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PHYSIOLOGICAL REACTIVITY TO COGNITIVE STRESSORS: VARIATIONS BY AGE AND SOCIOECONOMIC STATUS*

SHEVAUN D. NEUPERT†

LISA M. SOEDERBERG MILLER†

MARGIE E. LACHMAN

Brandeis University

ABSTRACT

The present study focused on age and SES differences in stress reactivity in response to cognitively challenging tasks. Specifically, we assessed within-person trajectories of cortisol, a steroid hormone released by the adrenal gland in response to stressors, before, during, and after exposure to cognitively challenging tasks. We extend the current literature by simultaneously examining age and SES differences in physiological reactivity. Findings suggest that age and SES both play an important role in reactivity, such that it was the older adults with higher SES who were the most physiologically reactive to cognitive stressors. Implications of these findings for cognitive aging research are discussed.

The stress response is a natural and common function of the human body, but over time, it can also be harmful (Sapolsky, 1992). For this reason, it is important

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†Shevaun D. Neupert and Lisa M. Soederberg Miller are now affiliated with North Carolina State University.

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to understand the relationship between individuals and situations that illicit physiological responses. We were particularly interested in exploring the effects of age and socioeconomic status (SES) on the stress response because the combination of these two factors has been relatively unexplored in the literature. The particular type of challenge that we selected for this investigation was a cognitive challenge. We outline the benefits of this approach below.

Dickerson and Kemeny (2004) proposed a social self-preservation system that makes some predictions regarding the relative salience of various stressors. They argued that stressors arise from threats to one's social esteem or social status. The social self-preservation system coordinates psychological, physiological, and behavioral responses to cope with these threats. The magnitude of the stress response depends on the intensity of the threat, its context, and the presence of vulnerability and protective factors in the individual and social environment. Importantly, threats are most likely to occur when failure or poor performance could reveal lack of a valued trait or ability.

This framework suggests that cognitive threats may be particularly informative to use when investigating the stress response among a wide range of individuals. Consistent with this notion, cognitive testing situations have been found to be stressful among younger (e.g., Seeman, Singer, Wilkinson, & McEwen, 2001), middle-aged, and older adults (e.g., Hayslip, 1989; Kelly, Hayslip, Servaty, & Ennis, 1997; Préville et al., 1996; Wetherell, Reynolds, Gatz, & Pedersen, 2002; Whitbourne, 1976). There is also reason to believe that cognitive challenges could be particularly salient among older individuals because, for example, older adults are even more concerned about cognitive abilities than are younger adults (e.g., Lachman, 1991). Concerns about cognitive declines with aging are commonly found in middle-aged as well as older adults (Lachman, 2004). Moreover, older adults are more likely than the young to attribute their cognitive performance to uncontrollable factors such as ability, which could make test taking more stressful (Blatt-Eisengart & Lachman, 2004). In addition, Gotthardt et al. (1995) demonstrated that cognitive challenge resulted in an increase in stress-induced hormonal secretion that was more pronounced in older adults than in younger adults. Seeman and Robbins (1994) also found that older adults were more reactive (i.e., took longer to return to a baseline cortisol level) to cognitive testing. However, none of these studies assessed the role of SES in reactivity.

Although intelligence and competence are considered core attributes that are valuable across many different domains (e.g., Crocker & Wolfe, 2001), stress stemming from cognitive testing may be most evident among those with high SES, who typically have higher levels of education, and who may place a particularly high value on cognitive ability. Those with higher SES may work in jobs and engage in activities in which peak cognitive performance is required and poor performance or decrements could be seen as threatening to optimal overall functioning.

Many studies that have examined SES differences in reactivity have found that lower SES is associated with heightened reactivity, but these studies have been restricted to self-reports of naturally-occurring stressors and emotional or physical well-being (e.g., Grzywacz, Almeida, Neupert, & Ettner, 2004; Kessler & Cleary, 1980). Another way to index a stress response is through levels of cortisol, a steroid hormone released by the adrenal gland in response to a stressor. Many researchers have used cortisol levels to investigate stress reactivity. For example, reactivity has been calculated by measuring the difference between baseline levels of cortisol and the level of cortisol after exposure to a stressor, where a smaller difference indicates a lower reactivity level (Smyth et al., 1998). Another approach involves the measurement of the length of the recovery phase; that is, the time required to return to a baseline cortisol level (e.g., Seeman & Robbins, 1994). Seeman and Robbins (1994) suggested that the recovery phase is an important aspect of homeostasis in that the quicker one returns to baseline, the more resilient one is to the effects of stress.

The present study utilized a different technique for assessing physiological reactivity; between-person differences in trajectories of cortisol assessments over time were examined with multilevel models. This approach is advantageous because in addition to providing estimates for the change in cortisol levels over time (i.e., within-person trajectory), we could also examine whether change depended on between-person differences in important characteristics such as age and SES. Another advantage of this technique is that it allows for the simultaneous examination of all cortisol assessments across the entire testing period.

THE PRESENT STUDY

The main goal of the present study was to examine potential age and SES differences in physiological reactivity to cognitive stressors. In the present study, we examined physiological responses to stressors that were equated across participants by administering the same battery of cognitive tests. Although such laboratory-based procedures may limit generalizability to everyday responses compared to studies of naturally occurring stress, the use of standardized procedures with the same measures facilitates direct comparisons of stress reactions between individuals.

Based on previous investigations, we expected that older adults would be more reactive to stressors than younger adults, even though we operationalized reactivity differently in this study, focusing on interindividual differences in intraindividual fluctuations. By implementing this method and including a wide age range of participants, we were able to describe differences in trajectories of reactivity in younger, middle-aged, and older adults.

We also sought to examine the role of SES in reactivity. We hypothesized that physiological reactivity to cognitive stressors could vary by SES as suggested by Dickerson and Kemeny's (2004) idea of social self-preservation. Specifically, we expected higher SES would be associated with greater physiological reactivity to cognitive tasks. Further, we simultaneously examined patterns of reactivity by age and SES to determine whether older adults with higher SES would be the most reactive.

METHOD

Sample

Participants in the present study were from the Boston oversample of the Midlife in the United States (MIDUS) Survey which was conducted by the John D. and Catherine T. MacArthur Foundation Network on Successful Midlife Development. The Boston In-Depth Study of Management Processes in Midlife included 302 adults (aged 25-74 years) from a probability sample of the Greater Boston area (see Lachman & Firth, 2004). Eighty-eight (29%) individuals provided salivary cortisol readings during the cognitive tests. Nonparticipation in the cortisol assessment was likely due to multiple factors, including the presentation of cortisol assessments as an optional part of the study, as well as our initial design for collecting cortisol only for those who were scheduled for testing after 4 P.M. This restriction was modified after we found that few people were willing to schedule so late in the day. Participants who did not provide salivary cortisol readings were slightly older than those who did, t (300) = 1.98, p = .049, but there were no differences in education, gender, or cognitive abilities (i.e., vocabulary, short-term working memory, speed, and reasoning) between the samples. Participants with a history of stroke, diabetes, neurological disorders, or who did not report English as their language spoken at home when growing up were excluded from the present investigation. Additionally, one 55-year-old male participant with cortisol readings four standard deviations above the sample mean was excluded, resulting in 74 individuals (ages 25 to 74; M = 45.84, SD = 12.68) available for analysis. The final sample was 35% female and 61% of the participants completed one to two years of college education or less, while 39% completed a Bachelor's degree or higher. The sample is representative of the Greater Boston area which has slightly higher education levels compared to the U.S. national average (Curriculum Review, 2004). Means, standard deviations, and intercorrelations among sample variables can be found in Table 1.

Measures and Procedures

Cognitive Challenge

Cognitively challenging tests in four domains (vocabulary, short-term working memory, speed, and reasoning) were given to participants. Similar cognitive tests have elicited stress reactions in past studies (e.g., Seeman et al., 2001). Vocabulary was tested using the WAIS vocabulary subscale. Short-term working memory was tested by the WAIS forward and backward digit span subscales, as well as a counting backward task (i.e., serial sevens) that required participants to count backwards by seven starting with a three-digit number. Speed was tested using the WAIS digit symbol substitution test and the letter comparison task (Salthouse & Babcock, 1991). Lastly, the Schaie-Thurstone letter series and Raven's Advanced Progressive Matrices were used to assess reasoning abilities. Means, standard deviations, and intercorrelations among the cognitive factors can be found in Table 1.

Socioeconomic Status

Socioeconomic status was operationalized as years of education. This strategy was chosen because it captures the well-established gradient of socioeconomic disadvantage (Marmot, Ryff, Bumpass, Shipley, & Marks, 1997), and it captures the primary educational benchmarks that provide the foundation for subsequent stratification processes by occupation and earnings (Marks & Shinberg, 1998). Moreover, educational attainment has been the primary proxy for socioeconomic status in previous investigations, thereby allowing comparability with other studies. It is also less prone to exhibiting missing data values; it is relatively stable across the life course after early adulthood; it is more comparable across men and women than occupation, and is more comparable across single and married persons than income. Most importantly, education is less prone to endogeneity bias from reverse causality (e.g., health affecting the SES measure) than measures such as income and occupation.

Cortisol Measures

Physiological stress was assessed by salivary cortisol levels which were collected via Sarstedt Salivettes; the participants inserted a cotton-like swab into their mouths for 30 seconds and then placed it into a glass container. The Salivettes were stored in an airtight freezer (–20.0°C) and shipped to the University of Trier, Germany for analysis (cf. Kirschbaum, Wolf, May, Wippich, & Hellhammer, 1996). Each participant completed between five and seven Salivette trials, depending on how much time they required to complete the interview after the cognitive tests. Participants were instructed not to eat for four hours prior to the testing session which took place in the homes of the participants between 9 A.M. and 8 P.M. Because of the diurnal cycles of cortisol (Kirschbaum et al., 1996), we used the time of testing as a covariate in all analyses. The first cortisol trial was assessed at the beginning of the interview. The second was assessed after the WAIS forward and backward digit span and WAIS vocabulary task; the third after the simultaneous letter comparison and counting backwards; the fourth after the digit symbol substitution test, the Schaie-Thurstone Letter Series, and the Raven's Advanced Progressive Matrices; and the fifth, sixth, and seventh were taken during the interview at 15 minute intervals after completion of cognitive tests.

Table 1. Means, Standard Deviations, and Between-Person Correlations for Independent Variables, Cortisol, and Covariates (*N* = 74)

Variables	*M*	(*SD*)	1	2	3	4	5	6	7	8	9	10
1. Age	45.84	(12.68)	—									
2. Education[a]	7.34	(2.45)	–.11	—								
3. Household income[b]	71.53	(55.57)	.17	.25*	—							
4. Self-rated health[c]	3.72	(0.91)	–.10	.33**	.37**	—						
5. Gender[d]	1.35	(0.48)	–.09	.03	–.02	–.02	—					
6. Speed[e]	0.07	(0.92)	–.55***	.22	.10	.19	.15	—				
7. Reasoning[e]	0.04	(0.90)	–.48***	.40**	.25*	.27*	.11	.58***	—			
8. Short-term memory[e]	0.02	(0.74)	–.13	.16	.20	.13	–.14	.39***	.55***	—		
9. Vocabulary[e]	–0.02	(1.00)	.11	.55***	.25*	.22	–.10	.24*	.47***	.49***	—	
10. Average cortisol	7.28	(5.36)	.14	.04	.01	.00	–.11	–.07	–.18	–.16	–.01	—

[a]Education ranged from 2 (*junior high/8th grade*) to 12 (*doctoral degree*).
[b]Household income is reported in thousands.
[c]Self-rated health ranged from 1 (*poor*) to 5 (*excellent*).
[d]Gender was coded such that 1 = male, 2 = female.
[e]Cognitive variables are factor scores.
*$p < .05$. **$p < .01$. ***$p < .001$.

Analyses

Multilevel modeling was used to examine age and education differences in cortisol trajectories. In the multilevel modeling framework, individual change/variability is represented through a two-level hierarchical model (Hawkins, Guo, Hill, Battin-Pearson, & Abbott, 2001). At Level 1, each person's variability (e.g., change in cortisol levels over time) is represented by an intercept and slope that become the outcome variables in a Level 2 model in which they may depend on person-level characteristics (e.g., age and education) (Hawkins et al., 2001). By examining the rate of change in outcomes across multiple waves of data (e.g., seven cortisol trials), multilevel modeling is a powerful and flexible approach compared to techniques that treat change in two-wave segments (Schulenberg & Maggs, 2001). Multilevel modeling is frequently used to model intraindividual variability; that is, people's variability around their own average. Because estimates of both between-person effects and within-person variability are possible with multilevel models (Lee & Bryk, 1989), conclusions regarding the variability within people across occasions and the differences between people can be made. Additionally, multilevel modeling uses all available data from each participant to estimate a trajectory for that participant, controlling for the timing of that individual's measurements (Karney & Bradbury, 1997).

It is recommended to conduct a preliminary analysis to ensure that there is sufficient variability at Level 1 and Level 2 to warrant continuation with analyses (e.g., Nezlek, 2001; Raudenbush & Bryk, 2002). This preliminary analysis is termed a fully unconditional model (also referred to as a null model), in which no term other than the intercept is included at any level (Curran, 2000; Nezlek, 2001). Results from this analysis indicated that 78% of the variability in cortisol assessments was between people and 22% was within people. Therefore, the fully unconditional model indicated that there was sufficient variability for further analyses.

RESULTS

Descriptive Information

Because the time of day of measurement was not constant across all participants, analyses were conducted to determine whether testing time differed significantly for important study variables. There were no significant differences by age, but people with higher levels of education tended to be tested later in the day, $r(72) = .26$, $p = .03$. Additional analyses examined the relationships between testing time and baseline cortisol levels and reactivity. As expected with the diurnal cycles of cortisol, testing time was negatively associated with baseline cortisol level, $r(72) = -.30$, $p = .01$, such that cortisol levels were higher earlier in the day. However, testing time was not associated with reactivity and the relationship between testing time and cortisol did not depend on age. Analyses were also conducted to determine whether baseline cortisol levels differed by age or education. Results indicated that there were no age or education differences in baseline cortisol. Cortisol levels ranged from 0.64 to 43.38 nmol/l across all timepoints, with a mean level of 7.28 nmol/l (*SD* = 5.36). Correlations between average cortisol level and the independent variables can be found in Table 1. Means and standard deviations of cortisol levels across all timepoints can be found in Table 2. All subsequent analyses controlled for testing time.

Multilevel Models

We defined reactivity as a within-person slope of cortisol assessments over trials, so multilevel models with between-person predictors of the within-person slope were utilized. For example, the following model (Model 1 in Table 3) was used to test for age differences in reactivity:

$$\text{Level 1: } \text{CORTISOL}_{it} = \beta_{0it} + \beta_1(\text{TRIAL})_{it} + r_{it}$$
$$\text{Level 2: } \beta_{0i} = \gamma_{00} + \gamma_{01}(\text{TESTING TIME}) + \gamma_{02}(\text{AGE}) + u_{0i}$$
$$\beta_{1i} = \gamma_{10} + \gamma_{11}(\text{AGE})$$

Similar to a regression analysis, the Greek letters represent the values of coefficients related to the target variables (e.g., the intercept and slope). In Level 1, the intercept, $\beta_{0it,}$ is defined as the expected level of cortisol for person i. The reactivity slope, β_1, is the expected change in cortisol associated with subsequent trials. The error term, r_{it}, represents a unique effect associated with person i (i.e., how much that individual fluctuates or varies over time). In the Level 2 equations, each variable was centered around the grand sample mean, so γ_{00} is the mean cortisol level for a person of the average age (i.e., 45.84 years) who was tested at the mean

Table 2. Means and Standard Deviations of Cortisol Levels across the Trials

Variables	*M*	*SD*
Trial 1	6.80	4.59
Trial 2	7.45	6.28
Trial 3	7.64	4.89
Trial 4	7.26	5.38
Trial 5	7.51	6.95
Trial 6	7.12	6.96
Trial 7	6.86	8.57

Note: Cortisol levels are reported in nmol/l.

Table 3. Unstandardized Coefficients (and Standard Errors) of Multilevel Models of Age and Education Differences in Physiological Reactivity

Fixed effects	Model 1		Model 2		Model 3	
Cortisol level, β_0						
Intercept, γ_{00}	7.24***	(.67)	7.21***	(.67)	7.23***	(.70)
Testing time, γ_{01}	–.00	(.00)	–.00*	(.00)	–.00*	(.00)
Age, γ_{02}	–.00	(.05)			.00	(.06)
Education, γ_{03}			–.11	(.28)	–.11	(.28)
Age × Education, γ_{04}					.00	(.03)
Reactivity slope, β_1						
Intercept, γ_{10}	.05	(.07)	.05	(.07)	.12	(.07)
Age, γ_{11}	.02**	(.01)			.03***	(.01)
Education, γ_{12}			.10**	(.03)	.12**	(.03)
Age × Education, γ_{13}					.01*	(.00)

*p < .05. **p < .01. ***p < .001.

of the testing times. The effects of testing time and age on cortisol level are represented by γ_{01} and γ_{02}, respectively, and the degree to which people vary from the sample mean of cortisol level is represented by u_{0i}. The average slope between trials and cortisol levels controlling for age is represented by γ_{10}, and γ_{11} is the effect of age on the slope between trials and cortisol levels. The reactivity slope (β_{1i}) was constrained to be equal across persons by removing the term representing the degree to which people vary from the sample slope.

The model above indicated that older adults were more reactive than younger adults (see Model 1 of Table 3), as expected. This model accounted for 2% of the within-person variance and 4% of the between-person variance in cortisol levels. An additional model testing for education differences (i.e., replacing age with the continuous education variable in the previous model) indicated that those with higher education were more reactive than those with less education (see Model 2 of Table 3). This model accounted for 2% of the within-person variance and 3% of the between-person variance in cortisol levels. However, these findings were qualified by a significant interaction (i.e., simultaneously adding Age, Education, and Age × Education in both Level 2 equations). In order to interpret this interaction, two additional models were conducted; one for those with low education (operationalized as two years of college or less) and one for those with high education (operationalized as college degree or higher). The slopes in reactivity from the two additional models were then plotted for younger adults (operationalized as one standard deviation below the average age of the sample), middle-aged adults (average age), and older adults (one standard deviation above the average age of the sample). Older adults with higher levels of education were the most physiologically reactive (see Figure 1 and Model 3 of Table 3). The final model accounted for 6% of the within-person variance and 4% of the between-person variance in cortisol levels, and demonstrated that age and education were not related to cortisol level, but were important for reactivity.

We also conducted analyses to determine whether the age and SES differences in reactivity would remain when controlling for cognitive performance and gender. The pattern of results for reactivity was the same as those reported above, and neither cognitive performance nor gender was related to cortisol level.

DISCUSSION

The main purpose of this study was to investigate age and SES differences in physiological reactivity to cognitive stressors. Consistent with past work (e.g., Gotthardt et al., 1995; Seeman & Robbins, 1994) and in line with our hypotheses, older adults were more reactive compared to younger adults. Higher SES (in this case, education) was also associated with heightened reactivity. When examined simultaneously, age and SES both played a role in reactivity, in that older adults with higher SES were the most physiologically reactive to cognitive stressors.

The finding that age was positively related to reactivity to cognitive stressors fits with previous work suggesting that older adults take longer to return to baseline after exposure to a stressor (e.g., Seeman & Robbins, 1994). However, our finding extends previous work by examining differences in trajectories over time, rather than recording the amount of time needed to return to baseline. Older adults continued to increase cortisol secretions throughout the tasks, while younger adults seemed to be less affected by the tasks and experienced decreases in secretions. Perhaps older adults found the cognitive tasks more stressful because they were experiencing some age-related cognitive decline. Indeed, speed and reasoning were negatively associated with age (see Table 1). It is important to note, however, that the age differences in reactivity were further qualified by the role of SES. Older adults with lower SES did not experience heightened reactivity, but older adults with higher SES did.

Further work is needed to explore the basis for the interesting patterns of reactivity for individuals with higher SES. Unlike previous research showing that those with lower SES are more vulnerable to the negative effects of naturally-occurring stressors (Grzywacz et al., 2004; Kessler & Cleary, 1980), we found that individuals with higher SES were the most physiologically reactive to laboratory-based cognitive stressors. These differential patterns could be due, in part, to measurement and construct differences; previous research focused on self-reported stressors and health outcomes, whereas we examined the underlying physiological process of cortisol secretions after exposure to laboratory-based tests. Indeed, past work has shown that self-report and physiological indicators are not necessarily related (e.g., Avero & Calvo, 1999). When examining previous

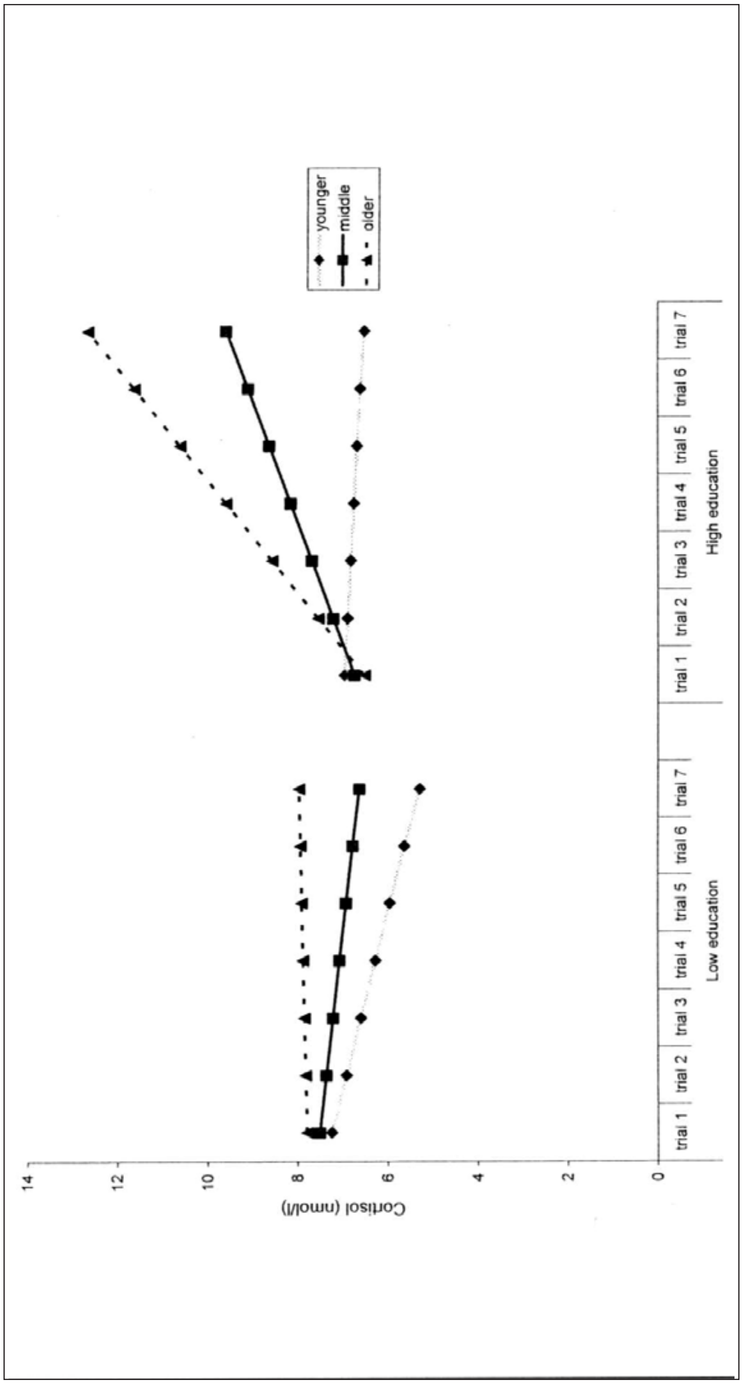

Figure 1. Age and education differences in physiological reactivity across trials, controlling for testing time. The lines for age were plotted using the average age (46 years) for the middle, one standard deviation below the mean (33 years) for the younger, and one standard deviation above the mean (59 years) for the older adults.

studies with similar methodologies (i.e., laboratory-based with a cognitive stressor), Dickerson and Kemeny (2004) postulated the role of social self-preservation; individuals who might be expected to experience greater threat due to a highly valued ability (e.g., cognitive performance) were the ones who secreted higher amounts of cortisol during the threat. Our finding regarding greater reactivity for those with higher SES is in line with Dickerson and Kemeny's (2004) ideas. It is possible that cognitive testing is more stressful among higher, relative to lower, SES individuals because the former are more concerned about decline and have a greater stake in their cognitive performance. This is also consistent with Lazarus's (1999) notion of primary appraisal, in which a situation or event must be considered valuable or salient before it can become stressful.

Cognitive testing may be the most stressful among older adults with higher levels of SES because they perceive the greatest threat in assessment of cognitive performance. Older adults who have higher education (the high SES group) may also be more invested in their cognitive performance. Those who start higher and rely on their good cognitive abilities regularly would have more to lose if performance deteriorates. Their arousal could be indicative of their greater concern and more intense focus on the performance situation perhaps due to concerns about declines with age. Future studies that are able to examine participants' self-reported assessments of their investment in the tasks and whether they are related to physiological reactions could shed light on these issues.

Limitations

The findings of the present study should be considered in light of its limitations. Specifically, our baseline indicator of cortisol level may have been influenced by anticipation of the upcoming tasks (e.g., Nicolson, Storms, Ponds, & Sulon, 1997), as it was taken at the beginning of the session, rather than in advance. Although there may have been some anticipatory reaction to the stressors, the average cortisol level at baseline (M = 6.80 nmol/l) was similar to baseline levels in previous work (e.g., Lupien et al., 1997). Moreover, there were no age or SES differences in baseline cortisol levels. Although we speculated that one reason for heightened reactivity in the older adults with higher SES was investment in the task, it should be noted that we did not have a measure of investment, challenge, or threat in the investigation. An additional limitation could be the participation rate; while we only received cortisol assessments from 29% of our sample, it is important to note that they differed little from the larger sample. Nevertheless, the participation rate could affect the generalizability of the findings. Moreover, although the strength of our findings is relatively small (i.e., explaining 6% of the within-person variance and 4% of the between-person variance), the Age x Education differences in reactivity resulted in a Cohen's d effect size of .23, which is consistent with the range of previous studies of cortisol (for a review, see the meta-analysis by Otte et al., 2005).

CONCLUSIONS

The results of this study shed light on the nature of age and SES differences in the way and degree to which people react to cognitive stressors. While the present study provides descriptive information regarding age and SES differences in physiological reactivity, there are many possible avenues for future research. For example, future studies could explicitly examine the role of investment or motivation in regards to the cognitive tasks to elucidate the SES differences in reactivity. Additionally, future studies could examine whether age differences in stress reactivity play a role in cognitive aging. Given that many older adults experience decline in cognitive functioning and that previous research has linked stress to poorer cognitive performance, it is important to determine whether stress reactivity differentially affects cognitive performance among older adults. If future research finds that the relationship between stress and cognition is more important among older adults, this could have important implications for cognitive aging research. Specifically, age-related declines in cognitive performance seen on many laboratory tasks could be in part attributable to stress, which may be modifiable and thus, could be targeted in intervention work (e.g., Hayslip, 1989).

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Direct reprint requests to:

Shevaun D. Neupert, Ph.D.
Department of Psychology
North Carolina State University
Box 7650
Raleigh, NC 27695-7650
e-mail: shevaun_neupert@ncsu.edu