variable, % stands for the percentage of the sample, M and SD denote mean and standard deviation. Correlations values are based on Pearson correlations, *$p < .05$, **$p < .01$, bolded correlation values (*r*) represent $p < .001$, . [1]White represents non-Hispanic White/Caucasian and "Other" includes Latino, Hispanic-White, Hispanic-Black, Black/African American, Asian, Native American or Alaska Native, Native Hawaiian or Pacific Islander. [2]Education was treated as continuously with 12 categories ranging from no school or some grade school up to a professional degree (e.g., M.D., Ph.D.). measured using five categories ranging from completion of grade school or less, to a graduate or professional degree. [3]BMI = Body Mass Index. [4]TNF-α = Tumor Necrosis Factor-alpha, CRP = C-Reactive Protein, IL-6 = Interleukin-6, all pro-inflammatory cytokines are standardized with a mean of 0 and standard deviation of 1. [5]BTACT = Brief Test of Adult Cognition by Telephone, a standardized composite measure of memory and executive function.

Table 3.2

Hierarchical Regression Results for Mediation Analysis

Parameters	*β*	*SE*	*t*	*p*	*95% CI* Lower	*95% CI* Upper	R^2_{Adj}
STEP 1: X → Y							
Intercept	-1.33	0.23	-5.73	<.0001	-1.78	-0.87	
Age	0.01	0.00	6.30	<.0001	0.01	0.02	
Education	-0.03	0.01	-2.62	0.01	-0.05	-0.01	
Married	-0.05	0.05	-0.93	0.35	-0.16	0.06	
Race/Ethnicity	0.06	0.09	0.64	0.52	-0.12	0.23	
Work Status	-0.10	0.06	-1.67	0.10	-0.21	0.02	
BMI	0.03	0.00	6.18	<.0001	0.02	0.04	
Perceived Stress	-0.05	0.03	-2.13	0.03	-0.10	0.00	0.29
STEP 2: X → M (TNF-alpha)							
Intercept	-1.33	0.23	-5.73	<.0001	-1.78	-0.87	
Age	0.01	0.00	6.30	<.0001	0.01	0.02	
Education	-0.03	0.01	-2.62	0.01	-0.05	-0.01	
Married	-0.05	0.05	-0.93	0.35	-0.16	0.06	
Race/Ethnicity	0.06	0.09	0.64	0.52	-0.12	0.23	
Work Status	-0.10	0.06	-1.67	0.10	-0.21	0.02	
BMI	0.03	0.00	6.18	<.0001	0.02	0.04	
Perceived Stress	-0.05	0.03	-2.13	0.03	-0.10	0.00	0.11
STEP 2: X → M (CRP)							
Perceived Stress	-0.01	0.03	-0.41	0.68	-0.06	0.04	0.07
STEP 2: X → M (IL-6)							
Perceived Stress	0.02	0.03	0.74	0.46	-0.03	0.08	0.07
STEP 3: M → Y							
TNF-alpha	-0.01	0.03	-0.16	0.87	-0.07	0.06	0.29
CRP	-0.03	0.03	-0.96	0.34	-0.09	0.03	0.29
IL-6	-0.01	0.03	-0.45	0.65	-0.07	0.04	0.29

Note. Inflammatory cytokines were entered in separate models to test for mediation effects. All estimates are standardized.

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