THE GERONTOLOGICAL SOCIETY OF AMERICA®

Journals of Gerontology: Psychological Sciences
cite as: *J Gerontol B Psychol Sci Soc Sci*, 2019, Vol. 74, No. 1, 38–46
doi:10.1093/geronb/gby042
Advance Access publication May 15, 2018

OXFORD

Special Section: Back to the Future: Anticipating Stress

Waking Up on the Wrong Side of the Bed: The Effects of Stress Anticipation on Working Memory in Daily Life

Jinshil Hyun, MA,[1] Martin J. Sliwinski, PhD,[1] and Joshua M. Smyth, PhD[2]

[1]Department of Human Development and Family Studies and Center for Healthy Aging and [2]Departments of Biobehavioral Health & Medicine, Pennsylvania State University, University Park.

Address correspondence to: Martin J. Sliwinski, PhD, The Center for Healthy Aging, The Pennsylvania State University, 402, Biobehavioral Health Building, University Park, PA 16802. E-mail: mjs56@psu.edu

Received: November 15, 2017; Editorial Decision Date: March 8, 2018

Decision Editor: Shevaun Neupert, PhD

Abstract

Objectives: The aim of this study was to examine the association between stress anticipated for the upcoming day and cognitive function later on that day, and how this relationship differed across age.
Method: A diverse adult community sample (N = 240, age 25–65 years) completed ecological momentary assessment (EMA) reports for 2 weeks on a smartphone; each day they completed a morning survey upon waking, beeped surveys at five times during a day, and an end-of-day survey. Morning and end-of-day surveys included questions to measure stress anticipation, and each beeped survey included measures of stressful events, followed by a spatial working memory (WM) task.
Results: Results from multilevel models indicated that stress anticipation reported upon waking, but not on the previous night, was associated with deficit in WM performance later that day; importantly, this effect was over and above the effect of EMA-reported stress. The detrimental effect of stress anticipation upon waking was invariant across age.
Discussion: These findings suggest that anticipatory processes can produce harmful effects on cognitive functioning that are independent of everyday stress experiences. This may identify an important avenue to mitigate everyday cognitive lapses among older adults.

Keywords: Anticipating stress, Cognition, Working memory

Everyday stress, even if relatively minor, can have deleterious effects on cognitive function (Sliwinski, Smyth, Hofer, & Stawski, 2006). Most research on everyday stress has focused on identifying, typically by self-report, events that have happened in the recent past (often the same day) and linking those events to current emotions, physical symptoms, and cognitive function. This focus on past events ignores an alternative way in which stress manifests in everyday life—anticipation. Although several laboratory studies have examined the role that anticipation of stress plays on cognitive function (e.g., Cain, Dunsmoor, LaBar, & Mitroff, 2011; Starcke, Wolf, Markowitsch, & Brand, 2008), little evidence exists regarding whether anticipatory stress is linked to cognition in everyday life. Further, identifying factors that influence cognition in real life contexts is especially important among older adults, who already experience age-related cognitive decline, to prevent from further lapses and slips. The overall aim of present study is to examine whether anticipation of stress for a day is associated with cognition on that day and to examine age differences therein.

Stress Anticipation and Cognition

There are a number of laboratory studies that have tested the effect of anticipatory stress on cognition. In those studies, anticipatory stress, triggered by informing participants to prepare for public speaking (Lupien et al., 1997; Preston, Buchanan, Stansfield, & Bechara, 2007; Starcke, Ludwig, & Brand, 2012; Starcke et al., 2008), a naturalistic acute stressor (helicopter underwater evacuation training; Robinson, Sünram-Lea, Leach, & Owen-Lynch, 2008), or providing cues for electronic shocks (Cain et al., 2011), was followed by assessing cognitive performance. Although most of the studies have observed deleterious effects of anticipatory stress on attention (Cain et al., 2011), declarative memory (Lupien et al., 1997), decision making (Preston et al., 2007; Simonovic, Stupple, Gale, & Sheffield, 2017; Starcke et al., 2008), and moral judgment (Starcke et al., 2012), cognitive performance measured in the artificial, standard testing environments may not have ecological validity to reflect cognitive function in naturalistic settings. Intensive repeated measurement designs such as daily diaries and ecological momentary assessment (EMA) assess participants in naturalistic contexts in their daily lives with fewer biases such as evaluative threats that may arise from laboratory settings (Sliwinski et al., 2018; Timmers et al., 2014). Moreover, repeated sampling of situations allows exploring dynamic links between cognitive performance and time-varying stress processes (Allard et al., 2014). Thus, translating a laboratory cognitive test into an ambulatory format (i.e., smartphone test) in EMA would allow to measure memory function (e.g., failures, difficulties) in the context of everyday life. However, there is little empirical work that has examined the link between anticipatory stress and cognitive impairment in everyday life.

Several studies have demonstrated associations between everyday stress and cognition (Neupert, Almeida, Mroczek, & Spiro III, 2006; Rickenbach, Almeida, Seeman, & Lachman, 2014; Sliwinski et al., 2006) but, as noted above, very few have examined anticipatory stress processes and cognitive function. Neupert and colleagues (2016) examined how subjective memory failures on a current day were associated with the previous night's anticipatory coping for potential upcoming stress. They found that a coping form typically considered maladaptive (i.e., stagnant deliberation) was associated with fewer self-reported memory failures in response to stressful events the next day. In moving to in situ experiences in daily life to capture ecologically valid processes, it is more difficult to capture objective measures of cognition, although doing so would help better explicate the link between anticipation and cognition. We are unaware of any research to date that has examined whether everyday stress processes prior to stressful events occur are associated with objective cognitive performance; given recent developments in the ambulatory and momentary assessment of cognition (Sliwinski et al., 2018), such approaches are now feasible and reliable.

There are different ways to conceptualize and operationalize anticipatory stress processes: stressor forecasting and stress anticipation. In lab studies, people are often told in concrete terms about a stressful event that will happen at a specified time (e.g., during their lab visit) and then perform cognitive tasks during a time in which they are anticipating the (imminent) event. In naturalistic studies, anticipatory stress has been measured by self-reports obtained at the end of the day that asked about the perceived likelihood that specific types of stressful events would happen tomorrow (Neupert et al., 2016). These types of anticipatory stress forecast whether actual stressful events would occur within limited time (e.g., several hours, day) and we operationalize them as *stressor forecasting*. In contrast to the anticipation of future events, *stress anticipation* involves making predictions about potential affective and cognitive consequences (i.e., feeling stressed) (see Neupert, Neubauer, Scott, Hyun, & Sliwinski, 2018 for details about conceptual framework). In the present study, we used the latter term "stress anticipation" and operationalize it by asking the extent to which a person expects to experience stress during the upcoming day.

The first aim of the present study was to examine the association between stress anticipation for the upcoming day and working memory (WM) performance assessed during that day, in naturalistic settings. One theoretical account to support the link between stress anticipation and WM impairment is attention-depletion hypothesis (Scott et al., 2015; Sliwinski et al., 2006). It posits that stress-related thinking and/or coping efforts deplete the amount of attentional resources available for information processing, resulting in short-term decrements in cognitive performance. This view predicts that stress would impair attention-demanding cognitive performance that requires effortful or controlled processing, such as WM tasks (Hasher, Zacks, & May, 1999; Klein & Boals, 2001; Sliwinski et al., 2006). Stress anticipation may also trigger stress-related thinking and/or coping efforts prior to stressful events happen, which may occupy attentional resources and produce interference effect for cognitive tasks that place heavy demands on attentional control. This line of reasoning leads to our first hypothesis, which predicts that higher levels of daily stress anticipation for the upcoming day would be associated with impairment on subsequent WM performance (Hypothesis 1).

Age, Anticipation, and Cognition

A number of findings from both cross-sectional and longitudinal studies have shown age-related decrease in WM capacity (e.g., Park et al., 2002; Wingfield, Stine, Lahar, & Aberdeen, 1988). One explanation for this is a diminished capacity among older adults in inhibiting irrelevant, off-task information (Gazzaley, Cooney, Rissman, & D'esposito, 2005; Hasher et al., 1999). Stress-related thinking would be one type of information that individuals need to inhibit to perform goal-driven tasks at the current moment, such as performing a cognitive test. Wrzus and colleagues (2015) found that such stress-related ideation, after a stressful event occurred, had more detrimental effects among older compared to younger adults. Considering inhibitory deficiency and diminished attentional resources among older adults, it is thus plausible that older adults could be more affected by stress-related preoccupation prior to the occurrence of a stressful event. As such, the second goal of the current study was to examine whether the effect of stress anticipation varies across age (i.e., stress anticipation × age interaction). We hypothesized that WM performance of older adults would be more impaired by stress anticipation than that of younger adults (Hypothesis 2).

To evaluate our hypotheses, we adopted a 14-day EMA protocol that includes a morning survey upon waking, beeped surveys at five quasi-random times during a day, and a bedtime survey at the end of each day. Stress anticipation was assessed at two timepoints: in the morning ("Overall, how stressful do you expect *today* will be?") and on the prior evening ("Overall, how stressful do you expect *tomorrow* will be?"). Spatial WM tasks were performed at five times during the day immediately following participants' subjective reports of stressful events and recent experiences.

Method

The data were drawn from the first wave of the longitudinal Effects of Stress on Cognitive Aging, Physiology and Emotion (ESCAPE) study. The entire study protocol is described elsewhere (Scott et al., 2015); details relevant for the present study are provided below.

Participants

Participants were 240 adults (34% men, 66% women) from racially and economically diverse sample of 25–65 years (Mean = 46.99) recruited using systematic probability sampling of New York City Registered Voter Lists for the zip code 10475 (Bronx, NY). Eligible participants are 25–65 years of age, ambulatory, fluent in English, without visual impairment that would interfere with operating the study smartphone, and resident of Bronx County. The sample slightly over-represents women (66% of the sample compared to 58% of the population), but is otherwise representative of the area from which it is obtained (see Scott et al., 2018 for the detailed description of the sample).

Measures

Morning stress anticipation

Morning stress anticipation was assessed upon waking by asking participants "Overall, how stressful do you expect *today* will be?" to which they responded on a visual analog scales slider anchored at "Not at all stressful" to "Very stressful"; the scale was coded from 0 to 100.

EOD stress anticipation

End-of-day (EOD) stress anticipation was assessed daily before going to bed by asking participants "Overall, how stressful do you expect *tomorrow* will be?" to which they responded from "Not at all stressful" (0) to "Very stressful" (100).

Stressful events

At each beeped survey, participants used a yes/no checkbox to answer the question: "Did anything stressful occur since the last survey? A stressful event is any event, even a minor one, which negatively affects you." and the answer was scored 1 for occasions on which an event was reported and 0 when stressors were not reported. Stressful events variable indicated a total number of stressful events across beeped occasions in each day.

WM

To measure ambulatory WM performance, a spatial dot memory task was used. Participant was asked to remember the location of three red dots that appeared on a 5 × 5 grid. After 3 s, the dots and grid were removed and the distraction phase lasted for 8 s. Then an empty 5 × 5 grid reappeared on the screen and participants were prompted to recall the locations of the three dots initially presented and press a "Done" button after entering their responses to finish the trial. Participants completed two trials in total with 1 s delay between trials at each assessment occasion. Error score was calculated with partial credit given based on deviations from the correct locations. Euclidean distance of the location of the incorrect dot to the correct grid location was calculated, with higher scores indicating less accurate placement and poorer performance (Siedlecki, 2007). Previous work has shown this test to be a reliable and valid indicator of WM (Sliwinski et al., 2018). The final dependent variable was error score averaged across beeped occasions within each day.

Other items

Other constructs were assessed in the morning, beeped, and EOD reports that were not used in this study. Please refer to Scott et al. (2015) for additional information.

Covariates

The following person-level covariates were collected by the mailed questionnaire: *age* was coded in years (centered at 45); *gender* was coded as "male" and "female"; *education* was coded as low ("Less than high school diploma"), middle ("High school diploma/some college"), and high ("College degree or Higher"). *Study day* (i.e., day 1 to day 14) was included as a day-level covariate to model practice effects on cognitive tasks that might result from repeated testing.

Procedure

During recruitment, introductory letters were mailed to individuals from a sampling frame (obtained from the

Registered Voter Lists) and a research assistant phoned to establish eligibility, and enroll and consent interested persons. Participants were asked to respond to the mailed paper survey batteries assessing demographic and individual difference characteristics. They also visited the research offices to be trained on the use of study smartphone in which surveys for EMA were administered. The EMAs were administered on a Droid X which has a 4.3" display (480 × 854 pixels) and a 60 Hz refresh rate. Beginning the next day after their lab visit, participants completed a 2-day "run-in" phase to practice and habituate to the EMA protocol. Participants who completed 80% of the EMA surveys during the run-in were invited to the 14-day EMA study, resulting in 86.6% of participants obtained from the run-in phase.

During the 14-day EMA protocol, participants completed a brief smartphone morning survey upon waking, beeped surveys at five quasi-random times during a day, and a bedtime survey at the end of each day for 14 days. Upon waking, participants completed a survey about their previous night's sleep and their anticipation regarding the day ahead. At five quasi-random times during the day, the smartphone produced an audible alert ("beep") signaling participants to complete a survey about their recent experiences and psychological states, immediately followed by several brief ambulatory cognitive tasks including the WM task. The average time between beeped assessments was approximately 2.5 hr. At the end of each day, participants completed a separate end-of-day survey that assessed anticipation regarding the next day. The morning, beeped, and end-of-day surveys took an average of 1 min 33 s, 2 min 58 s, and 3 min 11 s to complete, respectively. Participants were generally highly adherent to the study protocol, responding to an average of 90.7% of morning survey, 81.4% beeped surveys, and 81.1% of end-of-day survey. Participants who satisfactorily completed the entire study protocol could receive up to $160.

Analytic Approach

Two level multilevel mixed models (MLMs) were estimated in SAS PROC MIXED (version 9.4) in order to account for the nested structure of the data (i.e., days within persons). Full maximum likelihood was used for model estimation and robust standard errors were used for fixed effects hypothesis testing. In the main analyses, WM performance was modeled as a function of stress anticipation variables of interests, stressful events, age, and person- and day-level covariates. For stress anticipation variables of which the scores ranged from 0 to 100, we rescaled them from 0 to 10, to enlarge coefficients without changing the statistical significance. All predictor variables were person-mean centered by subtracting each person's average across all 14 days from their scores on individual days in order to disentangle within-person effects from between-person effects.

Two variables were used to represent stress anticipation: stress anticipation that measured upon waking on a given day *i* (*morning stress anticipation*) and stress anticipation from the end-of-day assessment of the previous day (day *i-1*) (*previous night's stress anticipation*), both of which were used to predict WM performance on a given day (Figure 1). Because previous night's stress anticipation was a lagged variable, data from the first day of each person were necessarily missing in the analysis. To make the results from previous night's stress anticipation and morning stress anticipation comparable, we used subset of data (2,915 among 3,141 observations) in which both stress anticipation variables exist for all analyses.

Results

Descriptive Statistics and Model Building

Table 1 shows descriptive statistics, intraclass coefficients (ICCs), and person-level correlations among our main variables. Although the correlation between morning stress anticipation and previous night's stress anticipation was strong at the between-person level ($r = .88$, $p < .001$), the magnitude of within-person correlation was smaller ($r = .36$, $p < .001$), suggesting that the reports of morning and previous night's stress anticipation may have different predictive values related to WM. Older age was associated with higher error scores in WM ($r = .14$, $p = .03$) after partialing out education, which is a well-known covariate of cognitive performance. In contrast to previous work (e.g., Almeida & Horn, 2004), older age was related to more frequent reports of stressful events ($r = .19$, $p = .003$). This difference might be due to the current study's probability sampling, sample characteristics (e.g., 63% identified as non-Hispanic black), and design that assessed stress multiple times a day, which might have minimized age-related biases and errors in self-reports (e.g., positivity bias, forgetting events that occurred earlier in the day).

Before testing our hypotheses, preliminary models were fit to test for the presence of autocorrelation in day-level WM performance and to examine the effects of covariates.

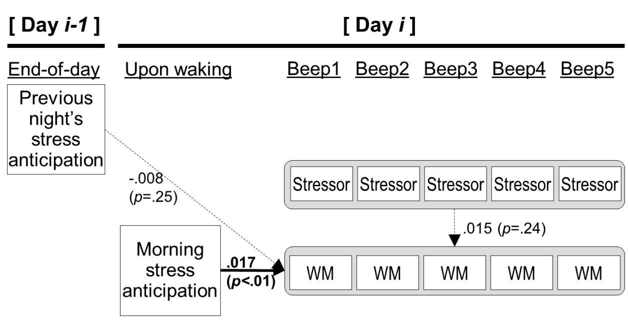

Figure 1. Study design and key variables of the current study. *Note*: Parameter estimates indicate within-person effect of each variable. WM = Working memory.

Table 1. Descriptive Statistics

Variable	*M* (*SD*)	Range	ICC	Between-person correlation			r_{age} [b]	r_{age} [c]
				1	2	3		
1. Working Memory[a]	1.82 (0.94)	0.06–4.05	0.73	–			.10	.14*
2. Morning stress anticipation	3.22 (1.92)	0–8.36	0.46	0.07	–		−.11	−.10
3. Previous night's stress anticipation	3.24 (1.99)	0–8.68	0.49	0.27	0.88**	–	−.12	−.13*
4. Stressful events	0.74 (0.73)	0–3.83	0.39	−0.05	0.36**	0.39**	.19**	.19**

Note: [a]Unit: Euclidean distance. Higher scores mean low cognitive function (higher error scores for the dot memory task).
[b]Pearson correlation coefficients with age.
[c]Pearson correlation coefficients with age after partialing out education.
ICC = Intraclass coefficients.
**p* < .05, ***p* < .01.

Fitting an empty model resulted in evidence of a small but significant lag 1 residual autocorrelation AR(1) (b = .06, p = .007), which became nonsignificant (b = .02, p = .385) after detrending the time series by including practice effects in the model (i.e., study day). Thus, subsequent models did not include the autocorrelation term, but did include study day as a day-level covariate. Results from the MLM, which examined the effects of baseline as well as day-level covariates on WM, indicated that older age was significantly associated with higher error scores in WM (b = .01, p = .008), low and middle education categories compared to high education were related to higher error scores (bs = .95 and .51, ps < .001), and being male compared to female was associated with lower error scores (b = −.34, p = .003). The linear practice effect (i.e., study day) was significant (b = −.01, p = .001), indicating that WM performance improved across 14 study days. Quadratic effect of study day was not significant. Random slope for study day was significant (p = .001). All the covariates and random effect of linear study day were significant and included in subsequent analyses.

As a result of the model building, shown below is the multilevel model for morning stress anticipation that specifies two levels of analysis.

Level 1:

$$\text{Error}_{ij} = b_{0j} + b_{1j}\left(\text{Study day}_{ij}\right) + b_{2j}\left(\text{Morning Stress Anticipation}_{ij}\right) + e_{ij}$$

The Level 1 model describes within-person variation in error score of the dot memory task for person j on day i as a function of a person-specific intercept (b_{0j}), linear practice effect (b_{1j}), the effect of morning stress anticipation (b_{2j}), and a day- and person-specific residual deviation from that intercept (e_{ij}). Our interest was to examine b_{2j} , the individual within-person effect of stress anticipation, which is then specified solely as a fixed effect (β_{20}) at level 2.

Level 2:

$$b_{0j} = \beta_{00} + \beta_{01}\left(\overline{\text{Morning Stress Anticipation}}_{.j}\right) + \beta_{02}\left(\text{Age}_{.j}\right) + \beta_{03}\left(\text{Gender}_{.j}\right) + \beta_{04}\left(\text{LowEduc}_{.j}\right) + \beta_{05}\left(\text{MiddleEduc}_{.j}\right) + u_{0j}$$

$$b_{1j} = \beta_{10} + u_{1j}$$

$$b_{2j} = \beta_{20}$$

The Level 2 model describes between-person variation in the mean error score across days. β_{00} represents the sample average error score for 45-year-old men in the highest education group who reported average morning stress anticipation. β_{10} and β_{20} indicate linear practice effect and the effect of morning stress anticipation respectively. β_{01} reflects the difference in error score with a 1 unit between-person difference in morning stress anticipation. β_{02} indicates the difference in error score with a 1 year difference in age, and β_{03} indicates gender differences in error score. β_{04} and β_{05} reflect the difference in error score between the high education group and the low and middle education group, respectively. Finally, u_{0j} and u_{1j} reflect person-specific deviations from the average level of error score and the practice effect respectively. For previous night's stress anticipation, similar models were run that include $(EOD\,Stress\,Anticipation_{i-1,j})$.

The Effects of Stress Anticipation on WM

We evaluated Hypothesis 1 that predicted reporting higher levels of morning stress anticipation is prospectively associated with lower WM performance. We first tested whether morning stress anticipation predicted worse WM performance of the same day. Then, in a separate model, we tested whether previous night's stress anticipation predicted worse WM performance today. The results described in Table 2

Table 2. Multilevel Models Predicting Cognitive Function: Coefficient (standard error)

Fixed effects	Model 1	Model 2	Model 3	Model 4
Intercept	1.478 (0.134)**	1.500 (0.132)**	1.474 (0.134)**	1.498 (0.136)**
Age	0.015 (0.005)**	0.017 (0.005)**	0.017 (0.006)**	0.018 (0.006)**
Low Education[a]	1.007 (0.192)**	1.013 (0.201)**	0.998 (0.197)**	0.987 (0.200)**
Middle Education[a]	0.521 (0.114)**	0.509 (0.115)**	0.508 (0.115)**	0.507 (0.115)**
Male[b]	−0.333 (0.115)**	−0.298 (0.117)*	−0.297 (0.116)*	−0.301 (0.116)**
Study day	−0.011 (0.003)**	−0.013 (0.004)**	−0.013 (0.004)**	−0.013 (0.004)**
Morning stress anticipation (WP)	0.012 (0.005)*		0.017 (0.006)**	0.017 (0.006)**
Morning stress anticipation (BP)	0.056 (0.028)*		0.067 (0.066)	0.068 (0.068)
Previous night's stress anticipation (WP)		−0.002 (0.007)	−0.007 (0.007)	−0.008 (0.007)
Previous night's stress anticipation (BP)		0.048 (0.027)	−0.010 (0.065)	0.004 (0.067)
Stressful events (WP)				0.015 (0.013)
Stressful events (BP)				−0.102 (0.095)
Random effects				
Var (Intercept)	0.625 (0.071)**	0.627 (0.074)**	0.621 (0.073)**	0.619 (0.073)**
Var (Study day)	0.001 (0.000)**	0.001 (0.000)**	0.001 (0.000)**	0.001 (0.000)**
Covar (Intercept, Study day)	0.002 (0.003)	0.001 (0.004)	0.001 (0.004)	0.001 (0.004)
Residual	0.308 (0.009)**	0.289 (0.009)**	0.289 (0.009)**	0.288 (0.009)**

Note: BP = Between-person effect; WP = Within-person effect.
[a]Reference group: High education.
[b]Reference group: Female.
*$p < .05$, **$p < .01$.

indicated that higher levels of morning stress anticipation were significantly associated with higher error scores in WM tasks on the same day ($b = .012$, $p = .027$ in Model 1). That is, on days individuals reported high levels of stress anticipation upon waking, compared low-anticipation days, they showed poorer performance on WM tasks throughout that day. Previous night's stress anticipation, however, was not significantly associated with today's WM performance (Model 2). When morning stress anticipation and previous night's stress anticipation were included in the same model (Model 3), only the effect of morning stress anticipation remained significant ($b = .017$, $p = .006$). In order to see if the significant effect of morning stress anticipation was driven by higher actual/experienced stress, we controlled for number of reported stressful events on that day in Model 4. Results indicated that the effect of morning stress anticipation remained significant ($b = .017$, $p = .0096$) but the effects of the previous night's stress anticipation and stressful events were not significant (ps $\geq .24$). Supplementary analyses that included stress severity on that day and end-of-day perceived stress in Model 4 did not change the results. Moreover, the effect of morning stress anticipation on WM remained significant ($b = .017$, $p = .006$) after controlling for the effect of a concurrent beep-level stressor, but the effect of a concurrent stressor was not significant.

We tested Hypothesis 2 that older compared to younger adults would show worse WM performance associated with stress anticipation by adding a two-way age × morning stress anticipation interaction term in the above model. The interaction between age and morning stress anticipation was not significant ($p = .63$), indicating that the effect of morning stress anticipation was invariant across age.

Discussion

The primary goal of the current study was to examine the relationship between stress anticipation for the upcoming day and subsequent cognitive functioning, and how this relationship differed across age. In partial support of our first hypothesis, stress anticipation reported in the morning, but not the prior evening, predicted worse WM performance throughout the day. Our second hypothesis that the effects of stress anticipation would be larger for older compared to younger adults was not supported—the effect of stress anticipation was invariant across age.

Most research on effects of everyday stress on cognitive function has focused on the effects of stressful events that happened in the past. The current study extends this research by showing that stress anticipation for the upcoming day had harmful effects on cognitive performance. Importantly, the effect of stress anticipation was over and above the effect of stressful events reported to have occurred, indicating that anticipatory processes can produce effects on functioning independent of the presence of an external stressor (Smyth, Zawadzki, & Gerin, 2013). Our findings that the stress effects derived directly from cognitive appraisals are consistent with a theoretical account from Lazarus and Folkman (1984), which proposes that stress occurs when individuals appraise environmental demands as taxing or exceeding their resources.

In line with the attention depletion hypothesis (Scott et al., 2015; Sliwinski et al., 2006), findings of the current study suggested the possibility that reports of stress anticipation prior to stressful events happen can occupy attentional resources and impair attention-demanding cognitive performance. Although we did not examine mechanisms underlying the hypothesis, there are several possible pathways through which stress anticipation could deplete attentional resources. First, stress anticipation may have predicted subsequent cognitive functioning because it also predicted the occurrence of actual stressful events (see Scott et al., 2018), which in turn impacted cognition. However, the effect of stress anticipation upon waking was significant even after controlling for the frequency of stressful events, and therefore we ruled out the possibility that the anticipatory effect was driven by its prediction of stressors. Second, it is also possible that people felt stressed even though anticipation was not linked to subsequent stressful events. Even without actual stressors, internal representation of stress might lead to stress-related ideation and draw attentional resources. Third, our results may reflect that, after anticipation, individuals engaged in proactive coping strategies (Neubauer, Smyth, & Sliwinski, 2018; Neupert & Bellingtier, 2018) that occupied attentional resources—thus compromising WM performance—but also effectively prevented the anticipated event from occurring. That is, the particular coping strategies one employs might be a more important determinant of attentional resources available to perform a cognitive task than the mere anticipation of stress. Because our study did not link anticipation with specific events and did not measure coping strategies, distinguishing between these competing explanations will await future research.

We found significant effects of stress anticipation on WM performance only for morning, not for EOD, stress anticipation. The fact that morning reports, compared to previous night's reports, are temporally more proximal to subsequent WM tasks may explain the differential effects. Alternatively, given that sleep loss and sleep impairment are linked to the effect of anticipation upon waking (Fries, Dettenborn, & Kirschbaum, 2009; Vargas & Lopez-Duran, 2014), it is possible that sleep plays a role in the association between morning stress anticipation and cognition. Moreover, recently experienced emotional and psychological states may be associated with the reports of stress anticipation, such that EOD anticipation is more influenced by how one felt earlier in that day and morning anticipation is more influenced by mood states upon waking. These differences might contribute to differential effects of morning versus previous night's stress anticipation on WM performance.

Although findings of this study are not entirely consistent with previous work of Neupert and colleagues (2016), who observed beneficial effects of anticipatory coping on cognition, several differences between two studies should be noted. First, Neupert and colleagues (2016) found that anticipatory coping, which was measured regardless of the reported likelihood of anticipatory stress, moderated the association between actual stressful events and cognitive outcomes. This study, however, did not assess coping and focused on stress anticipation itself and examined its direct association with cognition. Second, measures of cognitive outcomes differed. Neupert and colleagues (2016) used retrospective reports on subjective memory failures at the end of each day; the current study assessed cognitive performance with ambulatory WM tasks in EMA protocol. Third, although this study included a diverse adult sample aged 25–65 years, participants in Neupert and colleagues (2016) included older participants only (ages 60+), which might also contribute to the different findings. Despite these methodological differences, both studies illustrate that anticipatory stress processes are prospectively associated with aspects of cognitive function in daily life.

We did not find the age differences in the effect of morning stress anticipation on WM performance. Indeed, Sliwinski and colleagues (2006) found mixed supports on amplified effects of daily stressors on WM among older adults. It is possible that amplified effects of stress anticipation only emerge when older adults are preoccupied with stress-related idea (i.e., age × stress anticipation × stress-related preoccupation). Alternatively, older adults' prioritization of emotionally meaningful goals may encourage older adults to favor proactive coping strategies that impose lower demands on their cognitive resources. Older adults are likely to favor passive coping strategies that serve to avoid or disengage themselves from negative experiences, which may occupy few cognitive resources than problem-focused coping strategies (Charles, 2010; Neupert et al., 2016). Problem-focused coping strategies preferred by younger adults, on the other hand, may not occupy as much cognitive resources for younger adults as it would occupy for older adults. Thus, our failure to find age difference in effects of stress anticipation may reflect age difference in the differential impact of preferred coping strategies on cognitive resources.

There are some limitations to this study that should be considered for future research. First, the present study did not test the psychological mechanisms of attention depletion hypothesis regarding whether stress-related thinking and/or coping strategies follow anticipatory stress and deplete available resources for goal-directed tasks. Second, biological mechanisms through which anticipatory stress and stress-related cortisol secretion (e.g., Powell & Schlotz, 2012; Smyth et al., 1998) influence cognition were not examined in this study. Future studies could test whether the measures of cortisol as well as anticipatory stress-related preoccupation or rumination mediate the effect of anticipatory stress. Third, the present sample (age 25–65 years) is not inclusive of the entire age range of adulthood, which might have prevented from observing amplified stress effects on cognition among older adults. Although many cross-sectional studies suggest that memory starts to decline as early as in the 20s, findings from longitudinal studies suggest a relatively late onset of age-related decline. For example, significant episodic memory decline appears after age 60 and visuo-spatial reasoning skills start to decline after age 55 (Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012). To observe age effects, including wider age range of the sample may be necessary in future research.

Despite these limitations, the results highlight the importance of "anticipatory" phase in everyday stress processes. The present study also shows that there is some truth in the notion that people wake up on the wrong side of the bed. This study suggests an avenue for stress-reduction interventions; for example, targeting days with anticipated stress may help ameliorate cognitive micro-impairment on that day. This may be particularly useful among older populations and others with basally lower levels of WM to prevent cognitive lapses in everyday life.

Funding

This research was supported by National Institutes of Health (NIH) grants R01 AG039409, R01 AG042595, P01 AG03949, National Institute on Aging (NIA) grant T32 AG049676 to the Pennsylvania State University, CTSA 1UL1TR001073 from the National Center for Advancing Translational Sciences (NCATS), the Leonard and Sylvia Marx Foundation, and the Czap Foundation.

Conflict of Interest

None reported.

References

Allard, M., Husky, M., Catheline, G., Pelletier, A., Dilharreguy, B., Amieva, H.,…Swendsen, J. (2014). Mobile technologies in the early detection of cognitive decline. *PLoS ONE*, **9**, e112197. doi:10.1371/journal.pone.0112197

Almeida, D. M., & Horn, M. C. (2004). Is daily life more stressful during middle adulthood? In O. G. Brim, C. D. Ryff, & R. C. Kessler (Eds.), *How healthy are we? A national study of well-being at midlife* (pp. 425–451). Chicago, IL: The University of Chicago Press.

Cain, M. S., Dunsmoor, J. E., LaBar, K. S., & Mitroff, S. R. (2011). Anticipatory anxiety hinders detection of a second target in dual-target search. *Psychological Science*, **22**, 866–871. doi:10.1177/0956797611412393

Charles, S. T. (2010). Strength and vulnerability integration: A model of emotional well-being across adulthood. *Psychological Bulletin*, **136**, 1068–1091. doi:10.1037/a0021232

Fries, E., Dettenborn, L., & Kirschbaum, C. (2009). The cortisol awakening response (CAR): Facts and future directions. *International Journal of Psychophysiology*, **72**, 67–73. doi:10.1016/j.ijpsycho.2008.03.014

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

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In D. Gopher & A. Koriat (Eds.), *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application* (pp. 653–675). Cambridge, MA: MIT Press.

Klein, K., & Boals, A. (2001). Expressive writing can increase working memory capacity. *Journal of Experimental Psychology General*, **130**, 520–533. doi:10.1037//0096-3445.130.3.520

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal, and coping*. New York, NY: Springer.

Lupien, S. J., Gaudreau, S., Tchiteya, B. M., Maheu, F., Sharma, S., Nair, N. P.,…Meaney, M. J. (1997). Stress-induced declarative memory impairment in healthy elderly subjects: Relationship to cortisol reactivity. *The Journal of Clinical Endocrinology and Metabolism*, **82**, 2070–2075. doi:10.1210/jcem.82.7.4075

Neubauer, A. B., Smyth, J. M., & Sliwinski, M. J. (2018). Age differences in proactive coping with minor hassles in daily life. *The Journals of Gerontology: Series B*. Advance online publication.

Neupert, S. D., Almeida, D. M., Mroczek, D. K., & Spiro, A. 3rd. (2006). Daily stressors and memory failures in a naturalistic setting: Findings from the VA Normative Aging Study. *Psychology and Aging*, **21**, 424–429. doi:10.1037/0882-7974.21.2.424

Neupert, S. D., & Bellingtier, J. A. (2018). Daily stressor forecasts and anticipatory coping: Age differences in dynamic, domain-specific processes. *The Journals of Gerontology: Series B*, **74**, 17–28. doi:10.1093/geronb/gby043

Neupert, S. D., Ennis, G. E., Ramsey, J. L., & Gall, A. A. (2016). Solving tomorrow's problems today? Daily anticipatory coping and reactivity to daily stressors. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, **71**, 650–660. doi:10.1093/geronb/gbv003

Neupert, S. D., Neubauer, A. B., Scott, S. B., Hyun, J., & Sliwinski, M. J. (2018). Back to the future: Examining age differences in processes before stressor exposure. Overview article to accompany the Anticipating Stress special section. Advance online publication.

Nyberg, L., Lövdén, M., Riklund, K., Lindenberger, U., & Bäckman, L. (2012). Memory aging and brain maintenance. *Trends in Cognitive Sciences*, **16**, 292–305. doi:10.1016/j.tics.2012.04.005

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging*, **17**, 299–320. doi:10.1037//0882-7974.17.2.299

Powell, D. J., & Schlotz, W. (2012). Daily life stress and the cortisol awakening response: Testing the anticipation hypothesis. *PLoS One*, **7**, e52067. doi:10.1371/journal.pone.0052067

Preston, S. D., Buchanan, T. W., Stansfield, R. B., & Bechara, A. (2007). Effects of anticipatory stress on decision making in a gambling task. *Behavioral Neuroscience*, **121**, 257–263. doi:10.1037/0735-7044.121.2.257

Rickenbach, E. H., Almeida, D. M., Seeman, T. E., & Lachman, M. E. (2014). Daily stress magnifies the association between cognitive decline and everyday memory problems: An integration of longitudinal and diary methods. *Psychology and Aging*, **29**, 852–862. doi:10.1037/a0038072

Robinson, S. J., Sünram-Lea, S. I., Leach, J., & Owen-Lynch, P. J. (2008). The effects of exposure to an acute naturalistic stressor on working memory, state anxiety and salivary cortisol concentrations. *Stress*, **11**, 115–124. doi:10.1080/10253890701559970

Scott, S. B., Graham-Engeland, J. E., Engeland, C. G., Smyth, J. M., Almeida, D. M., Katz, M. J.,…Sliwinski, M. J. (2015). The effects of stress on cognitive aging, physiology and emotion

(ESCAPE) project. *BMC Psychiatry*, **15**, 146. doi:10.1186/s12888-015-0497-7

Scott, S. B., Kim, J., Smyth, J. M., Almeida, D. M., & Sliwinski, M. J. (2018). Additive effects of forecasted and reported stressors on negative affect. *Manuscript submitted for publication*.

Siedlecki, K. L. (2007). Investigating the structure and age invariance of episodic memory across the adult lifespan. *Psychology and Aging*, **22**, 251–268. doi:10.1037/0882-7974.22.2.251

Simonovic, B., Stupple, E. J., Gale, M., & Sheffield, D. (2017). Stress and risky decision making: Cognitive reflection, emotional learning or both. *Journal of Behavioral Decision Making*, **30**, 658–665. doi:10.1002/bdm.1980

Sliwinski, M. J., Mogle, J. A., Hyun, J., Munoz, E., Smyth, J. M., & Lipton, R. B. (2018). Reliability and validity of ambulatory cognitive assessments. *Assessment*, **25**, 14–30. doi:10.1177/1073191116643164

Sliwinski, M. J., Smyth, J. M., Hofer, S. M., & Stawski, R. S. (2006). Intraindividual coupling of daily stress and cognition. *Psychology and Aging*, **21**, 545–557. doi:10.1037/0882-7974.21.3.545

Smyth, J., Ockenfels, M. C., Porter, L., Kirschbaum, C., Hellhammer, D. H., & Stone, A. A. (1998). Stressors and mood measured on a momentary basis are associated with salivary cortisol secretion. *Psychoneuroendocrinology*, **23**, 353–370. doi:10.1016/S0306-4530(98)00008-0

Smyth, J., Zawadzki, M., & Gerin, W. (2013). Stress and disease: A structural and functional analysis. *Social and Personality Psychology Compass*, **7**, 217–227. doi:10.1111/spc3.12020

Starcke, K., Ludwig, A.-C., & Brand, M. (2012). Anticipatory stress interferes with utilitarian moral judgment. *Judgment and Decision Making*, **7**, 61–68.

Starcke, K., Wolf, O. T., Markowitsch, H. J., & Brand, M. (2008). Anticipatory stress influences decision making under explicit risk conditions. *Behavioral Neuroscience*, **122**, 1352–1360. doi:10.1037/a0013281

Timmers, C., Maeghs, A., Vestjens, M., Bonnemayer, C., Hamers, H., & Blokland, A. (2014). Ambulant cognitive assessment using a smartphone. *Applied Neuropsychology Adult*, **21**, 136–142. doi:10.1080/09084282.2013.778261

Vargas, I., & Lopez-Duran, N. (2014). Dissecting the impact of sleep and stress on the cortisol awakening response in young adults. *Psychoneuroendocrinology*, **40**, 10–16. doi:10.1016/j.psyneuen.2013.10.009

Wingfield, A., Stine, E. A., Lahar, C. J., & Aberdeen, J. S. (1988). Does the capacity of working memory change with age? *Experimental Aging Research*, **14**, 103–107. doi:10.1080/03610738808259731

Wrzus, C., Luong, G., Wagner, G. G., & Riediger, M. (2015). Can't get it out of my head: Age differences in affective responsiveness vary with preoccupation and elapsed time after daily hassles. *Emotion*, **15**, 257–269. doi:10.1037/emo0000019