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Age Differences in Negative Emotional Responses to Daily Stressors Depend on Time Since Event

Stacey B. Scott
Stony Brook University

Nilam Ram, Joshua M. Smyth, David M. Almeida, and Martin J. Sliwinski
Pennsylvania State University

Research on age differences in the experience of negative emotional states have produced inconsistent results, particularly when emotion is examined in the context of daily stress. Strength and vulnerability integration (SAVI; Charles, 2010) theory postulates that age differences in emotional states are contingent upon whether a stressor occurred, and whether sufficient time has passed since the stressor to allow older adults to benefit from theorized strengths. The present study uses an ecological momentary assessment design to examine how timing of daily stressors relates to age differences in negative emotional responses. Participants (N = 199, aged 25–65) completed mobile surveys up to 5 times daily for 14 days. They reported current mood and stressor exposure, as well as how long ago the stressor occurred. As expected, no age differences were observed in current negative affect (NA) for stressors which occurred in the previous 0–10 min. As predicted, older age was associated with less of a stressor-related increase in NA when a greater time had passed (i.e., 10 min to 2.5 hours) since stressor exposure. Consistent with previous results, there were no age differences in the effects of more distal stressors that occurred 2.5 to 5 hr ago, although NA remained significantly elevated. The present findings are consistent with SAVI's predictions and advance understanding age differences in the time course relating everyday stressors to emotional responses.

Keywords: stress, emotion, aging, reactivity, recovery

Most people feel angry, tense, frustrated, or unhappy from time to time, often in response to situations that are unpredictable, uncontrollable, unpleasant, and stressful. Experiencing negative emotions for long periods of time has implications for physical health, however. For example, individuals who experience persistent negative emotions such as depression, anxiety, and anger-hostility are at an increased risk for developing coronary heart disease (CHD) and CHD-related death (Kiecolt-Glaser, McGuire, Robles, & Glaser, 2002). Exposure to relatively minor yet frequently occurring negative events and situations represents a frequent source of emotional distress in people's daily lives. Individuals who exhibit greater emotional responses to daily stressors have been found to have greater chronic health conditions and mental health problems 10 years later (Charles, Piazza, Mogle, Sliwinski, & Almeida, 2013; Piazza, Charles, Sliwinski, Mogle, & Almeida, 2013). Therefore, identifying which individuals respond more strongly to stressors offers a target for preventative health interventions as well as an opportunity to refine theory.

Predictions extended from socioemotional selectivity theory (Carstensen, Isaacowitz, & Charles, 1999) posit that older age will be associated with smaller emotional responses to stressors because of older adults' limited time perspective and motivation to maintain emotional well-being. The daily diary and ecological momentary assessment (EMA) studies of emotional responses to everyday stressors have collectively mixed findings with some research showing that aging is related to increases in negative emotional responses to daily stressors (Mroczek & Almeida, 2004; Sliwinski, Almeida, Smyth, & Stawski, 2009), some showing no age difference (Röcke, Li, & Smith, 2009), and still others showing age-related decreases (Brose, Schmiedek, Lövdén, & Lindenberger, 2011; Stawski, Almeida, Lachman, Tun, & Rosnick, 2010). The present study builds on strength and vulnerability integration (SAVI; Charles, 2010) theory to better understand how the age differences in negative emotional responses to daily stressors depend upon the timing of events. Specifically, we test SAVI's prediction that older adults will exhibit reduced stressor-related NA only after sufficient time has passed after the stressor. Using data from an ecological momentary assessment (EMA) study that included a fine-grained assessment of stressor timing, we will examine age differences in the time course of emotional responses to everyday stressors.

Age Differences in Temporal Dynamics of Emotional Responses to Stressors

Until recently, no aging theory explicitly incorporated the time course of response in its predictions regarding age-related differences in emotional responses to stressors. SAVI theory (Charles, 2010), however, has offered a principled account of the boundary

Stacey B. Scott, Department of Psychology, Stony Brook University; Nilam Ram, Department of Human Development & Family Studies, Pennsylvania State University; Joshua M. Smyth, Department of Biobehavioral Health, Pennsylvania State University; David M. Almeida and Martin J. Sliwinski, Department of Human Development & Family Studies, Pennsylvania State University.

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Correspondence concerning this article should be addressed to Stacey B. Scott, Department of Psychology, Stony Brook University, Psychology B-142, Stony Brook, NY 11794-2500. E-mail: stacey.scott@stonybrook.edu

conditions under which age benefits in emotional well-being will be observed. One of these conditions is time-relative-to-stressor. According to SAVI, older adults maintain emotional well-being through their strengths in limiting exposure to stressors and, when stressors do occur, regulating the negative emotions produced by the event through "strengths of aging" (skills including attentional strategies, appraisals, and behavior; Charles, 2010, p. 1069). The effects of these efforts are expected to take time, thus, older adults are expected to be as affected by stressors initially but that given time age differences will begin to appear in which older adults are less affected by these stressors (Charles & Piazza, 2009). How much time is required has not yet been proposed or documented. In sum, SAVI predicts that although a stressor is occurring and in the immediate period of the stressor, small or no age differences in emotional reactivity will be observed. Only after some amount of time will older adults show more emotional recovery following a stressor; to date, no theory has specified this time course for everyday stressors.

Using Time to Operationalize Responses to Stress

The role of time is rarely considered in the definitions of reactivity and recovery used in studies of age differences in responses to everyday stressors. Experimental paradigms define these terms with much more temporal specificity than is the norm for observational research. In laboratory studies, experimenters trigger a controlled stressor and measurements are obtained of participants' states prior to the stressor, during the stressor, and after the stressor has ended. *Reactivity* is then specifically defined as the difference between measurements taken during the prestressor baseline period and during the stressor exposure period, and *recovery* is defined as the difference between measurements taken during the prestressor baseline period and during the period after the stressor has ended (Linden, Earle, Gerin, & Christenfeld, 1997). Acknowledging that recovery is itself a dynamic process, the difference between measurements taken during the prestressor baseline period and measurement taken at a specific time during the recovery period is often referred to as *residual affect* (Cohen et al., 2000).

An example of this approach is Wrzus, Müller, Wagner, Lindenberger, and Riediger's (2014) comparison of age differences in physiological and emotional responses to a laboratory stressor in a sample spanning adolescence to older adulthood. Participants completed three trials of a mental arithmetic task while lying down and being observed and corrected by the experimenter. Heart rate was measured continuously for several minutes prior to the laboratory stressor, during the task, and for several minutes following the stressor. Participants provided emotion ratings prior to laboratory stressor, immediately after the tasks, and 3 min after this second emotion report. High arousal emotions included nervous, tense, stressed; low arousal emotions included disappointed, sad, and depressed. Wrzus and colleagues found significant effects for physiological reactivity, indicating that heart rate increased between baseline and during the stressor and that older age was associated with significantly less heart rate reactivity. Significant reactivity was observed in high arousal negative emotions, but low arousal emotions did not increase significantly from baseline in response to the task. No age differences were observed in high or low arousal affective reactivity to the arithmetic task. Regarding physiological recovery, participants' heart rates returned to baseline following the stressor but older age was associated with significantly greater time to return to pretask baseline. Affective recovery was observed such that high arousal negative emotions measured immediately after completing the arithmetic task were significantly lower 3 min later and had returned to baseline levels. No significant changes were observed in low arousal emotions. No age differences were observed in either high or low arousal affective recovery.

Wrzus et al.'s experiment highlights and operationalizes key features of stress response: (a) immediate reactivity as change from a prestressor baseline and (b) recovery period as the time an individual takes to return to the prestressor baseline. Although the fine-grained assessment of multiple outcomes across time is a strength of this approach, external validity of this—and most experimental stress inductions—as a model for emotional responses to stressors in daily life is limited. First, completing the arithmetic task did not produce any change in low arousal emotions. Second, although significant high arousal NA reactivity was observed, the average rating of posttask high arousal NA scores just under 2 on a scale ranging from 0 (*not at all*) to 6 (*very much*). Participants' moderate feelings of being tense, anxious, and stressed following the task returned to negligible levels within about 5 min after the task was complete. Although less is known about the time course of affective responses of naturalistic stressors, naturalistic stressors are theorized to exert their effects on well-being because they pose a significant threat to personally relevant goals, relationships, and possessions (Almeida, Wethington, & Kessler, 2002). It may be difficult to design and get ethical approval for experimental stressors with this level of threat.

In contrast to the controlled setting created in the laboratory, naturalistic stressors occur at irregular times. Although researchers use a variety of microlongitudinal paradigms to study exposure and response to naturalistic stressors, these designs have not typically afforded the precision needed to articulate the temporal evolution of the emotional response to stressors. For example, daily diary stress assessments involve querying participants by survey or interview at the end of each day at which time they are asked whether a set of events occurred earlier that day (e.g., Bolger & Zuckerman, 1995) or in the previous 24 hr (e.g., Almeida et al., 2002). Similarly, signal-contingent EMA studies involve querying participants at numerous quasi-random intervals throughout the day using electronic devices, each time asking whether any events occurred since the last query (Bolger & Laurenceau, 2013). EMA stressor recall periods tend to be briefer than diary assessments, asking participants to report whether a disruptive or stressful event occurred since the last survey, which may have been, for example, between 15 min to 2 hr before (Wrzus, Müller, Wagner, Lindenberger, & Riediger, 2013) or some other time interval chosen by the researchers. Because of their designs, naturalistic stress studies do not always provide clear demarcation between prestress, stressor event, and recovery periods. This has created both ambiguity and inconsistency in the use of a key concept in daily stress research, namely *stress reactivity*.

Compared with experimental work, reactivity as a concept in daily stress research is underdefined. Researchers using daily diary data have simply operationalized reactivity as the difference in, for example, negative affect (NA) between end-of-day measurements taken on days where no stressor events were reported and measurements taken on days where one or more stressor events were reported (e.g., Almeida, 2005; Stawski, Sliwinski, Almeida, & Smyth, 2008). With such vague timing of the stressor events, these naturalistic stress studies group, by necessity, the measurements into two broad stressor/nonstressor "bins," each of which holds a combination of reactivity/recovery (stressor observations) or baseline/recovery (nonstressor observations) information.

To illustrate, consider an EMA study of the effects of everyday stressors on NA in which a participant completes five surveys in a day. In this example, the stressor is reported at the third survey of the day. The typical approach to defining reactivity would treat both of the preevent assessments (Surveys 1 and 2) and both of the postevent assessments (Surveys 4 and 5) as part of the nonstressor baseline. In this case, a slow recovery resulting in a prolonged emotional response at the postevent assessments would bias downward reactivity estimates because postevent affect levels are included in the baseline. The same issue applies to daily diary studies if the effects of stressful events accumulates across days (Schilling & Diehl, 2014) and elevated NA levels on postevent days contributes to estimates of baseline (nonstressor) for purposes of calculating reactivity. In sum, Linden and colleagues' (1997) definitions of reactivity, as separate from recovery, have not been articulated precisely.

Components of the Daily Stress Process

To integrate the present study with previous research examining age differences in what has been termed daily stressor reactivity, we offer an explicit conceptualization of the components of the emotional response to naturally occurring everyday stressors, depicted in Figure 1. *Response* is a general term that describes the pattern of change in emotions from the onset of a stressor until the return to baseline, prestressor level. This response encompasses both the magnitude of an individual's immediate reactivity to and recovery from the event.

In the present study, as in most other daily stress studies, we examine point estimates reflecting negative affect at various times poststressor. Estimates very proximal to the event likely represent an individual's initial and, often, peak response, and as such fit best with definitions of reactivity. Estimates at more distal periods after the event show post stressor elevations compared to baseline but are typically lower than immediate or peak response, and thus likely reflect recovery processes. The key point is that, depending on when emotions are assessed relative to a stressful event, the estimates produced may describe the initial uptick of reactivity or could reflect incomplete recovery.

Previous research on age differences in daily stress has mostly ignored, both conceptually and operationally, the temporal dynamics of the daily stress process. Notable exceptions include Ong, Bergeman, and colleagues' work (e.g., Ong & Bergeman, 2004;

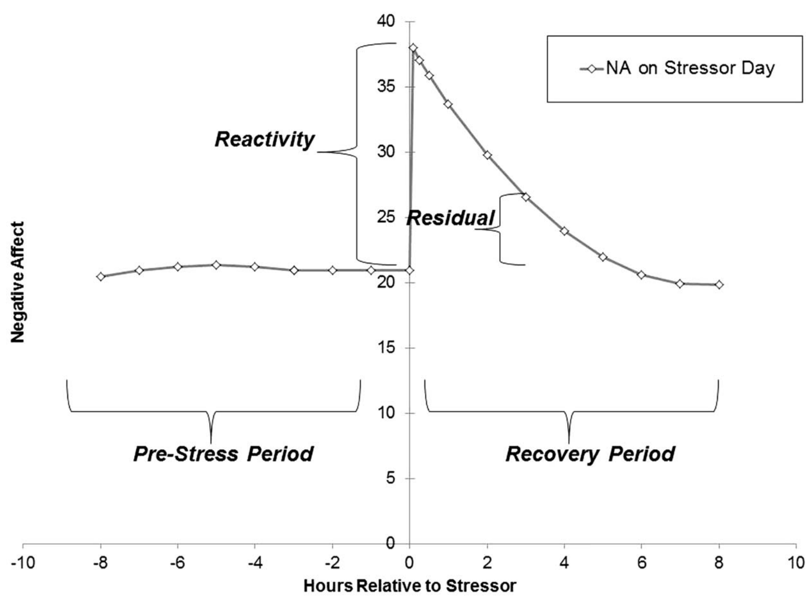

Figure 1. A conceptual figure for the time course of daily stress response. This figure depicts a theorized time course of negative affect (NA) prior to and following a stressor. Level of NA is displayed on the *y*-axis. Hours relative to stressor is displayed on the *x*-axis. Emotional experiences prior to the stressor (i.e., negative hours relative to stressor) are part of the prestress period. Emotional experience after the stressor has occurred (i.e., positive hours relative to stressor) are part of the recovery period. The solid line with open diamonds represents level of NA at different times relative to a stressor. Reactivity is defined as the difference between NA in the immediate period of a stressor and prestressor NA. Residual, or emotional residue, is defined as the difference between NA at a given point after a stressor compared to prestressor NA. Here, we highlight the residual at 3 hours poststressor but the other points during the recovery period are also examples of residual. As noted in the text, depending on the recency of a stressor, postevent observations of NA obtained in ecological momentary assessment and diary reports may represent either reactivity or persisting emotional residue during the recovery period.

Ong, Bergeman, & Bisconti, 2004; Ong, Edwards, & Bergeman, 2006) using lags to test for individual differences in the effects of daily stressors on next day's mood. Recent methodological work by Bergeman and Deboeck (2014) and Schilling and Diehl (2014) has offered approaches for examining the accumulating burden of stressors and dissipation of negative emotions over the course of days. This innovative work has focused exclusively on end of day reports of stressors and emotions. What occurs in the immediate minutes and hours after a naturalistic stressor, however, is largely unknown.

From these propositions, Scott, Sliwinski, and Blanchard-Fields (2013) formulated predictions for when age differences in emotional responses to stressors would be observed and tested these in an EMA study: (a) in the immediate period following a stressor, no age differences in the amount of increase in NA would be observed, and (b) in a later period, older age would be associated with less of an increase in NA from stressors reported at the previous survey. To test the first prediction regarding the immediate period, Scott and colleagues examined what they termed recent stressors which were reported at the same survey (recalling over the approximately 3-hr period between surveys) as the current emotion reports. For the second prediction regarding a later period, they examined the effects of more distal stressors occurring 3 to 6 hr before the emotion report. These distal effects were tested by examining lagged effects of stressors reported at the previous survey on current NA.

Scott et al. (2013) found mixed support for SAVI's predictions. Regarding the immediate period of stressors, a significant interaction between recent stressors that occurred 0 to 3 hr ago and age was found such that older adults showed less of an increase in NA related to these events than younger adults. No significant interaction was found for lagged stressors; that is, 3 to 6 hr after a stressor, older and younger individuals showed similarly higher NA relative to nonstress observations. Scott and colleagues concluded that this unexpected pattern may be because age differences in recovery from stressors emerge sooner than the design could detect. Specifically, the spacing of the observations was too wide to capture the similar NA responses in the immediate period following stressors and that the 3-hr window following recent stressors was primarily capturing the period in which older adults' strengths at strategy use had already taken effect. Although there were enduring lagged effects of stressors occurring 3 to 6 hr ago, older and younger people showed similar responses. That is, by this time, the younger people in the sample may have "caught up" to older adults in their recovery.

On the basis of these findings, what is needed to test SAVI's predictions regarding time is more detailed information about the recency of the stressor. A recently published EMA study (Wrzus, Luong, Wagner, & Riediger, 2015) collected detailed information on stressor recency (i.e., stressors reported to have occurred <5, <10, <30, <60, >60 min prior to the report of current emotional state) in a sample ranging in age from adolescence to older adulthood. Consistent with findings from other studies that used composite NA scales and ignored stressor recency, they found that current levels of both activating (i.e., angry, tense, nervous) and deactivating (i.e., disappointed, downcast, tired) negative emotions were higher when stressors were reported occurring since the last survey than when stressors were not. The main purpose of Wrzus and colleagues' (2015) study was to examine the time-related trends in emotions poststressor and whether age differences were apparent. Compared with when stressors were reported in the last 5 min, activating emotions were lower for greater periods of time poststressor, whereas deactivating emotions were higher for greater periods of time poststressor. Age did not moderate the effect of elapsed time on activating or deactivating NA, however, there were age differences in the effect of lagged stressor on activating NA. Although Wrzus and colleagues' design is an important advance in the measurement of stressor recency, their model specification limits tests of the timing of age differences. They modeled elapsed time as a linear variable, with the time categories coded 0, 1, 2, 3, and 4. As the authors mentioned, this specification is based on the assumption of a logarithmic function (fast change early over the narrow time windows, slower change over the wider later time categories). Patterns that do not follow this linear specification may not be detected.

Present Study

The present study has two aims. First, we aim to provide a description of the time course of emotional responses to naturalistic stressors in two ways. Information about the immediate and proximal responses to stressors will be obtained from participant reports of the recency of stressors since the last survey (i.e., 0 to 5, 5 to 10, 10 to 30, 30 to 60, and 60 or more min ago). Second, information about enduring responses to more distal stressors will be obtained from whether the participant reported a stressor at the previous survey, which refers to stressors occurring in the approximately 2.5- to 5-hr period prior to their current report of NA.

In this study, we test refined versions of SAVI's predictions regarding the timing of the presence and absence of age differences in emotional responses to stressors by building from Scott and colleagues' findings. Specifically, we use the stressor recency reports to provide a narrower window on the timing of age differences in emotional responses to stressors. We specify our models such that the comparisons are to times at which stressors were not reported and had not been reported at the prior observation. The interpretation of our findings, then, is very similar to the prestressor baselines used in experimental work. On the basis of SAVI, we expect there to be no age difference in immediate reactivity to a stressful event. At later times after the stressor, it is theorized that age differences favoring older adults will emerge as they are able to bring to bear their strengths. Given the current state of the literature, the timing of when differences will be present and absent is unclear. We do, however, expect to replicate Scott and colleagues' finding that there is an enduring effect of stressors occurring 2.5 to 5 hr ago on current NA. Further, we expect to also find that younger adults will have "caught up" in their emotional response by the Time 2.5 hr or more have passed since the stressor (i.e., nonsignificant age differences in lagged effect of stressor reported at previous survey). Although SAVI does not propose differential predictions related to activation or arousal, based on recent work examining different subgroupings of NA items (Wrzus et al., 2014, 2015) we conducted follow-up analyses for each NA item.

Method

Data were drawn from the first wave of the longitudinal Effects of Stress on Cognitive Aging, Physiology, and Emotion study.

Details relevant to the present study are given below. Further information on the study protocol is provided in blinded for review Scott et al. (2015).

Participants. Participants were 199 adults (67% women) aged 25 to 65 years ($M = 47.22$, $SD = 10.71$) recruited from Co-Op City, a large housing cooperative in Bronx, New York and the surrounding area using systematic probability sampling of New York City Registered Voter Lists for the zip code 10475. With respect to ethnicity, 9% identified as Non-Hispanic White, 62% as Non-Hispanic Black, 17% as Hispanic White, 7% as Hispanic Black, <1% as Asian, and 4% as other. Most of the sample had completed high school or some college (51%) or had a college degree (44%); 5% had not completed high school. Data collection occurred during 2011 to 2013. During this period, 52% of the sample was working, 13% were retired, 26% were unemployed looking for work, and 9% were unemployed not looking for work. The sample displayed marked diversity in annual household income as well: 4% reported an annual income <$4,999; 17% between $5,000 and $19,999; 25% between $20,000 and $39,999; 20% between $40,000 and $59,999; 11% between $60,000 and $79,999; 7% between $80,000 and $99,999; 8% between $100,000 and $149,999; and 1% greater than $150,000 annually; 7% declined to report income. Married persons made up 32% of the sample, 10% were not married but were living with someone, 16% were divorced or separated, 33% were never married, 2% were widowed, and 7% described their marital status as other. The sample is representative of the Bronx, New York area from which it is sampled and provides for inference to a relatively heterogeneous and diverse population of 25- to 65-year-old adults.

Procedure. Introductory letters were mailed to individuals from the sampling frame and trained study staff phoned to establish eligibility and enroll and consent interested persons. Eligibility criteria included being aged 25 to 65, ambulatory, fluent in English, without visual impairment that would interfere ability to use the study smartphone, resident of Bronx County. Participants were mailed paper survey packets assessing demographic and individual difference characteristics which they were to complete at home and bring to their first lab visit. At the first visit to the research offices, participants received training on the use of the study smartphone to complete surveys.

The EMA protocol involved carrying specially programmed study smartphones and responding to five momentary surveys each day. Smartphones were programmed to beep to alert participants to complete surveys on schedules based on the participant's self-reported typical waking time. The scheduled interval between beeps was between 2 to 3 hr, the average time between scheduled beeps was 2 hr, 33 min. Throughout this study, we use this average interbeep interval of about 2.5 hr when referring to the time between surveys. Schedules appeared quasi-random to participants so that they would not anticipate beeps. On average, momentary surveys took approximately 3 min to complete. Data were saved on the smartphones and sent to a secure server after each survey was completed. Beginning the next day after their lab visit, participants completed a 2 day "run-in" of the EMA protocol then returned to the lab for additional study tasks and to determine compliance with the EMA protocol. As described in the consent, those participants who completed 80% of the EMA protocol were invited to the 14-day EMA study. At the end of 14 days, participants returned phones to the lab and completed additional assessments. As described in the consent, study payment was tied to compliance with the protocol. Participants who completed the entire protocol could receive up to $160. The data for this analysis are from the momentary surveys during the 14-day period. Participants were compliant with study protocol, responding to an average of 85% surveys; most (79%) survey responses occurred within 10 min of the beep prompt. On the basis of the number of participants ($n = 199$), days ($n = 14$), and momentary surveys ($n = 5$ daily), the maximum number of observations for this study would be 13,930; 11,459 observations were collected. Because of missing data and procedures for lagged analysis (i.e., the first lagged observation of each day set to missing), 8,416 were used in the analyses described subsequently.

Measures. Participants completed demographic surveys as part of paper-and-pencil questionnaires prior to the EMA study. They completed surveys of their momentary emotions and recent stressors using study smartphones.

Momentary NA was calculated as the average of participant's ratings of five negative emotional states (i.e., tense/anxious, angry/hostile, depressed/blue, frustrated, unhappy). For each emotion item, participants responded to the question "How ______ do you feel right now?" using a slider ranging from *not at all* (0) to *very* (100) for each emotion. Nearly one half of the variability in NA was due to differences between persons (51%), the other portion was due to fluctuations in NA within individuals across days (14%) and within days (35%). Similar between person (BP and within person [WP] variability was observed in the NA items: angry [BP: 40%, WP across day: 11%, WP within day: 49%], tense/anxious [BP: 38%, WP across day: 11%, WP within day: 51%], depressed [BP: 52%, WP across day: 12%, WP within day: 36%], unhappy [BP: 43%, WP across day: 14%, WP across day: 43%], frustrated [BP: 41%, WP across day: 12%, WP within day: 47%]). Inertia of NA from previous occasion (not attributable to stressors) was operationalized using a lagged NA variable (i.e., the momentary NA score from the previous occasion).

Assessment of stressor timing. Stressors were reported concurrently with emotions to capture events which occurred in the last 2.5 hr. Participants used a yes/no checkbox in response to "Did anything stressful occur since the last survey? A stressful event is any event, even a minor one, that negatively affected you." Endorsing this variable does not necessarily mean that the individual is currently exposed to the stressor while completing the survey. Instead, further information about the timing of the stressor is provided in a follow-up question regarding stressor recency. If a stressor was reported, participants reported how long ago the stressor occurred from a menu of 0 to 5, 5 to 10, 10 to 30, 30 to 60, 60 or more min ago. Only one stressor could be reported at each survey; participants were instructed to base their responses on the most significant stressor that occurred since the last survey. In analyses, stressor recency was coded so that the reference category was no event reported. The enduring effect of stressors beyond the approximately 2.5-hr window between surveys was investigated by using a lagged variable that indicated whether a stressor was reported at the previous survey. Lagging the stressor report one time allowed for testing the effect of a stressor reported at the previous survey and occurring 2.5 to 5 hr before the report of current NA. Lagging this variable twice allowed for testing the effect of a stressor occurring 5 to 7.5 hr before the report of current

NA. The first observation of the day was set to missing for lagged variables.

Age. Age was operationalized as self-reported age on the initial mailed questionnaire and verified from dates of birth in voter registration lists.

Covariates. Person-level covariate data were assessed in the mailed questionnaire and coded as follows. Gender was coded as male = 1, female = 2. Race and ethnicity were coded as Non-Hispanic White = 1, Non-Hispanic Black = 2, Hispanic White = 3, Hispanic Black = 4, Asian = 5, Other = 6. Education was coded as *less than high school diploma* = 1, *high school diploma or some college* = 2, *college degree or higher* = 3. Income was coded as *chose not to answer* = 1; <$4,999 = 2; $5,000 to $19,999 = 3; $20,000 to $39,999 = 4; $40,000 to $59,999 = 5; $60,000 to $79,999 = 5; $80,000 to $99,999 = 6; $100,000 to $149,999 = 7; and ≥ $150,000 = 8. Momentary-level covariates were reported in the smartphone surveys and coded as follows. Current location was assessed at the beginning of each momentary survey; participants reported whether they were currently in *another location* = 1, *another person's home* = 2, *outside* = 3, *vehicle* = 4, *work/school* = 5, *or home* = 6. Current activity reports were also recorded at each survey; participants reported whether they were currently engaging in *chores* = 1, *eating* = 2, *other* = 3, *physical activity* = 4, *recreation* = 5, *resting* = 6, *self-care* = 7, *socializing* = 8, or *work-related activity* = 9. Current social partners were reported via a checklist; participants could endorse multiple social partners from the list (i.e., coworker, family, friends, partner, pet, other) or that they were currently not with anyone.

Data analysis. Three level multilevel models (MLM) were used to account for the nested structure of the data (i.e., beeps within days within persons) using SAS proc mixed (Littell, Milliken, Stroup, Wolfinger, & Schabenberger, 2006), with incomplete data treated as missing at random. In all analyses, NA was modeled as a function of the stressor variables of interest (stressor recency, lagged stressor, person-average stressor exposure), age, and the interaction between age and the stressor variables. Age was centered at 45 years. Person-mean stress exposure was included in the model to separate individual differences in frequency of stressor exposure from the within-person effect of experiencing a stressor on current NA. Stressor recency was represented by five dummy variables which where coded as 1 if a stressor fell into its temporal category (i.e., 0 to 5, 5 to 10, 10 to 30, 30 to 60, 60 to 150 min) and 0 otherwise. The lagged stressor variable was coded 1 if a stressor was reported at the previous observation and 0 otherwise. Because the reference category for stressor recency was no event reported, all comparisons in the results are to times at which stressors were not reported and had not been reported at the prior observation.

Random intercepts were included at the day and person levels to allow for variability across days and persons. A *yes/no* dummy variable for momentary stress exposure (called *stressor* in the random effects section of Tables 2 and 3) was included as a random effect at the person level to account for between person differences in the stress response, following recommendations for modeling the effects of categorical indicators of repeated measures (Snijders & Bosker, 1999). A random slope for lagged stressor was also included at the person level. Race, ethnicity, education, gender, and income were included as person-level covariates. As situational factors may affect both mood and probability of stressor occurrence, current location and activities were also included as beep-level covariates. We included lagged NA as time-varying predictor and centered it around the mean NA for each person on each day, following the procedure described in Scott et al. (2013).

Results

Descriptive statistics. Descriptive statistics and correlations among age and average momentary reports of NA and stressor occurrence are provided in Table 1. A total of 2115 stressor events were reported across the study. Stressors were reported at 19% of beep surveys, and at least one stressor was reported 44% of study days. The sample average total stressors was 10.42 across the 14 days, but individuals varied greatly in this tally (SD = 9.91; minimum = 0, maximum = 49); the median total was eight stressors reported. Regarding the number of stressors on a typical day, based on person-means of day-level totals, the average person reported .8 events per day. Age was not associated with individuals' average NA ($r = -.03$, $p = .67$). Older age was associated with reporting slightly more stressors ($r = .14$, $p = .04$).

When participants reported experiencing a stressor since the last survey, they also reported how long ago the event occurred (stressor recency): 7% of stressors were reported to have occurred in the 0 to 5 min prior to the current beeped survey, 18% within 5 to 10 min prior, 25% within 10 to 30 min prior, 19% within 30 to 60 min prior, and 31% were reported to have occurred 60 min or more ago. Age was not associated with temporal recency of stressors after controlling for overall stressor frequency.

Age differences in stressor-related NA. To compare our main results to previous EMA and diary studies, we first examined age, stressor exposure, and the age-by-stressor interaction. In this preliminary MLM, exposure to a stressor (i.e., a stressor was reported having occurred since the previous survey) was related to significantly higher momentary NA ($\beta = 16.24$, $SE = .80$, $p < .001$); there was a significant interaction between recent stressor exposure and age ($\beta = -.19$, $SE = .08$, $p < .02$) such that older age was associated with less of an increase in NA when stressors were reported. In summary, this preliminary analysis considered a binary *yes/no* momentary stressor exposure and found that individuals reported higher levels of NA at surveys in which they reported that a stressor had occurred. Further, younger age was associated with greater increase in NA (from baseline nonstressor level) after a recent stressor (i.e., within the 2.5-hr window).

Stressor recency, age, and stressor-related composite NA. Using a MLM with stressor recency, lagged stressor, and covari-

Table 1
Descriptive Statistics and Correlations

	M (*SD*)	Range	*r* Age	*r* WP average NA
Age	47.15 (10.77)	25–65		
WP average NA	22.55 (15.10)	.07–94.53	−.03	
WP proportion of beeps stressor reported	.19 (.17)	.00–.81	.14*	.32***

Note. $N = 199$. WP = within-person; NA = composite negative affect.
* $p < .05$. *** $p < .001$.

Table 2
Momentary Composite NA as a Function of Stressor Recency, Lagged Stressor, Lagged NA, and Age

Fixed effect	Category	Estimate	*SE*
Intercept		21.60*	10.35
Stressor recency	0–5	20.80***	1.57
	5–10	18.04***	1.21
	10–30	16.39***	1.15
	30–60	14.07***	1.24
	60–150	12.82***	1.19
	No stressor	ref.	
Age		.02	.15
Age × Stressor Recency	0–5	−.02	.14
	5–10	−.14	.11
	10–30	−.33**	.11
	30–60	−.32**	.12
	60–150	−.23*	.11
	No stressor	ref.	
Lagged stressor		5.74***	.69
Age × Lagged Stressor		−.04	.06
Lagged NA		−.19***	.01
Person–average stressor exposure		12.33	7.01
Age × Person-Average Stressor Exposure		−.39	.69
Ethnicity	Caucasian	−2.25	6.35
	Black	−2.50	5.39
	Hispanic, White	4.94	5.82
	Hispanic, Black	−2.90	6.56
	Asian	12.92	15.55
	Other	ref.	
Education	<High School Diploma	−9.72	5.20
	High School Diploma or Some College	−3.53	2.33
	College Degree or Higher	ref.	
Male		.84	2.30
Income	Chose not to answer	−80	9.49
	<$4,999	12.06	10.08
	$5,000–$19,999	3.92	9.08
	$20,000–$39,999	−1.29	8.88
	$40,000–$59,999	−1.53	8.83
	$60,000–$79,999	−4.72	9.08
	$80,000–$99,999	−3.39	9.40
	$100,000–$149,999	−2.13	9.25
	≥$150,000	ref.	
Random effect			
Level 3: Between–person			
Var (Intercept)		203.74***	22.48
Var(Stressor)		113.37***	17.09
Var (Lagged stressor)		28.55***	6.35
Cov (Intercept, stressor)		−30.61*	14.47
Cov (Intercept, lagged stressor)		−6.21	8.93
Cov (Stressor, lagged stressor)		31.41**	8.32
Level 2: Within–person (across days)			
Var (Intercept)		47.97***	2.67
Level 1: Within–person (Across beeps and days)			
Residual		112.56***	2.14

Note. $N_{person} = 199$; $N_{observations} = 8{,}416$. *Stressor recency* refers to self–reported minutes between stressor occurrence and the current survey; period between surveys was 2.5 hr on average. *Lagged stressor* refers to the lagged effect of stressor reports at the previous survey, which represents stressors occurring approximately 2.5 to 5 hr prior to the reports of current NA. The stressor term in the random effects is a binary variable that describes whether a stressor was reported as occurring since the last survey. The reference category for stressor recency, stressor, and lagged stressor is no stressor reported. This model includes momentary reports of current location, activities, and social partners as controls. For parsimony, these effects are not reported in the table.
* $p < .05$. ** $p < .01$. *** $p < .001$.

ates, we tested two aims simultaneously. The first aim was to describe the time course of emotional responses to naturalistic stressors. Relative to observations when no stressors were reported, current NA was significantly higher at all time intervals when a stressor was reported as occurring since the previous survey (see Table 2). These effects held even when accounting for the effects of individual difference and situational covariates on NA. The stressor effect on NA was graded according to recency, decreasing as a function of time since the event. Stressors reported occurring at times proximal to completing a survey (0 to 5 min) were associated with 20.8 point increase in NA compared with a 12.8-point increase for more distal events reported as occurring 60

Table 3

Momentary Negative Affect Items as a Function of Stressor Recency, Lagged Stressor, Lagged Affect, and Age

Fixed effect	Categories	Angry/hostile Estimate	*SE*	Tense/ anxious Estimate	*SE*	Depressed/ blue Estimate	*SE*	Unhappy Estimate	*SE*	Frustrated Estimate	*SE*
Intercept		21.75*	9.38	30.03**	10.71	21.74	11.90	21.79	11.68	21.27	12.01
Stressor recency	0–5	19.42***	1.84	22.04***	2.17	8.98***	1.81	23.60***	2.19	28.75***	2.30
	5–10	16.98***	1.40	19.31***	1.58	10.00***	1.39	19.30***	1.70	23.93***	1.74
	10–30	14.41***	1.33	18.24***	1.48	8.17***	1.32	18.56***	1.62	22.05***	1.64
	30–60	12.95***	1.43	13.58***	1.62	9.30***	1.42	16.55***	1.74	18.56***	1.78
	60–150	10.65***	1.37	12.02***	1.54	9.78***	1.36	14.90***	1.66	17.61***	1.70
	No stressor	ref.		ref.		ref.		ref.		ref.	
Age		−.07	.15	.09	.16	−.13	.19	−.09	.18	−.12	.18
Age × Stressor Recency	0–5	−.05	.16	.36	.19	.06	.16	−.20	.19	−.28	.20
	5–10	−.32*	.13	.02	.15	.17	.13	−.20	.16	−.39*	.16
	10–30	−.46**	.12	−.15	.14	<−.01	.12	−.50**	.15	−.52**	.15
	30–60	−.53**	.14	−.12	.15	−.06	.13	−.38*	.16	−.45**	.17
	60–150	−.24	.13	−.09	.14	−.29*	.13	−.29	.15	−.33*	.16
	No stressor	ref.		ref.		ref.		ref.		ref.	
Lagged stressor		5.14***	.72	6.53***	.83	4.06***	.71	6.22***	.81	7.99***	.88
Age × Lagged Stressor		−.12	.06	.04	.19	.02	.07	−.06	.07	−.11	.08
Lagged affect		−.23***	.01	.04	.08	−5.26	7.26	−.20	.07	−.22***	.01
Person-average stressor exposure		2.86	6.90	18.55*	7.33	6.71	8.68	12.95	8.58	15.99	8.22
Age × Person-Average Stressor Exposure		−.12	.70	−.87	.73	.54	.89	.06	.87	.37	.82
Random effect											
Level 3: Between-person											
Var (Intercept)		158.05***	18.66	209.44***	24.06	258.11***	29.72	248.23***	28.99	273.83***	30.75
Var (Stressor)		138.37***	21.12	131.46***	22.15	144.40***	23.74	226.34***	33.95	205.56***	32.27
Var (Lagged stressor)		34.15***	8.36	40.97***	11.19	37.58***	8.64	43.12***	10.69	51.01***	12.83
Cov (Intercept, stressor)		−21.14	14.33	−13.26	17.40	−21.89	17.83	−43.85	21.96	−56.65*	23.38
Cov (Intercept, lagged stressor)		−9.48	9.30	−15.76	13.27	−12.08	11.28	−5.83	12.27	39.41**	15.18
Cov (Stressor, lagged stressor)		46.13***	10.37	30.02*	11.80	52.49***	11.53	66.31***	14.91	51.01***	12.82
Level 2: Within-person (Across days)											
Var (Intercept)		39.83***	3.09	63.37***	4.77	47.83***	3.14	58.37***	4.17	67.30***	4.80
Level 1: Within-person (Across beeps and days)											
Residual		174.40***	3.36	273.09***	5.16	158.29***	3.06	226.64***	4.36	272.61***	5.12

Note. Tense/anxious and frustrated: $N_{\text{person}} = 199$, $N_{\text{observations}} = 8{,}413$. Angry and unhappy: $N_{\text{person}} = 184$, $N_{\text{observations}} = 7{,}989$; Unhappy: $N_{\text{person}} = 184$, $N_{\text{observations}} = 7{,}983$. Stressor recency refers to self–reported minutes between stressor occurrence and the current survey; period between surveys was 2.5 hr on average. *Lagged stressor* refers to the lagged effect of stressor reports at the previous survey, which represents stressors occurring approximately 2.5 to 5 hr prior to the reports of current NA. The stressor term in the random effects is a binary variable that describes whether a stressor was reported as occurring since the last survey. The reference category for stressor recency, stressor, and lagged stressor is no stressor reported. Models are parallel to the composite NA model displayed in Table 2. As such, this model included race–ethnicity, education, gender, income, and momentary reports of current location, activities, and social partners as controls. For parsimony, these effects are not reported in the table.
* $p < .05$. ** $p < .01$. *** $p < .001$.

to 150 min (i.e., the approximately 2.5-hr window between surveys) prior to the survey.[1] Testing the persistence of stressor-related increased NA at more distal periods after the stressor, we included lagged effects of stressors reported at the previous survey in the model (see Table 2): A small but statistically significant increase in NA (5.7 points) was evident 2.5 to 5 hr postevent. The average time gradient of NA response to stressors is displayed in Figure 2.

In follow-up analyses, we also tested the persistence of stressor-related elevations in NA at even more distal periods using twice-lagged stressor reports. Stressors reported two surveys ago (i.e., events occurring 5 to 7.5 hours ago) were related to significantly higher NA than if no events occurred ($\beta = 5.31$, $SE = .50$, $p < .0001$). The pattern of results for stressor recency and single lagged stressor effect was consistent with the results in Table 2. Because of the missing data inherent in lagging data multiple times, these models required additional constraints to converge (e.g., uncorrelated random effects).

Our second aim was to test SAVI's predictions regarding when age differences in emotional responses to stressors would be observed. For people of all ages, NA decreased as a function of time since stressor, but, as predicted, age differences in stressor-related NA depended on stressor recency (see Table 2). Specifically, age differences were not evident in stressor-related NA for events that occurred 0–5 ($\beta = -0.02$, $p = .88$) or 5 to 10 min ($\beta = -0.14$, $p = .21$) prior to the survey; however, age differences emerged for stressors that were relatively less recent: 10 to 30 min

[1] We conducted follow-up tests using estimate commands with Helmert contrasts with stressors occurring in the last 0 to 5 min as the reference category to test at various time intervals NA was significantly lower than at the average peak in the 0 to 5 min poststressor period. NA levels for stressors 5 to 10 min ago did not significantly differ from levels at 0 to 5 min poststressor; stressors occurring a greater time ago (10 to 20, 30 to 60, or 60+ min ago) were associated with significantly lower NA than stressor occurring 0 to 5 min before the survey.

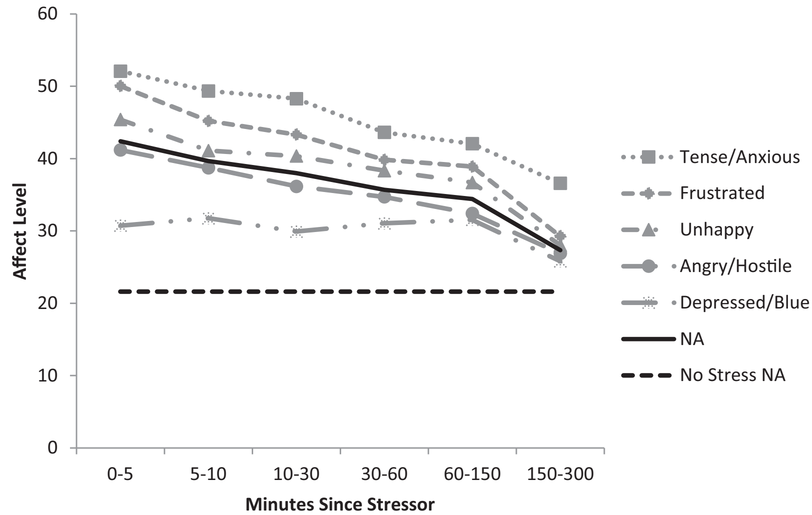

Figure 2. Estimated negative affect after a stressor. The bold dashed line represents the intercept (i.e., level of negative affect [NA] prior to a stressor on a stressor day). The bold solid line represents composite NA at time intervals poststressor. NA is a composite of items tense/anxious, frustrated, unhappy, angry/hostile, and depressed/blue. Individual NA items are displayed on their respective dashed lines. When stressors occurred since the previous survey, participants reported whether they happened 0 to 5, 5 to 10, 10 to 30, 30 to 60, or 60 or min ago. For display purposes, this figure displays 60 to 150 min for the 60 or more min ago category to indicate the average maximum time since the previous survey. The final category displayed, 150 to 300 min ago, represents the lagged effect for a stressor reported at the previous survey. These stressors occurred 2.5 to 5 hr (i.e., 150 to 300 min) prior to the current NA reports. Composite NA and each NA item were significantly higher poststressor at each time interval displayed relative to nonstressor observations.

($\beta = -0.33$, $p < .01$), 30 to 60 min ($\beta = -0.32$, $p < .01$), and 60+ minutes ($\pi = -0.23$, $p = .03$). Older age was associated with less of an increase in NA for these time periods. The interaction between age and single lagged stressor was not significant ($\beta = -0.04$, $p = .44$), indicating that older age was no longer associated with significantly less stressor-related NA once 2.5 to 5 hr had passed. Figure 3 plots the age-by-recency and age-by-single lagged stressor effects from Table 2. It illustrates how at times proximal to the stressor, no age differences are observed but that age differences are apparent for stressors 10 to 60 to 150 min poststressor. These age differences are nonsignificant by the time 2.5 hr or more have passed since the event. In our follow-up analyses using twice-lagged stressors to examine NA at periods 5 to 7.5 hr ago, age differences in this effect were not significant ($\beta = -0.01$, $SE = .044$, $p = .81$).

Stressor recency, age, and stressor-related NA items. Parallel models to those used in Table 2 were conducted separately for each NA item (see Table 3). As highlighted in Figure 2, the NA items differed somewhat in their intensity but all were significantly higher at all time intervals poststressor compared with the no stressor baseline. No age differences were observed for stressors occurring in the last 0 to 5 min for any of the NA items (see Figure 3). Older age was associated with less of a stressor-related increase in feeling unhappy compared with baseline for time intervals between 10 to 60 to 150 min poststressor, consistent with composite NA. Older age was also associated with less of increase in angry/hostile and frustrated feelings relative to baseline for these time intervals as well as for stressors occurring 5 to 10 min ago. No age differences were observed at any time interval for feeling tense/anxious. The recovery pattern for depressed/blue is different from the other NA items. Although intensity of depressed/blue feelings was significantly higher for all stressor recency categories and lagged stressor relative to baseline, significant age differences were only observed for stressors occurring 60 to 150 min ago.[2]

Discussion

This study contributes to a small but growing set of papers examining age differences in momentary NA responses to everyday stressor modeled as a function of time since exposure. We found support for a pattern expected from laboratory studies but that is rarely examined in naturalistic settings and in daily life. That is, compared with nonstressor times, NA was highest immediately after a stressor and lower at more distal time intervals. Interestingly, although the pattern suggests that emotional recovery toward baseline levels was occurring, the effect of stressors on momentary negative mood endured for hours. NA was still significantly higher if a stressor occurred 5 to 7.5 hr ago than if no stressor had occurred earlier in the day. Testing hypotheses ex-

[2] We conducted similar follow-up Helmert contasts to compare the effect of recency relative with 0 to 5 min for each NA item. Angry/hostile showed the same pattern as composite NA, whereas no significant differences were found across any of the stressor recency categories for depressed. For tense/anxious, stressors 5 to 10 and 10 to 30 min ago did not differ from those 0 to 5 min ago, but stressors 30 to 60 or 60+ were associated with lower NA than stressors 0 to 5 min ago. For unhappy and frustrated, all time intervals were associated with significantly lower NA than stressors 0 to 5 min ago.

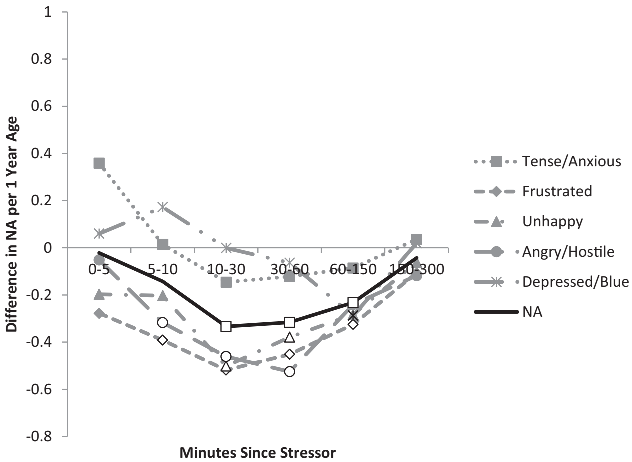

Figure 3. Estimated age differences in negative affect after a stressor. The solid black line in this figure plots the effect of age on the stressor-related increase in composite NA (i.e., the stressor slope) at different time intervals poststressor. NA is a composite of items tense/anxious, frustrated, unhappy, angry/hostile, and depressed/blue. Individual NA items are displayed on their respective dashed lines. When stressors occurred since the previous survey, participants reported whether they happened 0 to 5, 5 to 10, 10 to 30, 30 to 60, or 60 or min ago. For display purposes, this figure displays 60 to 150 min for the 60 or more minutes ago category to indicate the average maximum time since the previous survey. The final category displayed, 150 to 540 min ago, represents the lagged effect for a stressor reported at the previous survey. These stressors occurred 2.5 to 5 hr (i.e., 150 to 300 min) prior to the current negative affect (NA) reports. The solid black line in this figure plots the effect of age on the stressor-related increase in NA (i.e., the stressor slope) at different time intervals poststressor. Significant age differences are indicated by the open square symbols outlined in black. Age differences were observed in the following time intervals: 5 to 10 min: angry/hostile, frustrated; 10 to 30 min: frustrated, unhappy, angry/hostile, composite NA; 30 to 60 min: frustrated, unhappy, angry/hostile, composite NA; 60 to 150 min: frustrated, angry/hostile, depressed, composite NA. No significant age differences were observed at 0 to 5 min or 150 to 300 min; no significant age differences were observed in tense/anxious at any time period. All significant age differences were negative, indicating that older age was related to significantly less of an increase in NA at these time periods.

tended from Charles' (2010) SAVI theory and Scott and colleagues' (2013) results, we found that age differences depended upon the recency of the stressor. We elaborate on the pattern of age effects in the following text.

No evidence for age-differences in reactivity. Most studies of age differences in reactivity to everyday stressors have defined reactivity as the differences between NA (assessed by 24-hr recall) on days during which a stressor was reported and NA on days when a stressor was not. As reviewed in the introduction, some of these studies found that older age is associated with less increase, some found that older age is associated with more increase, and some found no age differences in stressor-related NA (for review, see Riediger & Rauers, 2014; Sliwinski & Scott, 2014). Beyond differences in samples and study designs, some of these inconsistencies may be because this type of "daily reactivity" reflects a mixture of immediate reactions to and recovery from daily events; our study used EMA to obtain a temporally fine-grained assessment of mood to more carefully explore this issue. The pattern of results from the present study refine this interpretation of stress responses by showing temporal gradients of NA responses to events over the course of minutes and hours, and that age differences depend upon the timing of the event.

Specifically, from our results it appears that momentary NA was at its peak level when assessed during the 10 min immediately following the occurrence of a stressor. Across age, participants showed similar increases in their NA during this immediate post-stressor time period. This means that when emotional reactivity is defined by the magnitude of the initial response, no evidence for age differences in reactivity were observed in these data. This result aligns with a key prediction of SAVI, namely that younger and older people will be similarly affected by stressors in the proximal period in which they occurred. Next we examine how the present results fit with SAVI's prediction that as time passes from the event, age-related benefits will be observed (Charles & Piazza, 2009).

Evidence for age differences in emotional recovery. We defined *emotional recovery* as elevations in NA at poststressor periods after the initial reactivity or peak response. Older age was associated with lower stress-related increases in NA for stressors occurring 10 to 30, 30 to 60, and 60 or more min ago. According to SAVI, these differences may be present because older adults' strengths at strategy use such as reappraisal and distraction have resulted in reduced NA, or physiological inflexibility with older age may contribute to this pattern. Although the mechanisms (i.e., strategy use, physiological inflexibility) were not assessed in this study, this result provides evidence consistent with the prediction in a naturalistic setting. Luong and Charles (2014) tested whether goals, appraisals, and strategies explained why age differences in emotional states 20 to 25 min after a negative social interaction in the laboratory. Although older age was associated with less NA and more positive affect (PA) at this posttest, strategies mediated age differences only in recovery for PA but not NA.

One interpretation of our findings is that although the magnitude of the initial NA reaction (i.e., 0 to 10 min for composite NA, angry/hostile, frustrated; 0 to 5 min for unhappy) to daily stressors is age invariant, older age is associated with greater emotional recovery after this initial reaction (i.e., 30 to 60+ minutes ago for composite NA, angry/hostile, frustrated, unhappy). Examination of the lagged stressor effect, however, revealed no age differences in negative emotional responses during the 2.5- to 5-hr period following the stressful events. That the NA responses of older and younger adults do not differ 2.5-hr post event may seem inconsistent with SAVI's prediction that older adults' advantage should increase over time. Another possibility, however, is that by 2.5-hr postevent both younger and older adults are approaching their prestressor baseline levels of NA, essentially allowing younger adults to "catch-up." This was Scott and colleagues' explanation for their lack of support for this SAVI prediction when tested on emotional responses to stressors occurring in the last 3 hr. The pattern of results displayed in Figures 2 and 3 are consistent with this explanation. Although small but significant effects on NA endure past 2.5 to 5 hr after the stressor on average, the age differences in NA are reduced because individuals, particularly older persons, have mostly returned to their prestress baseline NA. An alternate explanation is that older adults may have been less physiologically aroused by the stressors, and thus emotionally recover more rapidly. Neither strategy use nor physiological arousal were assessed in this or most naturalistic stress studies, thus future experimental work may provide the most fruitful resolution of why age differences are observed. The focus of the present study was on if and when age differences in emotional responses would be observed.

Reconciling present findings with prior naturalistic studies of time-since-stressor. We view the present findings as clarifying the time course of the pattern predicted by SAVI. Both the present study and Scott et al. (2013) expected to observe no or small age differences in reactivity for the immediate period after a stressor, but that age benefits would be apparent at later time periods post event. The studies differed in their definitions of immediate and later time periods following stressors. Scott et al. operationalized the immediate period as stressors that were reported having occurred in the last 0 to 3 hr. In the present study, participants were able to report specific time windows within the 0 to 2.5 hr poststressor period. In the prior study, Scott et al. observed age benefits for stressors 0 to 3 hr ago; the present study identified that within this early window, there were no age differences for stressors 0 to 10 min ago but age benefits for stressors occurring 10 min to about 1 hr ago. For SAVI's time-since-stressor prediction to account for both the results in the present study and Scott et al., this would mean that the lack of age differences in reactivity occur very early (<10 min) post event, and that age benefits for NA are apparent for about an hour afterward. Thus, the findings from Scott et al. likely resulted from averaging the time immediately after the event with longer periods of time after the stressor. Both studies used lagged effects to examine effects of stressors for several hours afterward; both studies found that although there was a persistent effect of these more distal stressors on NA, age differences were not apparent for this later window.

Many features of our design and assessment of time-since-stressor are shared with Wrzus and colleagues' (2015) study, yet we found a somewhat different pattern of findings. As described earlier, this may be partly due to differences in dependent variable (composite NA and items vs. activating and deactivating NA). The primary reason, however, is likely the different approaches to modeling time-since-stressor. Wrzus and colleagues imposed a log-linear constraint on the unequal time intervals, assuming that rapid change would occur early and level off across time. We did not constrain age differences in responses to stressors to be monotonically increasing (or decreasing) over time, because whatever age differences in the magnitude of the response emerge must vanish once both younger and older adults return to baseline. We modeled time-since-stressor as ordered categories which allowed us to detect age differences occurring in the middle time periods (10 min to 150 min) that were not apparent at times proximal to stressor occurrence and that were no longer present after sufficient time had passed for individuals to return to baseline. Building from these studies, future work should both include (a) reports of time-since-stressor and (b) test whether SAVI's predictions for timing of age differences align with the window deduced from this study and Scott et al. or the later period of lagged stressors observed by Wrzus and colleagues (2015). Because the set of studies examining time-since-stressor are still small and theory is not yet explicit about the time windows, we recommend modeling time-since-stressor in a way that does not impose linear constraints.

Implications for aging and daily stress. Examining the results over the entire response period, which spanned self-reported times ranging from less than 5 min to 7.5 hr post stressor, suggests alternate interpretations of previous work, particularly daily diary studies. Although studies of daily stress typically interpret findings of age differences in stress-related NA in terms of reactivity (e.g., Almeida & Horn, 2004; Sliwinski, Almeida et al., 2009), the results likely reflect some combination of reactivity and recovery. Elevations in NA in response to a daily stressor persist for many hours: in the follow-up analyses using two lags, we found significantly higher NA after stressors for periods of 5 hr and beyond. This implies that end of day reports that query individuals about how often they experienced specific negative emotions (e.g., anger, anxiety, sadness) very likely reflect, at least to some degree, not just the magnitude but the duration of their emotional responses. Moreover, daily diary studies that rely on end of day reports of emotions experienced throughout the previous day also capture both peak emotional intensities, perhaps reflective of immediate reactivity, as well as "end" effects, that might disproportionally reflect the respondent's current emotional state when completing their end of day reports (e.g., Stone, Schwartz, Broderick, & Shiffman, 2005).

This line of reasoning presents an alternative interpretation for recent findings that those with higher levels of stress-related NA are at increased risk for poor somatic and mental health outcomes (Charles et al., 2013; Piazza et al., 2013). These studies framed their results in terms of stressor exposure, defined as the frequency of reported daily stressors, and reactivity, defined as the difference between end of day reports of NA on stressor days compared with nonstressor days. In fact, we view it as unlikely that these results solely or even mostly reflect effects of immediate reactivity to daily stressors and more likely convey increased health risk imposed by longer lasting negative emotional responses, that is, incomplete or slowed recovery of emotional responses to everyday stressors. This reinterpretation of these findings brings them more in line with recent stress theory, which emphasizes that prolonged, rather than larger acute responses to stressors carry negative health consequences (e.g., Smyth, Zawadzki, & Gerin, 2013).

Limitations

In line with the careful operationalizations of the stress response provided in the introduction, it is important to note limitations in the data and assumptions on which the present interpretations are based. First, although this study refined the time period during which older and younger people differ in their NA response to stressors, we did not directly assess why these age differences occur. We assumed, according to SAVI and other socioemotional aging theories, that differential strategy use drives these differences, but we did not directly assess strategy use nor physiological response, another possible explanation. Other factors which may vary across development, such as the nature of the stressors and the environmental affordances in dealing with stressors, could have contributed to the observed pattern of age differences. Thus, as Isaacowitz and Blanchard-Fields (2012) pointed out regarding most interpretations for the reasons for age differences in affective outcomes, this study provides data consistent with predictions based on theories of socioemotional aging but is not a strong test of their explanations.

Second, the definitions of reactivity and recovery provided in the introduction assume a fixed or stable response set—across events, time, and ages. Individuals could use different thresholds for labeling a stressor when they are in different moods, when the event is part of a chronic stressor compared to a novel problem, or in when they are in different periods of development. If thresholds for appraising and labeling what is a daily stressor changes with aging, what constitutes an input may differ (e.g., as one ages, it may take more or less of a stressor to be labeled in a momentary survey as having occurred). According to SAVI, this is what is occurring—individuals are presumably cognitively appraising and responding similarly to events in the immediate period, but with time from the event, differential strategy use (and potentially physiological response) result in age divergence in recovery. How these strategies develop and how preferences for their use changes with development, however, have not been examined longitudinally and are beyond the scope of this study. Similarly, little is known about age differences in physiological responses to stressors in daily life. As researchers design future studies to collect both physiological and self-reported data related to daily stressors, it is important to address that shifts in these outcomes may both unfold over different time scales (i.e., seconds and minutes in physiological outcomes, minutes and hours in reported affect; see Isaacowitz & Blanchard-Fields, 2012 for discussion) and show different patterns on average and across age. Future work is needed on these topics.

Third, the age range in the sample does not cover the entire period of adulthood. It is possible that in samples including individuals younger than 25 or older than 65 years, researchers may observe different patterns for stressor frequency, type, severity, reactivity, and recovery. It may be that within the narrower age range of the present sample, we do not observe age benefits in reduced exposure to stressors. Many of the findings for age differences in stressor exposure come from end of day diary studies which may result in age-dependent underreporting of events due to recollection failures and biases. That said, not every study finds age differences in stressor exposure—Scott et al. (2013) found no age differences in stressor exposure in EMA reports from a sample of 20 to 81 year olds. By design, the systematic probability sampling from registered voter lists within a relatively heterogeneous and diverse zip code resulted in a diverse sample for the present study. The sample is diverse not only in terms of race and ethnicity but also in income, marital status, work, and education. Although these demographics may differ from those in many previous daily diary and EMA studies, it is important to note that aside from large-scale studies such as Midlife in the United States many of these studies use convenience samples that are not necessarily representative of their communities or the nation. By systematically sampling in a specific area, the study likely controls for differences in residential status, something that could vary with age in other studies and potentially account for age differences in stressor exposure. It is important to keep in mind in all naturalistic stress research, however, that participant characteristics like age, race, ethnicity, employment, and marital status may be associated with both the way that individuals respond to stressors as well as the types of stressors to which they are exposed.

Relatedly, it is important to think carefully about what age differences in exposure and response might indicate—we found older age was correlated with greater exposure but inversely related to overall stress-related NA. This pattern is not entirely surprising. Although a person must be exposed to a stressor for researchers to assess his or her response, the total number of stressors occurring across the study period may not be tightly related to the way a person emotionally responds to the stressors during this time. Indeed, this pattern in our study suggests that experiencing fewer stressors was likely not the way that the older adults in this sample achieved lower levels of NA.

Several other limitations must be noted. First, the responses examined in this study may be specific to the emotions assessed in this study (tense/anxious, angry/hostile, depressed/blue, frustrated, unhappy) and the specific time-scale on which the measurement was obtained (hours across a specific 14-day period). From a functionalist emotion theory perspective (e.g., Frijda & Mesquita, 1998), the time-course of different discrete emotions should be different, with each promoting the use of a specific behavioral and cognitive responses that are appropriately matched to the specific environmental threats provoked the specific stressor event and the individual's current resources. Our goal was to test hypotheses extended to SAVI, which uses a generalized conception of negative affect. However, our follow-up tests with separate NA items are partially in line with Wrzus and colleagues' (2014; 2015) studies using high- and low-activation NA items. For example, we found that depressed/blue showed reactivity about half the magnitude of the other NA items and a relatively flat recovery profile. Future work should develop a priori tests for the poststressor time course of specific emotions. The present study also neglected a critically important component of daily stress—anticipatory stress. Elevations in NA in response to the anticipation of a future daily event could alter estimations of emotional reactivity and residue by elevating the prestressor baseline. Deriving and testing specific functional forms of the time-course of change in differential equation form may provide for a more precise empirical articulation of the theoretical conceptions of reactivity and recovery as dynamic processes (Ram & Grimm, 2015). Last, we instructed participants to report on the most severe stressor if multiple stressors occurred since the last survey. Thus, we do not know if individuals were exposed to single or multiple stressors at these times. Subsequent stressor exposure could disrupt and delay emotional recovery. Work by Schilling and Diehl (2014) has examined the accumulation of stressor exposures across days on mood, but there is scant information available on the possible compounding effects of multiple stressors within a day. This is an important issue for future research.

Despite these limitations, this study provides a step forward in operationalizing predictions of stress and emotional aging theory. Specifically, we found support for SAVI predictions that younger and older people had similar initial reactivity to stressors but that older adults had more emotional recovery as time passed from the event. Additionally, we found evidence that the effects of these minor stressors extend at least 5 hr, potentially longer, after the event. These findings provide a more refined time course of emotional responses to stressors. Studies of this kind, which disentangle differences in the magnitude of reactivity from the duration of the recovery response are the crucial next steps in linking stress-related emotional responses to long-term physical and mental health.

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