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Daily Stress Magnifies the Association Between Cognitive Decline and Everyday Memory Problems: An Integration of Longitudinal and Diary Methods

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We examined whether long-term fluid cognitive decline was associated with memory problems in everyday life, and whether stress plays a moderating role. We expected that the association between cognitive decline and everyday memory problems would be magnified in the context of self-reported and physiological stress. Data are from the Boston Longitudinal Study, a subsample of the Midlife in the United States study. Participants in the current study (n = 112) completed a battery of tests measuring fluid cognitive functioning at Time 1 (T1) and 2 (T2) over 10 years. At T2, participants completed weekly diaries of self-reported daily stressors and everyday memory problems for 12 consecutive weeks. Also at T2, participants provided 4 saliva samples over the course of 1 day to assess physiological stress using diurnal cortisol profiles [cortisol awakening response (CAR) and diurnal cortisol slope (DCS)]. Self-reported daily stressors and a less healthy DCS were associated with more everyday memory problems, and participants with greater cognitive decline reported more memory problems compared to those with less or no decline. Self-reported daily stressors and CAR moderated the relationship of cognitive decline and memory problems. As expected, more cognitive decline was associated with greater increases in memory problems on weeks when individuals reported more daily stressors and for individuals with a less healthy CAR. The current findings can inform interventions aimed to identify factors, such as daily stress, that contribute to daily functioning in the context of cognitive decline.

Keywords: daily stress, cortisol, cognition, longitudinal, diary study, everyday memory

Longitudinal studies have clearly documented that declines in cognition may begin as early as age 45 (Buckner, 2004; T. A. Salthouse, 2009; Singh-Manoux et al., 2012; Welsh, Butters, Hughes, Mohs, & Heyman, 1991). In addition, everyday memory problems, such as forgetting the name of a friend or relative, are also common throughout adulthood (Lachman, 2004, 2006; Slavin et al., 2010). However, research often examines longitudinal declines and everyday memory problems separately (e.g., Buckner, 2004; Vestergren & Nilsson, 2011); thus, little is known as to whether long-term declines are tied to experiences of cognitive difficulties in everyday life or under what conditions they are related.

Research that links subjective reports of cognitive abilities with objective cognitive performance typically shows low to moderate correlations. Indeed, the results of two meta-analyses showed a small association between self-reports and objective abilities: r = 0.15 (Beaudoin & Desrichard, 2011) and r = .06 (Crumley, Stetler, & Horhota, 2014). This research examining self-reports and performance typically includes retrospective ratings of how often, in general, participants experience specific problems, which may be subject to recall bias. In addition, this research mainly consists of cross-sectional study designs and samples with only older adult participants. In the current study, we build on previous work by examining whether 10-year age-related change in objectively measured fluid cognitive decline is related to naturally occurring everyday experiences of memory problems reported in a diary study with middle-aged and older participants. We then consider whether experiences of daily stress magnify the relationship between fluid cognitive decline and everyday memory problems.

Daily stressors include the minor, frequently occurring challenges of daily life, such as household chores or a spousal disagreement (Almeida, 2005; Bolger, Delongis, Kessler, & Schil-

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ling, 1989; McIntyre, Korn, & Matsuo, 2008). Previous work has found that individuals report a greater number of memory failures on stressor days than they report on nonstressor days (Miller, Neupert, Almeida, Mroczek, & Spiro, 2006; Neupert, Mroczek, & Spiro, 2008). There is also evidence that on days in which individuals report daily stressors that they exhibit worse performance on more complex lab-based tasks of working memory, and for older adults, in particular, worse performance on tasks of serial attention as well (Sliwinski, Smyth, Hofer, & Stawski, 2006). However, research has yet to examine whether individuals with greater longitudinal declines in fluid cognition report more everyday memory problems especially during times of more daily stress. Life span developmental theory posits that longitudinal changes in objective cognition may be associated with increased vulnerability to the experience of daily stressors because of limited resources, reduced reserve capacity, and constraints in dealing with activities and hassles of daily life (Staudinger, Marsiske, & Baltes, 1993). Therefore, individuals with greater age-related declines in fluid cognition may be more likely to experience greater stressor-related increases in everyday memory problems. Stawski and colleagues (Stawski, Almeida, Lachman, Tun, & Rosnick, 2010; Stawski, Mogle, & Sliwinski, 2013) compared individuals with higher versus lower fluid cognitive ability and found that individuals with lower fluid cognitive ability experienced greater increases in daily negative affect on stressor days. However, this work did not consider long-term change in fluid cognition or whether daily stressors exacerbate other outcomes in daily life, such as everyday memory problems.

Moreover, in order to capture stress that might not be measured using self-reports of the occurrence of specific daily stressors, ideally research should also incorporate physiological markers of stress. When a person encounters a stressor, the hypothalamic-pituitary-adrenal (HPA) axis triggers the release of the hormone cortisol, which helps the individual react to a potentially dangerous event. Chronic stress exposure may result in a dysregulated HPA axis (McEwen, 1998), continually elevated cortisol, or an unhealthy diurnal cortisol profile (McEwen & Seeman, 1999). A steeper morning rise [cortisol awakening response (CAR)], and a greater decline in cortisol throughout the day [daily cortisol slope (DCS)] are considered to be healthier cortisol profiles (Friedman, Karlamangla, Almeida, & Seeman, 2012; Karlamangla, Friedman, Seeman, Stawksi, & Almeida, 2013; Saxbe, 2008; Stawski et al., 2011). A steeper rise in CAR may be indicative of healthy HPA functioning in anticipation of the day's demands (Fries, Dettenborn, & Kirschbaum, 2009), while elevated levels in the evening may be maladaptive in that they may signal an inability to "turn off" a stress response. The most common "normative" cortisol profile shows a morning rise in addition to a decline in the afternoon, whereas profiles indicative of stress exposure may show a rise in the morning without declining in the afternoon or a blunted profile with no rise in the morning (Dmitrieva, Almeida, Dmitrieva, Loken, & Pieper, 2013). Unhealthy diurnal cortisol profiles have been associated with greater stress (O'Connor et al., 2009; Wong et al., 2012) and chronic stress, in particular (Miller, Chen, & Zhou, 2007), and individuals are more likely to have unhealthy cortisol profiles on stressor days than on nonstressor days (Almeida, McGonagle, & King, 2009; Stawski, Cichy, Piazza, & Almeida, 2013). Similar to self-reported daily stressors, a relationship between cognitive decline and memory problems may also be exacerbated by the experience of stress as indicated by less healthy cortisol profiles.

Unhealthy cortisol profiles have previously been associated with retrospective self-reports of greater long-term declines in general memory (Fiocco, Wan, Weekes, Pim, & Lupien, 2006; Wolf et al., 2005). The experience of stress may exacerbate memory problems via negative effects of stress on the hippocampus region of the brain responsible for memory functioning (McEwen & Seeman, 1999). Among women, elevated basal cortisol was associated with worse memory performance and greater memory decline over 2.5 years (Seeman, McEwen, Singer, Albert, & Rowe, 1997). However, work has yet to examine whether physiological markers of stress are related to naturally occurring reports of everyday memory problems, and whether physiological stress may exacerbate memory problems for individuals with fluid cognitive decline. Evidence from Souza-Talarico and colleagues found that individuals with mild cognitive impairment who had higher morning cortisol levels were more likely to have worse memory performance when compared to individuals with mild cognitive impairment who had lower morning cortisol levels (Souza-Talarico, Chaves, Lupien, Nitrini, & Caramelli, 2010). However, this work examined cortisol once in the morning rather than diurnal profiles over the course of a day, they examined cognitive functioning cross-sectionally rather than longitudinally, and they examined memory performance in the lab rather than naturally occurring performance in everyday life.

Current Study

Fluid cognition includes the ability to gather and synthesize information, reason, and respond to complex and novel situations, and these abilities have been shown to decline significantly with age (Horn, 1982; Horn & Cattell, 1967; Singh-Manoux et al., 2012; Stawski et al., 2010). In the current study, our first research question was to examine the relationship between 10-year changes in fluid cognition and memory problems reported in everyday life. Following life span developmental theory (Baltes, 1987), we were particularly interested in the extent of change (i.e., losses) in cognitive functioning over time rather than cross-sectional levels of cognitive functioning. While both level and change in cognition are important as they relate to functioning and reported problems experienced in daily life, the experience of declines in cognition is potentially more stressful than stable low levels for which individuals are likely to have become accustomed. We hypothesized that individuals with greater declines in fluid cognition would report more memory problems in daily life. Our second research question examined the role of daily stress as a moderator using both self-reported daily stressors and diurnal salivary cortisol profiles. Based on previous work and theory, we hypothesized that a relationship between greater cognitive decline and a greater number of memory problems would be magnified by daily stress. In other words, we hypothesized that, given their reduced cognitive resources, individuals with greater declines in cognition would experience greater memory problems under circumstances of a greater number of reported daily stressors. Similarly, we also hypothesized that individuals with greater cognitive declines would experience a greater number of memory problems if they experienced greater stress as indicated by less healthy cortisol profiles.

Method

Sample

Data are from a subsample of participants from the Midlife in the United States (MIDUS; Radler & Ryff, 2010) study who also participated in a satellite study from the Greater Boston area, the Boston Longitudinal study (BOLOS). MIDUS and BOLOS examine a range of factors influencing physical and mental health in midlife and late life, including behavioral, psychological, social, biological, cognitive, and neurological variables. Those in the current study participated in MIDUS at two time points [Time 1 (T1) 1995–6 and Time 2 (T2) 2004–6]. The mortality-adjusted retention rate for MIDUS from T1 to T2 was 75%. Of the 30% who did not participate in MIDUS at T2, 12% refused, 10% could not be contacted and 8% were either ill or deceased. As is the case in many longitudinal studies, MIDUS participants who were retained from T1 to T2 were more likely to be White, female, married, more highly educated, and have better health on a number of health indices (Radler & Ryff, 2010).

BOLOS assessments occurred 1 to 2 years after the MIDUS interviews on both occasions. At both T1 and T2, BOLOS participants completed cognitive assessments (Agrigoroaei & Lachman, 2011). In addition, BOLOS participants completed 12 consecutive weeks of at-home weekly diaries about daily stressors and memory problems following their T2 BOLOS assessment. At BOLOS T2 ($n = 151$), participants were on average, 59.65 years old ($SD = 12.64$), 44% were female, and approximately half of the sample (55%) completed a bachelor's degree or further advanced graduate education (see Table 1). At T1, the BOLOS sample ($n = 302$) was on average 48 years ($SD = 13.74$, range: 24–74), 44% of the participants were female and 47% of the participants completed a bachelor's degree or graduate degree. Independent samples t test and chi-square analyses examining the characteristics of BOLOS participants who dropped out after T1 ($n = 151$) compared to the longitudinal participants ($n = 151$) revealed that the longitudinal participants were more highly educated [$M = 15.13$ years of education versus $M = 14.24$ years of education, $t(300) = 2.77$, $p = .006$]. There were no differences in terms of age, gender or cognition ($ps > .05$). The BOLOS sample has been described in greater detail elsewhere (Agrigoroaei & Lachman, 2011). Participants included in the current study ($n = 112$) were those who completed at least 2 weeks of diaries and had complete data for covariates and longitudinal data for cognitive change. Participants completed an average of 10.6 out of 12 diaries.

Table 1
Descriptive Characteristics for Study Variables

Variable	Time 1 *M* (*SD*) or %	Time 2 *M* (*SD*) or %
Baseline measures		
Age (range 34–83)		59.65 (12.64)
Gender (% women)		44
Education (% Bachelors)		55
BOLOS life stress		1.38 (2.04)
Depressed affect		0.54 (1.56)
Functional health		3.20 (0.87)
Cognitive tasks included in cognitive decline measure		
Forward digit span	7.01 (1.25)	6.80 (1.36)
Backward digit span	5.03 (1.55)	4.81 (1.57)
Serial sevens	13.73 (8.69)	12.83 (8.69)
Letter series	17.25 (6.44)	16.03 (6.75)
Raven's matrices	7.33 (3.43)	6.57 (3.59)
Digit symbol substitution	56.97 (11.22)	53.54 (13.72)
Letter comparison	18.83 (4.76)	18.09 (5.56)
Cognitive composite	0.00 (1.00)	−0.26 (1.10)
Cognitive decline		−0.25 (0.55)
Weekly diary measures[a]		
Total daily stressors		5.71 (4.69)
Interpersonal stressors		2.18 (2.16)
Work stressors		0.94 (0.95)
Home stressors		1.07 (1.31)
Network stressors		0.70 (0.94)
Health stressors		0.91 (1.06)

Note. M = mean, SD = standard deviation.
[a] The person-mean, or individual participant average, was calculated for the weekly diary measures for descriptive purposes and to estimate intercorrelations between Level 1 and Level 2 study variables.

Measures and Procedures

Cognitive decline. Cognitive decline was based on assessments of fluid cognitive performance at BOLOS T1 and T2 with a composite measure of seven cognitive tests (Miller & Lachman, 2000). Three tasks measured working memory [forward and backward digit span and serial sevens (Wechsler, 1955)], two measured reasoning [Schaie-Thurstone letter series (Schaie, 1985) and Raven's Advanced Progressive Matrices (Raven, Raven, & Court, 1991)], and two tasks measured speed of processing [digit symbol substitution task (Wechsler, 1997) and a letter comparison task (Salthouse & Babcock, 1991)]. Reliability (Cronbach's alpha) for the composite of standardized scores for the seven tasks was acceptable (T1: $\alpha = .80$, T2: $\alpha = .85$). The test–retest correlation for T1 and T2 cognition was also high, $r = 0.85$, $p < .001$. To compute cognitive decline, scores for the seven individual tests were standardized using z-scores to convert all to the same metric ($M = 0.00$, $SD = 1.00$). The same seven tests measured at T2 were standardized using T1 means and standard deviations (SD) to preserve change information consistent with previous work (Ball et al., 2002). T1 and T2 scores were averaged and the composites were restandardized (T2 scores were restandardized using the Time 1 composite mean and standard deviation). Difference scores were calculated by subtracting the standardized T1 scores from the standardized T2 scores to determine change over the course of 10 years, resulting in a continuous measure of change with higher, positive scores indicating less decline and lower, negative scores indicating greater decline. Because participants declined, on average, in their raw scores for all seven tests from T1 to T2 (see Table 1), we refer to this measure as greater versus less decline. However, a relatively small proportion of individuals remained stable or improved in their raw scores over time.

Diary measures. The BOLOS weekly diary assessed everyday memory problems and daily stressors and was completed at home by the participant for 12 consecutive weeks following the BOLOS T2 cognitive assessment. At the end of each week, participants completed and mailed the survey back to research personnel.

Everyday memory problems. Everyday memory problems were measured using 11 items, 10 of which are from a previous

diary study (Whitbourne, Neupert, & Lachman, 2008). These items came from a 35-item measure of everyday memory failures (Sunderland, Harris, & Baddeley, 1983) which was adapted for a weekly diary format. One item was added ("On how many days did you have difficulty dividing your attention between two activities, or doing two things at once?). Each week, participants reported how many days (0–7) they experienced any of 11 memory problems. A weekly score was computed by totaling the 11 items to create a composite measure of the "total number of everyday memory problems per week" (range: 0–77; Cronbach's alpha = .85).

Self-reports of daily stressors. Self-reported daily stressors were measured using the Daily Inventory of Stressful Events (DISE; Almeida, Wethington, & Kessler, 2002). Each week, participants reported in a weekly diary how many days (0–7) they experienced any of six types of stressors (interpersonal, home, work, health, network, and any other events that may have been stressful). Network stressors are events that do not directly involve the individual, but that still turn out to be stressful for the respondent (e.g., a friend's illness). "Other" stressors were excluded because of low frequency. A composite of daily stressors was first examined by computing a sum score of interpersonal, work, network, home, and health stressors to determine whether there were differences in exposure or reactivity regardless of the type of stressor, following previous work (Stawski et al., 2010). Reliability of the composite of daily stressors was moderate (α = .65) suggesting people who experience a home-related stressor, for example, are somewhat more likely to experience a work-related stressor. Additional analyses were conducted separately by stressor type.

Diurnal cortisol profiles. A physiological marker of stress, salivary cortisol, was measured at four time points over the course of 1 day on the day before the BOLOS T2 cognitive assessment (immediately upon waking, 30 minutes after waking or peak, before lunch, at bedtime). Participants were sent kits to complete at home and were instructed to complete cortisol measurements via Salivettes with a cotton-like swab before eating, drinking, or brushing their teeth. They were asked not to consume any caffeinated products before collecting the sample. Participants recorded the time of measurement, placed the cotton swab in their mouth, chewed it until saturation, and then returned the swab to the Salivette® container. The samples were stored at −20°Celsius in an airtight freezer container and shipped on dry ice, in order to ensure the integrity of the frozen samples, for assay analysis to Professor Clemens Kirschbaum's lab at the University of Dresden in Dresden, Germany.

Two diurnal cortisol measures were calculated (CAR, DCS; Saxbe, 2008). Prior to calculations, nmol/L cortisol levels were log-transformed (see Adam & Kumari, 2009; Costanzo, Stawski, Ryff, Coe, & Almeida, 2012; Seltzer et al., 2010) because cortisol data is often positively skewed. CAR was calculated by subtracting the waking level of cortisol from the peak level. DCS (decline from waking to bedtime) was calculated by subtracting the bedtime cortisol level from the waking level. Lower values of CAR (i.e., less steep morning rise) and higher values of DCS (i.e., less steep decline) were considered to be less healthy. Analyses were also conducted with each level of cortisol at the four times of measurement to assess whether any effects of cortisol were due to a single time of measurement rather than cortisol profiles. Higher morning levels and lower afternoon and evening levels were considered healthier as specified in past work (Saxbe, 2008).

Potential measurement problems (flags) and outliers were excluded from analyses where relevant, consistent with previous work (Stawski et al., 2011). Flags included being awake less than 12 or more than 20 hours, waking up after noon, having a greater than 10 nmol/L increase in cortisol between the second and third samples, and recording less than 15 or more than 60 minutes between the first and second samples. Outliers (levels greater than 60 nmol/L) and samples with missing time stamps were excluded. Cortisol analysis included the subset of participants with complete and reliable data (DCS: n = 78; CAR: n = 73); participants excluded from cortisol analyses due to missing or unreliable data did not differ significantly on any study variables from the remaining sample ($ps > .05$).

Covariates. We included age, gender, education (0 = *less than bachelor's degree* vs. 1 = *bachelor's degree*), T1 cognition, life stress, functional health, and depressed affect as covariates, because of their relationships in the literature with cognition, memory problems, daily stress, and cortisol. Life stress was measured at BOLOS T2 and the remaining covariates were measured at MIDUS T2. To measure life stress, participants self-reported (yes/no) whether they experienced any of 10 events (e.g., chronic disease or disability) since T1 (i.e., in the previous 10 years; Prenda & Lachman, 2001). A count of the number of "yes" answers was computed with higher scores indicating greater life stress (range: 0–10; Cronbach's alpha = .61). Self-reported functional health was measured using the Physical Function subscale of the SF-36 Health Survey (Ware & Sherbourne, 1992), which measures the extent to which health interferes with 10 daily activities (e.g., lifting or carrying groceries) on a scale from (1) *a lot*, to (4) *not at all*. Scores for the 10 items were averaged with higher scores indicating better functional health (Cronbach's alpha = .95). For depressed affect, participants reported whether they experienced a period of 2 weeks in the past year when they felt sad, blue or depressed, and during that time they experienced any of seven symptoms (e.g., losing interest in most things; Wang, Berglund, & Kessler, 2000). The number of symptoms was summed, with higher scores indicating more symptoms (range: 0–7).

Statistical Approach

Descriptive analyses were conducted for all variables and we checked for multicollinearity. For research aim 1 and 2, a multilevel model (MLM) was run using Proc Mixed (SAS Version 9.2) to estimate whether cognitive decline was a predictor of everyday memory problems and whether self-reported daily stressors were a moderator of this relationship (Equation 1). MLM with repeated measurement estimates both within-person (WP) effects (i.e., how people compare to themselves from one moment to the next) as well as between-person (BP) effects (i.e., how people compare to other people). In Equation 1, the γ_{00}, is the grand-mean, or the average number of memory problems across observations and participants. γ_{01} represents the estimate for the effect of a given covariate (e.g., age) on the average number of memory problems. The estimates for the covariates are included as one term for simplicity. γ_{02} is the number of memory problems as a function of cognitive decline, and γ_{03} is the number of memory problems as a

function of the person-mean (PM) for daily stressors. This estimate provides the between-person association of cognitive decline and memory failures. γ_{04} is the change in the number of memory problems as a function of daily stressors that week (WP daily stressors). This estimate provides the within-person assessment of daily stressors and memory problems. We expect that on occasions when individuals experience more stressors than they typically experience, they will report more memory problems. The remaining coefficients represent the interactions of daily stressors with cognitive decline and with covariates.

$$\begin{aligned}\text{MEMORY PROBLEMS}_{ij} = {} & \gamma_{00} + \gamma_{01}(\text{COVARIATES}_j) \\ & + \gamma_{02}(\text{COGNITIVE DECLINE}_j) \\ & + \gamma_{03}(\text{PM DAILY STRESSORS}_j) \\ & + \gamma_{04}(\text{WP DAILY STRESSORS}_{ij}) \\ & + \gamma_{05}(\text{COVARIATES}_j * \text{WP DAILY STRESSORS}_{ij}) \\ & + \gamma_{06}(\text{COGNITIVE DECLINE}_j * \text{WP DAILY STRESSORS}_{ij}) \\ & + u_{0j} + u_{1j} + r_{ij} \quad (1)\end{aligned}$$

Self-reported daily stressors were defined as the number of stressors reported for each weekly diary and were person-mean centered in order to estimate the moderating effect of self-reported daily stressors compared to a person's average number of daily stressors. Covariates were included as predictors of both the intercepts and the slopes. To account for a person's average level of stressors and to better disaggregate the WP and BP effects, we included the person-mean of self-reported daily stressors (see Hoffman & Stawski, 2009). Additional analyses were run for each of the five stressor types.

We then examined in two separate MLM models whether stress as measured by diurnal salivary cortisol was a moderator of the relationship between cognitive decline and everyday memory problems (Equation 2). The first model included CAR as a cortisol profile measure, and the second model included DCS. Time of waking was controlled for in CAR analyses.

$$\begin{aligned}\text{MEMORY PROBLEMS}_{ij} = {} & \gamma_{00} + \gamma_{01}(\text{COVARIATES}_j) \\ & + \gamma_{02}(\text{COGNITIVE DECLINE}_j) + \gamma_{03}(\text{CORTISOL}_j) \\ & + \gamma_{04}(\text{CORTISOL}_j * \text{T1 COGNITION}_j) \\ & + (\text{CORTISOL}_j * \text{COGNITIVE DECLINE}_j) + u_{0j} + r_{ij} \quad (2)\end{aligned}$$

Because there was a significant drop-off in self-reports of memory problems and daily stressors across the 12 weeks of diary data collection, all MLM analyses controlled for the effects of time as a predictor in the Level 1 equation (week 1, week 2, etc.). An unconditional model estimated the intraclass correlation coefficient (ICC), which is the proportion of WP and BP variance in the outcome variables. The unconditional models for each of the outcome variables determined that there was significant variation both within- and between-persons. The WP and BP variance from the unconditional model was then compared to random effects in the MLM analyses to determine the percent of WP and BP variance explained by each model. The ICC was 0.77, indicating that 77% of the variance in memory problems over the 12 weeks of diary reports was between-persons and 23% of the variance was within-persons.

Results

Sample characteristics and intercorrelations are displayed in Tables 1 and 2. Greater cognitive decline was associated with being older ($p < .05$). Reporting a greater number of everyday memory problems was associated with higher age, lower functional health, more total daily stressors, and specifically, more interpersonal, network, home, and health stressors ($ps < .05$). Individuals who reported more daily stressors were more likely to be younger, have better T1 cognition, have lower waking and peak cortisol levels, and have a less steep decline in DCS ($ps < .05$).

Table 2
Intercorrelations for All Study Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Age																
2. Gender	−.17															
3. Education	.05	−.15														
4. Depressed affect	−.09	.17	−.09													
5. Functional health	**−.37**	−.14	**.21**	−.17												
6. Life stress	.14	.12	−.10	−.12	**−.28**											
7. T1 cognition	**−.39**	−.01	**.33**	−.14	**.42**	−.00										
8. Cognitive decline	**−.34**	.17	.13	.06	.03	−.05	−.09									
9. Memory problems[a]	**.31**	−.09	.16	.16	**−.20**	.17	−.01	−.16								
10. Daily stressors[a]	**−.26**	−.05	.05	−.06	−.01	.16	**.22**	.16	**.37**							
Cortisol measurements																
11. Waking	.11	.05	**.21**	−.20	−.04	.19	−.03	−.01	−.15	**−.31**						
12. Peak	.12	.16	.19	**−.22**	.01	.14	−.10	.14	**−.23**	**−.33**	**.63**					
13. Before lunch	**.24**	−.12	.18	.04	−.14	.14	.10	−.04	.08	.01	.13	.13				
14. Bedtime	.08	.04	.06	**.21**	−.17	**.20**	−.08	−.10	.16	.08	.11	.14	**.58**			
15. CAR	−.02	.20	.02	−.11	.07	.10	−.01	.17	−.10	−.01	**−.35**	**.39**	.10	.15		
16. DCS	.06	.02	−.07	**.25**	−.19	.12	−.14	−.06	**.23**	**.22**	**−.55**	−.20	**.32**	**.68**	**.50**	

Note. Bold indicates that correlation is significant at the $p < .05$ level. CAR = cortisol awakening response; DCS = diurnal cortisol slope; T1 = Time 1.
[a] The person-mean, or individual participant average, was calculated for the weekly diary variables.

Effects of Cognitive Decline on Everyday Memory

We first examined whether cognitive decline was associated with a greater number of everyday memory problems. In support of our hypothesis, Table 3 shows that individuals with greater declines in cognition reported a greater number of everyday memory problems. In addition, older age, higher depressed affect, higher education, and a greater person-mean of daily stressors were associated with a greater number of everyday memory problems. There was a main effect of WP daily stressors, indicating that regardless of the level of cognitive decline, participants reported more memory problems on weeks when they reported more daily stressors compared to weeks when they reported fewer stressors.

Moderating Effects of Daily Stress

Self-reported daily stressors. Our second research question examined whether daily stressors were a moderator of the relationship between cognitive decline and everyday memory problems. In support of our hypothesis, the significant interaction effect (WP Stress × Cognitive decline) in Table 3 shows that daily stressors were a significant moderator of the relationship between cognitive decline and everyday memory problems. To better understand the interaction effect, we conducted a simple slopes analysis using the Johnson-Neyman technique (Johnson & Neyman, 1936), as outlined by Bauer and Curran (2005) for multilevel analyses, for participants with greater decline (mean minus 1 *SD*) and less decline (mean plus 1 *SD*). Results of this analysis identified that participants with greater cognitive decline experienced a significant increase in memory problems from a low to a high stressor week (Est. = 0.59, *SE* = 0.07, $p = .000$) and individuals with less cognitive decline were stable from a low to high stressor week (Est. = 0.00, *SE* = 0.07), $p = .924$). In Figure 1, we plotted cognitive decline and daily stressors using 1 *SD* above and below the mean for the purposes of illustrating the interaction effects. Figure 1 illustrates this interaction effect and shows that daily stressors exacerbated the relationship between greater cognitive decline and a greater number of everyday memory problems. Specifically, individuals with less cognitive decline increased from 8.31 to 8.39 memory problems from a low stressor week to a high stressor week. However, individuals with greater cognitive decline increased from 9.33 to 13.14 memory problems from a low stressor week to a high stressor week. The model explained 37% of the WP variance and 39% of the BP variance.

Table 3
Fixed Effect and Random Effect Estimates of the Moderating Effect of Daily Stress in the Relationship Between Cognitive Decline and Everyday Memory Problems

Parameter	Est.	*SE*	*p*
Fixed effects			
Intercept	**11.38**	**1.01**	**<.001**
Time[a]	−0.11	0.06	.081
Covariates			
Depressed affect	**1.62**	**0.41**	**.000**
Age	**0.23**	**0.07**	**.001**
Gender	0.57	1.32	.669
Education	**3.95**	**1.45**	**.007**
Functional health	0.03	0.87	.968
Life stress	0.43	0.33	.190
Cognition			
T1 cognition	−0.69	0.82	.406
Cognitive decline	**−2.62**	**1.27**	**.042**
Daily stressors			
Daily stressors (PM)	**0.85**	**0.14**	**<.001**
WP Stress	**0.29**	**0.06**	**<.001**
Daily stress moderators			
WP Stress × Depressed affect	0.05	0.03	.168
WP Stress × Age	0.00	0.00	.843
WP Stress × Gender	**0.37**	**0.09**	**<.001**
WP Stress × Education	**0.30**	**0.10**	**.004**
WP Stress × Functional health	0.05	0.06	.382
WP Stress × Life stress	0.04	0.02	.054
WP Stress × T1 cognition	0.02	0.06	.752
WP Stress × Cognitive decline	**−0.54**	**0.09**	**<.001**
Random effects			
Memory problems intercept variance	**41.39**	**6.76**	**<.001**
WP stress variance	**0.30**	**0.06**	**<.001**
Intercept-slope covariance	−1.02	0.55	.064
Within-person variance	**12.54**	**0.6**	**<.001**

Note. *SE* = standard error; PM = person-mean; T1 = Time 1; WP = within-person.
[a] Time is the number of the weekly diary (Week 1, Week 2, Week 3, etc.).

Additional analyses were run to estimate the moderating effects of each stressor type and the findings were similar to the results of analyses with the composite of self-reported daily stressors. Results showed that greater cognitive decline was associated with more memory problems especially on weeks with more interpersonal stressors (Est. = −0.64, *SE* = 0.20, $p = .001$), more work-related stressors (Est. = −0.87, *SE* = 0.26, $p < .001$), and more health-related stressors (Est. = −0.67, *SE* = 0.22, $p = 0.002$). However, there was no moderating effect of network-related stressors (Est = −0.57, *SE* = 0.31, $p = .068$) or home stressors (Est = −0.47, *SE* = 0.25, $p = .058$) in the relationship between cognitive decline and everyday memory problems.[1]

Diurnal cortisol profiles. Next, we examined whether diurnal cortisol profiles were a moderator in the relationship between cognitive decline and everyday memory problems. Table 4 displays the results of two MLM models examining the moderating role of DCS and CAR in the cognitive-decline–memory-problems relationship. DCS was a significant predictor of memory problems

[1] We also conducted sensitivity analyses to examine whether our findings for cognitive change (T2−T1, controlling for T1) would be similar to those examining level of cognitive performance at T2 or change controlling for T2. We compared the results with models using a) T2 cognition rather than cognitive decline and b) cognitive change with T2 scores as a covariate rather than with T1 scores as a covariate. For the first alternate model, there was no main effect of Time 2 cognition as a predictor of memory problems. There was a significant interaction effect with T2 cognition × daily stress predicting memory problems. This interaction effect showed that individuals with low T2 cognition increase from 9.08 to 11.94 memory problems from a low to high stress week while those with high T2 cognition are stable (7.90 to 8.67 memory problems), suggesting that this interaction effect is similar to but less robust than our main study findings. In a second alternate model, we examined whether cognitive decline predicts memory problems and whether daily stress moderates this relationship with T2 cognition as a covariate instead of T1 cognition as a covariate. In these analyses the moderating effect of cognitive decline × daily stress predicting memory problems remained the same as our main findings. We also found that when we control for T2 cognition, neither the main effect of cognitive decline or the main effect of T2 cognition were significant predictors of memory problems.

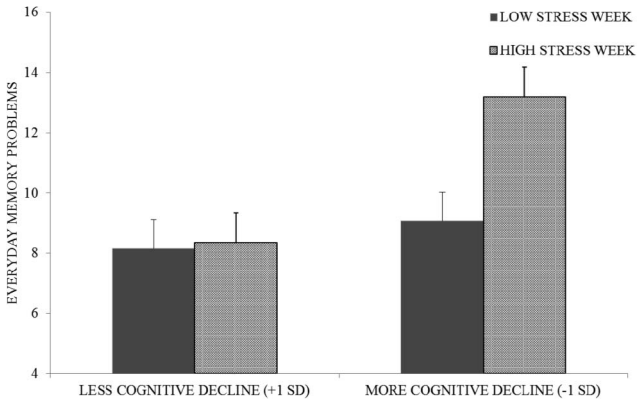

Figure 1. The moderating effect of daily stressors in the relationship between cognitive decline and everyday memory problems *Note*. *SD* = standard deviation. For the purposes of illustrating interaction effects, 1 *SD* above and below the mean for cognitive decline and daily stressors was computed. In the model, cognitive decline was a continuous difference score ($M = -0.25$, $SD = .55$), with higher scores indicating less decline and lower scores indicating greater decline. Analyses adjusted for age, gender, education, functional health, life stress, depressed affect, and Time 1 cognition. Error bars represent 1 standard error.

as a main effect suggesting that, regardless of the amount of cognitive decline, individuals with a less healthy DCS (less steep decline) reported a greater number of memory problems than did individuals with healthier DCS slopes. CAR was not a significant predictor of memory problems as a main effect. As shown in Table 4, CAR was a moderator of the relationship between cognitive decline and memory problems. We conducted a simple slopes analysis (Bauer & Curran, 2005; Johnson & Neyman, 1936) for individuals with greater decline (mean minus 1 *SD*) and less decline (mean plus 1 *SD*). Results of this analysis identified a marginally significant slope (Est. = −7.94, $SE = 4.31$, $p = .065$) suggesting that individuals with greater declines had fewer memory problems if they had a healthier CAR (steeper rise) compared to those with a less healthy CAR (less steep rise). In contrast, for individuals with less decline the relationship was inverted such that a less healthy CAR (less steep rise) was associated with significantly fewer memory problems (Est. = 11.26, $SE = 5.90$, $p = .044$). Figure 2 illustrates this relationship and shows the estimated number of memory problems for individuals with greater and less decline (mean plus and minus 1 *SD*) as a function of CAR (mean plus and minus 1 *SD*). The model including CAR explains 45% of the WP variance persons and 23% of the BP variance, and the model including DCS explains 41% of the WP variance and 25% of the BP variance.

Additional MLM analyses examined whether cortisol was a moderator of the relationship between cognitive decline and memory problems using the four measurements of cortisol to determine whether any moderating effects were due to a specific measurement. As expected, a healthier, higher waking cortisol level was associated with fewer memory problems as a main effect (Est. = −9.38, $SE = 3.47$, $p = .008$); however, the relationship between cognitive decline and everyday memory problems did not vary as a function of waking cortisol level (Est. = −10.74, $SE = 5.85$, $p = .070$). Adjusted MLM analyses revealed no significant effects for cortisol levels at peak, before lunchtime, or at bedtime (*p*s > .05).

Table 4
Fixed Effect and Random Effect Estimates of the Moderating Effect of Cortisol Profiles in the Relationship Between Cognitive Decline and Everyday Memory Problems

Parameter	CAR[a]			DCS		
	Est.	*SE*	*p*	Est.	*SE*	*p*
Fixed Effects						
Intercept	**13.54**	**1.42**	**<.001**	**13.46**	**1.40**	**<.001**
Time[b]	**−0.24**	**0.07**	**.002**	**−0.22**	**0.07**	**.003**
Covariates						
Depressed affect	**1.21**	**0.53**	**.025**	1.01	0.55	.070
Age	0.03	0.08	.745	0.03	0.08	.740
Gender	−1.77	1.79	.326	−1.00	1.67	.548
Education	**4.06**	**1.96**	**.041**	**4.42**	**1.88**	**.002**
Functional health	−1.49	1.07	.170	−0.41	1.05	.698
Cognition						
T1 cognition	−0.11	1.12	.920	−0.46	1.09	.676
Cognitive decline	−2.56	1.97	.197	−3.30	1.87	.081
Cortisol and cortisol moderator						
Cortisol	1.65	3.33	.620	**4.82**	**1.92**	**.014**
Cortisol × T1 Cognition	6.29	3.76	.098	**4.84**	**2.28**	**.037**
Cortisol × Cognitive decline	**17.46**	**6.77**	**.012**	6.88	3.62	.061
Random effects						
Memory problems intercept variance	**53.61**	**10.00**	**<.001**	**50.29**	**9.44**	**<.001**
Intercept-slope covariance	−1.28	0.78	.101	**-1.48**	**0.70**	**.034**
Slope variance	**0.29**	**0.07**	**<.001**	**0.28**	**0.07**	**<.001**
Within-person variance	**12.95**	**0.70**	**<.001**	**11.79**	**0.64**	**<.001**

Note. CAR = cortisol awakening response; DCS = diurnal cortisol slope; *SE* = standard error; T1 = Time 1.
[a] Controlling for time of waking. [b] Time is a level one variable for the number of the weekly diary (Week 1, Week 2, Week 3, etc.).

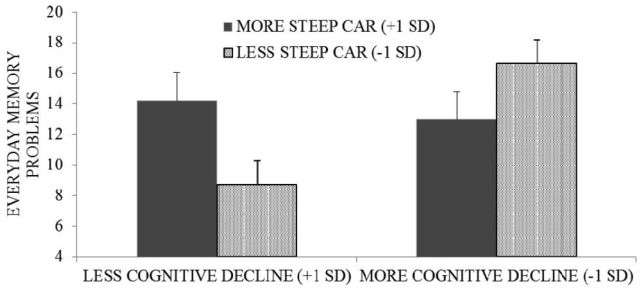

Figure 2. Moderating effect of the cortisol awakening response (CAR) in the relationship between cognitive decline and everyday memory problems. *Note*. CAR = cortisol awakening response, *SD* = standard deviation. For the purposes of illustrating interaction effects, 1 *SD* above and below the mean for cognitive decline and cortisol awakening response was computed. In the model, cognitive decline was a continuous difference score ($M = -0.25$, $SD = .55$), with higher scores indicating less decline and lower scores indicating greater decline. For CAR, lower scores indicated less healthy cortisol profile (less steep rise) and higher scores indicate healthier cortisol profiles (more steep rise). Analyses were adjusted for age, time of waking, gender, education, functional health, life stress, depressed affect, and Time 1 cognition. Error bars represent 1 standard error.

Discussion

The current study had several novel findings that advance our understanding of how cognitive aging is related to the experience of stress in daily life with a specific focus on everyday memory problems. First, individuals with greater cognitive decline reported a greater number of everyday memory problems than did individuals with less cognitive decline. We are not aware of other studies examining reports of everyday memory problems in the context of long-term cognitive decline. Moreover, there are mixed findings on the relationship between objective performance and subjective reports of cognition even when measured concurrently (e.g., Jungwirth et al., 2004; Van Bergen, Jelicic, & Merckelbach, 2009). The current study makes a contribution by showing that longitudinal cognitive declines were tied to self-reported naturally occurring everyday memory problems measured approximately 10 years after the initial cognitive assessment. Second, individuals with greater cognitive decline reported greater increases in memory problems during times of more stress measured by both self-report of daily stressors and there were marginally significant findings with a physiological measure (i.e., CAR). Collectively, these findings show that participants with the most memory problems are those with greater cognitive declines who have greater stress as measured by self-reports and cortisol profiles. These findings complement previous work showing greater increases in negative affect in response to daily stressors among individuals with lower fluid cognition (Stawski et al., 2010).

In support of our hypotheses, derived from life span developmental theory (Staudinger et al., 1993), individuals with greater declines in cognition reported more memory problems than did individuals with less cognitive decline and especially during times of greater stress. These results suggest that the fluid cognitive decline identified in the current study across many years may result in reduced abilities or cognitive resources to function well in daily life activities, and this is magnified under stressful conditions. Previous research has indicated that individuals with high levels of neuroticism (Neupert et al., 2008) and those older in age (Miller et al., 2006) report a greater number of memory problems during times of greater daily stress, and the present study extends this to those experiencing long-term cognitive decline.

We further examined whether physiological measures of stress, cortisol profiles, moderated a cognitive-decline–memory-problems relationship. Given the detrimental effects of stress, the expected finding of healthier cortisol profiles associated with fewer everyday memory problems was supported. The cognitive-decline–memory-problems relationship was further qualified by the extent of stress as measured by cortisol and the specific diurnal cortisol profile. This is consistent with and extends previous cross-sectional work examining whether memory performance among individuals with normal versus pathological cognitive functioning varies as a function of cortisol levels (Souza-Talarico et al., 2010). In the current study, the finding that CAR moderates a relationship between cognitive decline and memory problems supports our hypothesis that individuals with greater cognitive declines may have reduced reserve capacity and are therefore more vulnerable to the effects of stress. Moreover, the finding that a steeper DCS was related to fewer everyday memory problems for all participants underscores the relevance of cortisol profiles over the course of the entire day for individuals across the adult life span regardless of the extent of cognitive decline. Additional analyses that were conducted with the individual assessments of cortisol at four time points throughout the day suggest that a relationship between cortisol and memory problems, regardless of the extent of cognitive decline, may be driven by healthier, higher levels of cortisol at waking such that a higher morning level of cortisol is protective in relation to fewer everyday memory problems.

The finding that, among individuals with less cognitive decline, a healthier CAR (steeper morning rise) was related to a greater number of memory problems was unexpected. This could indicate that individuals who are gearing up for a busy day (i.e., steeper CAR) are likely to experience more activities that day, and as a result they may be more vulnerable to the experience of memory problems. This would follow from previous work which has found that on days when older adults (age 60 years and older) are busier, they are more likely to report forgetfulness, such as forgetting a medication (Neupert, Patterson, Davis, & Allaire, 2011). Future work is needed to explore this and other possible interpretations. As Souza-Talarico and colleagues (2010) noted, the moderating effects of cortisol on memory may be further complicated by changes in neuropathology and glucocorticoid receptors in the brain associated with cognitive decline. Future research could incorporate neuroimaging information and longitudinal data regarding cortisol profiles to examine the nature of the relationship between cognitive decline, memory problems, and cortisol profiles.

The finding that participants with higher education reported a greater number of memory problems seems counterintuitive. However, a population-based national study found that individuals of higher socioeconomic status (SES) are more likely to report poorer cognition than lower SES groups, despite better objective cognition (Caracciolo, Gatz, Xu, Pedersen, & Fratiglioni, 2012). These authors suggested that higher SES individuals, who likely have a higher brain reserve, may therefore compensate for changes resulting in no overt differences in objective performance despite a

self-report of change, and they may also be more self-aware of health, in general, and specifically, declines in cognition.

Limitations and Future Directions

Some limitations of the present study should be considered. Over the 12 weeks of diaries, there was a small, albeit significant, decline in subjective reports of memory problems and daily stressors. While short-term repeated measurement in diary studies may reduce recall bias (Bolger, Davis, & Rafaeli, 2003), the potential participant burden could result in a dropoff in reports over 12 weeks. In addition, there was dropout in the number of participants who completed the T2 versus the T1 cognitive assessments and the dropouts were significantly less educated. Future research may benefit from examining the current research questions with participants of more diverse socioeconomic statuses to explore the generalizability of findings. Also, there may be bias in self-reported memory problems, and we cannot be certain that reports of memory problems are accurate accounts of experiences in daily life. However, participants who experienced greater declines in objectively measured cognition reported a greater number of everyday memory problems than participants with less decline suggesting a degree of correspondence between objective cognitive decline and subjective memory in daily life.

A potential limitation of the current study is that we measured cognitive changes in a fluid ability composite with working memory, reasoning, and perceptual speed, and did not include assessments of other types of memory (e.g., episodic memory or prospective memory). It is possible the associations between change in these other aspects of memory would show an even more pronounced association with everyday memory problems. Yet, the advantage of focusing on fluid cognitive abilities is that they are considered the more basic cognitive dimensions that underly changes in higher-order cognitive performance such as that required for everyday memory tasks (Hertzog, Dixon, Hultsch, & MacDonald, 2003; Salthouse, 1996).

The current study cannot directly address causality between increased daily stressors or cortisol profiles, and memory problems. Future work with experimental or longer time series designs will be better suited to examine temporal order. The diurnal cycle for cortisol was measured on a single day prior to diary data collection, although this is similar to other research designs which also used a sample from 1 day (Matthews, Schwartz, Cohen, & Seeman, 2006) or at one time point on 1 day (Souza-Talarico et al., 2010). Nevertheless, there is evidence of variability in cortisol profiles across days (Almeida et al., 2009), and future research should examine whether both cortisol and memory problems covary over multiple days within persons. Also, the timing of cortisol samples was self-reported, and thus may not be exact. Although we made attempts to ensure the reliability of reported time-stamps by examining the length of time between awakening and the peak samples, and excluding samples with missing time stamps, we cannot be certain that reported time stamps are accurate. While the timing of the saliva samples is particularly important for diurnal profiles, especially CAR, participants are relatively accurate with respect to morning samples collections (DeSantis, Adam, Mendelsohn, & Doane, 2010; Dockray, Bhattacharyya, Molloy, & Steptoe, 2008; Kraemer et al., 2006). In addition, our data (waking: 15.33 nmol/L; peak: 21.33 nmol/L) are comparable to previously reported levels, such as from the National Study of Daily Experiences (waking: 15.21 nmol/L; peak: 21.22 nmol/L; Almeida et al., 2009).

The current study adds to the existing research with evidence in support of our hypotheses that individuals with greater cognitive decline experience more everyday memory problems, and especially when they are under greater stress. Given the prevalence of cognitive decline and everyday memory complaints across the adult life span (Lachman, 2004, 2006; Slavin et al., 2010), further work is needed to understand how these are related and to explore the role of contextual factors, such as daily stress. Moreover, research that examines factors contributing to functioning in daily life even in early stages of cognitive decline can have public health significance in that it may inform interventions aimed to improve well-being and daily functioning among older adults.

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