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An Investigation into the Impact of Acute Stress on Encoding in Older Adults

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Abstract

Instances of acute psychological stress are a common occurrence in the daily lives of both young and older adults. Though a wealth of research has examined the influence of psychological stress on how young adults learn new information, the present study is the first to directly examine these effects in older adults. Fifty older adults (*M* age = 71.9) were subjected to either stress induction or a control task prior to learning two types of information: a short video depicting criminal activity, and a series of pictures. Twenty-four hr later, they were exposed to misleading information about the video and then completed memory tests for the video and pictures. Pre- and post-stress measures of heart rate and cortisol suggest that a physiological stress response was successfully induced. Though pre-encoding stress had a minimal impact on memory for the video and pictures, stress did influence errors of omission on the cued recall test for the video. Findings are discussed in the context of previous research examining the effects of stress on memory in older adults.

Keywords: *stress, aging, older adults, eyewitness memory, misinformation paradigm*

Introduction

Research into how acute stress impacts learning and memory in older adults is limited. Whereas cognitive aging researchers have developed strong models to predict memory changes across the lifespan, it remains unclear how acute stress may influence well-established patterns of age-related memory decline. In the present study, we examined the ways in which stress influences how older adults learn new information. We explored the effects of acute psychological stress on encoding in older adults in the context of two different memory tasks: an eyewitness-memory task and a memory-for pictures task.

Though few studies have examined the influence of stress on encoding in older adults, several studies have been conducted with young adult participants (see Shields, Sazma, McCullough, & Yonelinas, 2017). Across these experiments, mixed results have been found. Studies have reported either detrimental effects of pre-encoding stress on young adults' memory (e.g., Maheu, Collicutt, Kornik, Moszkowski, & Lupien, 2005; Payne et al., 2007; Quaedflieg, Schwabe, Meyer, & Smeets, 2013; Zoladz et al., 2012), null effects (e.g., Domes, Heinrichs, Rimmele, Reichwald, & Hautzinger, 2004; Hidalgo et al., 2012; Smeets, Otgaar, Candel, & Wolf, 2008), or positive effects (e.g., Cornelisse, van Stegeren, & Joëls, 2011; Payne et al., 2007; Schwabe, Bohringer, Chatterjee, & Schachinger, 2008). A recent meta-analysis revealed two potential moderators of the effects of stress on encoding: the relevance of the to-be-remembered stimuli to the source of stress, and the temporal proximity of the stressor relative to the onset of encoding (Shields et al., 2017). That is, stimuli that are related to the stressor are likely to be well-learned in the context of stress. For example, participants who gave a videotaped speech in front of a panel of stern judges showed better memory for the judges' faces than a non-stressed control group, but similar memory for objects in the periphery of the room (Wiemers, Sauvage, Schoofs, Hamacher-Dang, & Wolf, 2013). Further, encoding may be enhanced during a brief interval (< 10 min) after the onset of stress during sympathetic arousal, but impaired when it occurs several min (> 22 min) post-stress when cortisol levels peak in response to the stressor (Shields et al., 2017).

Far fewer studies have examined the influence of stress on encoding in older adults. In the only studies that have been conducted, researchers induced stress prior to a learning task that was immediately followed by retrieval (Bohnen, Houx, Nicolson, & Jolles, 1990; Domes, Heinrichs, Reichwald, & Hautzinger, 2002; Hidalgo, Almela, Villada, & Salvador, 2014; Wolf, Kudielka, Hellhammer, Hellhammer, & Kirschbaum, 1998). Two experiments reported detrimental effects of pre-encoding stress on recall (Hidalgo et al., 2014; Wolf et al., 1998), and two found null effects (Bohnen et al., 1990; Domes et al., 2002). However, any effects of stress on memory performance in these studies cannot be attributed to the specific influence of stress on encoding. Because stress continues to influence cognition for up to 90 min after induction (Gagnon & Wagner, 2016), both encoding and retrieval occurred in the context of a stress response in these previous experiments. Thus, there has been no research to date that has investigated the effects of stress on encoding in a paradigm that decouples encoding and retrieval. Further, the prior studies used verbal learning paradigms and therefore the influence of stress on the encoding of a more complex event is yet to be determined.

To examine the influence of stress on the learning of a complex event, in addition to a standard image-learning paradigm, we used the misinformation paradigm (Loftus, Miller, & Burns, 1974). In typical misinformation experiments, participants witness an event and after a delay are exposed to misleading post-event information, typically in the form of a written synopsis of the event. After misinformation presentation, memory for the original event is assessed. Many prior studies have pitted young adult performance against older adult performance in both picture-learning paradigms and the misinformation paradigm. In standard picture-learning and verbal-learning paradigms, older adults generally perform similarly to young adults on recognition tests but remember fewer items on tests of free recall (see Craik, 1994). In the misinformation paradigm, older adults are typically more susceptible to post-event misleading information than young adults (Auslander, Thomas, & Gutchess, 2017; Bulevich & Thomas, 2012; Cohen & Faulkner, 1989; Coxon & Valentine, 1997; Karpel, Hoyer, & Toglia, 2001; Mitchell, Johnson, & Mather, 2003; Roediger & Geraci, 2007). That is, after misleading information has been presented, older adults are less likely to correctly remember details from the witnessed event and more likely to produce or accept misinformation on a final test of memory. Because robust norms regarding age-related changes in memory have already been established, the present research focused solely on the older adult population and how stressed older adults might encode information differently than their non-stressed peers.

Predictions regarding the effects of stress on encoding in older adults can be largely based on the influence of the physiological stress response on neural processing. Psychological stress activates the sympathetic-adrenal-medullary (SAM) axis, prompting the surge of catecholamines that characterizes the fight-or-flight response, and the hypothalamic-pituitary-adrenal (HPA) axis, resulting in the gradual secretion of the stress hormone cortisol. Whereas the SAM axis response occurs immediately post-stress, the HPA axis response takes 20-30 min to yield peak post-stress cortisol levels (Kirschbaum, Pirke, & Hellhammer, 1993). Due to their high density of glucocorticoid (i.e., cortisol) receptors, learning-related brain regions such as the hippocampus (Diamond et al., 2006) and pre-frontal cortex (PFC) (Gärtner, Rohde-Liebenau, Grimm, & Bajbouj, 2014; Maroun & Richter-Levin, 2003; Qin et al., 2009) experience impaired processing when cortisol levels are elevated in response to stress. Thus, older adults who experience pre-encoding stress may be predicted to demonstrate poorer memory performance than their non-stressed counterparts.

However, neural and behavioral evidence from studies conducted with older adults supports a null hypothesis regarding the effects of pre-encoding stress on older adults' memory performance. In the majority of studies that examined the effects of stress on any phase of memory in older adults, stress had no impact. These null results were not due to an inadequate cortisol response to stress induction (e.g., Hidalgo et al., 2015; Pulopulos et al., 2013; Wolf et al., 1998). Rather, they have been attributed to neural changes associated with aging (see Pulopulos et al., 2013). In particular, reductions in the density and sensitivity of glucocorticoid receptors in the hippocampus and PFC may leave the older adult brain less sensitive to stress-related cortisol increases (Bhatnagar et al., 1997; Heffelfinger & Newcomer, 2001; Mizoguchi et al., 2009; Newcomer, Selke, Kelly, Paras, & Craft, 1995). Additionally, older adults show reduced communication between the amygdala and hippocampus (St. Jacques, Dolcos, & Cabeza, 2009), a pathway for which increased activity is associated with stress-related memory changes in young adults (Roozendaal, McEwen, & Chattarji, 2009).

In the present experiment, we aimed to isolate the effects of acute psychological stress on the encoding phase of memory in older adults. It should be noted that stress induced before encoding incidentally influences the early consolidation of memories, and so a pure isolation of stress at encoding was not methodologically possible. In the first study of this nature, we induced stress prior to the learning phase and tested memory 24 hr later. Further, we examined these effects in the context of two memory paradigms: an image-learning paradigm and the misinformation paradigm. To that end, older adult participants underwent the stress-induction or control protocol associated with the Trier Social Stress Test (TSST; Kirschbaum et al., 1993) prior to learning a series of images and watching a video depicting a crime. A day later, participants were exposed to misleading information about the video, and then completed memory tests for the images and events depicted in the video. Due to the lack of previous research on the topic, we considered this experiment exploratory. However, considering the null effects reported across previous studies examining stress and cognition in older adults, we anticipated that stress would similarly have little impact on encoding.

Method

Participants

Fifty older adults participated in the experiment. Participants were selected from a pre-established participation pool maintained by the Cognitive Aging and Memory Laboratory at Tufts University and were paid $40 for their participation (M_{age} = 71.90, SD_{age} = 5.99, age range = 58-86, Female = 35). To be a member of the participant pool, older adults were prescreened for psychological and neurological health issues. Participants were excluded from the pool if they indicated that they were currently taking antidepressants, drugs with anticholinergic properties, benzodiazepines, opiates, and/or anticonvulsants. Participants were instructed to avoid eating, drinking, or taking medicine in the 1 hr prior to each experimental session. Participants were further told to refrain from consuming caffeine on each day of the experiment.

Twenty-five older adults were randomly assigned to the no-stress control group and 25 older adults were randomly assigned to the stress group. Random assignment was conducted by running a given participant through whichever condition (stress or control) was not run in the prior session. All participants completed the Vocabulary Subtest of the Shipley Institute of Living Scale 2 (Shipley, 1946), which serves as a measure of older adults' verbal abilities. The test presents participants with 20 words of increasing difficulty, and participants must choose the closest synonym for each word out of a set of six alternatives. The test is used to confirm that participants have a basic command over the English language, and to check that verbal abilities do not differ across experimental groups. Indeed, verbal performance did not differ across the stress and control groups, $t(48) = 0.63$, $p = .535$ ($M_{\text{Control}} = 15.16$, $SD_{\text{Control}} = 2.29$; $M_{\text{Stress}} = 14.80$, $SD_{\text{Stress}} = 1.76$). Similarly, older adults in the stress and control groups did not differ according to age, $t(47) = 1.94$, $p = .058$ ($M_{\text{Control}} = 70.25$, $SD_{\text{Control}} = 6.10$; $M_{\text{Stress}} = 73.48$, $SD_{\text{Stress}} = 5.55$), or total years of completed education, not including kindergarten, $t(48) = 0.47$, $p = .642$ ($M_{\text{Control}} = 17.68$, $SD_{\text{Control}} = 3.30$; $M_{\text{Stress}} = 17.28$, $SD_{\text{Stress}} = 2.72$).

Design

The experiment employed a mixed factorial design. We manipulated TSST Group (control, stress) between-subjects. We also manipulated two within-subjects variables. To examine the influence of stress on the learning of misinformation, we manipulated Item Type (consistent, neutral, or misleading) in the context of the post-event synopsis. To examine whether the formation of episodic memories is differentially influenced by the immediate (SAM axis) versus the delayed (HPA axis) stress response, we manipulated the timing of the image learning sessions (immediately post-TSST, 25 min post-TSST).

Materials

Images. Thirty nouns of negative valence (e.g., snake) were presented as images. Negatively-valenced stimuli were chosen to increase memorability. The stimuli were borrowed from the Snodgrass and Vanderwart (1980) norms, and featured an average valence rating of 2.98 ($SD = 0.61$) on a 1 (negative) to 10 (positive) scale. All images were semantically distinct.

Video. To simulate the witnessing of a crime, participants watched a 25-min episode of the Canadian television series *Flashpoint*. The video featured a bank robbery being carried out by one of the bank's former employees.

Anxiety Questionnaire. We administered the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA) to assess participants' self-reported levels of anxiety at various points throughout the experiment (Grös, Antony, Simms, & McCabe, 2007). STICSA scores range from 0-80 and higher scores are indicative of higher self-reported anxiety.

Empatica E4 Wristbands. Heart rate was measured continuously throughout the experiment using Empatica E4 wristbands (see www.empatica.com), which reliably estimate average beats per min (BPM; Ollander, Godin, Campagne, & Charbonnier, 2016; Ragot, Martin, Em, Pallamin, & Diverrez, 2018).

Procedure

Testing sessions occurred on two consecutive days between 8:00AM. and 12:00PM. Eight sessions began between 8:00AM and 9:00AM, 15 began between 9:00AM and 10:00AM, 16 began between 10:00AM and 11:00AM, and 11 began between 11:00AM and 12:00PM. On average, the control group started the experiment at 9:42AM (*SD* = 56 min) and the stress group started at 10:08AM (*SD* = 57 min). Start times did not differ for the two groups, $t(48) = 1.64$, $p = .107$. Although morning testing is discouraged because cortisol levels are naturally elevated in the morning (Weitzman et al., 1971), we chose this testing schedule because it best accommodated the schedules of our older adult participants and because older adults demonstrate their best cognitive performance in the morning (Anderson, Campbell, Amer, Grady, & Hasher, 2014). Further, we did not expect morning testing to interfere with our ability to detect effects of stress because previous studies have found stress effects on memory when participants were tested in the morning (e.g., Kuhlmann, Piel, & Wolf, 2005; Oei, Everaerd, Elzinga, van Well, & Bermond, 2006). All participants were tested individually.

Day 1. We refer the reader to Figure 1 for a graphic depiction of the following procedures. After providing informed consent, participants rinsed their mouth out with water in preparation for providing saliva samples. They then watched 7 min of a relaxation video featuring calm music and scenic photographs (https://www.youtube.com/watch?v=tq75nkjL6a8). The video was intended to reduce any anxiety that participants may have experienced prior to arriving at the lab. After the video, participants rested in silence for 1 min while resting heart rate was assessed.

All participants were then given 5 min for speech preparation, which was framed as a non-stressful creative-writing task. They were given a pen and paper and were instructed to prepare a speech in which they were applying for a hypothetical position as an instructor for any course of their choice. They were told that this task was an exercise to get them "warmed up" for upcoming creative thinking tasks, and that the speech would not be read by the experiments or used during any part of the experiment thereafter. It should be noted that, in the standard TSST paradigm, the speech preparation phase is included as part of the stress-induction procedure (Kirschbaum et al., 1993). However, we modified the TSST such that stress induction did not begin until the next phase in which participants deliver their speeches. This modification allowed us to keep the stress induction phase shorter than usual (approximately 6 min versus the usual 12 min) so that we could manipulate the learning of information during the 0-10 min window after the onset of stress when catecholamine levels are high but cortisol is still relatively low. After the "creative writing" speech preparation phase, participants' notes were collected. They then provided the first saliva sample and completed the first STICSA as pre-TSST measures of stress.

Participants next completed either the stress or control tasks associated with our modified version of the TSST (Kirschbaum et al., 1993). Those in the stress group delivered their speeches extemporaneously for 3 min and then solved difficult math subtraction problems aloud (e.g., 4,682 – 17) for 3 min. When participants answered a math problem incorrectly, they were instructed to try again until they reported the correct answer. During the speech and math phases, participants were videotaped and the experimenter appeared to be taking notes on a clipboard. Prior to giving their speeches, participants were told that these tasks were designed to evaluate their public speaking skills, memory, and math abilities. In the time-matched control group, participants read silently from a biology textbook for 3 min and then solved the same math subtraction problems using pen and paper. They were told that their memory for the textbook reading would not be tested, and that their answers to the math problems would not be graded. Further, participants in the control group were not videotaped or monitored by the experimenter during these tasks. Following the TSST, all participants completed the second STICSA.

Participants then completed the first image-learning task, which was placed approximately 8 min after the onset of stress to determine how the SAM axis stress response influences the formation of episodic memories. Participants were randomly presented with 15 of the 30 images described in the materials section, at a rate of 4 s per image. The set of 15 images was presented three times over, with 15 s breaks between each round. This task took approximately 4 min. A 10-min retention interval followed, in which participants completed the vocabulary test and made origami figures with the help of the experimenter. To measure cortisol at its peak post-stress level (i.e., 25 min post-stress; Kirschbaum et al., 1993), participants next provided the second saliva sample.

Participants then viewed the *Flashpoint* video described in the materials section. Our primary goal in this experiment was to determine how the cortisol response to stress influences the encoding of a witnessed crime. Thus, the start of the video was timed to occur as cortisol reached peak levels for individuals in the stress group. It should be noted that post-stress cortisol levels remain elevated for at least 90 min after a stressful event (see Gagnon & Wagner, 2016), and thus it is likely that stressed participants encoded the entire video under conditions of heightened cortisol.

Finally, participants completed a second image-learning task. This task was identical to the first, but presented 15 new images. Participants were then paid and excused. The day 1 experimental procedure took approximately 1 hr 10 min.

Day 2. Twenty-four hr later, participants returned to the same lab room. They again watched 7 min of a relaxation video (https://www.youtube.com/watch?v=Dsxv3z55lys). Afterward, participants completed a STICSA, gave the final saliva sample, and sat quietly for 1 min while their resting heart rate was assessed.

Participants were next presented with a written synopsis of the video (borrowed from LaPaglia & Chan, 2013). They were instructed to read the synopsis, and to take as much time as they needed. The synopsis (1,025 words) introduced six specific details that were consistent with what was presented in the video (e.g., *seven* people lost their jobs), six details that were non-specific (e.g., people lost their jobs), and six specific details that were inconsistent with the video (e.g., *twelve* people lost their jobs). All other sentences were used for filler and contained information that was never assessed on the subsequent cued recall test. The 18 sentences that presented consistent, neutral, and inconsistent details were counterbalanced across participants. Participants took, on average, 4 min 54 s to read the synopsis.

Following the synopsis, participants were given 3 min to take a free recall memory test for the images they studied on the previous day. They were instructed to recall as many images as they could from either of the image-learning phases and they were not asked to determine which of the two learning sessions each item came from. To avoid illegible handwriting, participants spoke their answers aloud and the experimenter recorded their responses. During a subsequent 5 min break, participants made origami figures.

Finally, participants completed a self-paced cued recall test for the information they learned in the video on day 1. They were instructed to answer questions based solely on their memory of the video, and to leave answers blank when they could not remember a detail. The test consisted of 18 questions: six questions probed for the consistent details presented in the synopsis, six probed for neutral details, and six probed for misleading details. Questions were always presented in the same order, and no feedback regarding correctness was provided. Test questions had been previously validated for effectiveness at eliciting misleading details (LaPaglia & Chan, 2013). To avoid issues of computer illiteracy, participants spoke their answers aloud and the experimenter typed their responses.

Last, participants were paid, debriefed, and excused. The day 2 experimental procedure took approximately 40 min. Both the image-learning tasks (day 1) and the cued recall test (day 2) were presented using E-Prime software (Version 2.1; Schneider, Eschman, & Zuccolotto, 2001).

Physiological Data Measurement

Heart rate was measured in average BPM. We used the MATLAB Kubios software package (see http://kubios.uef.fi/) to compute each participant’s average BPM over the span of the 1-min resting baseline measurement taken at the beginning of day 1 and over the span of the 6-min TSST task.

Saliva samples were collected using the oral swab method (www.salimetrics.com) and were stored at -20ºC until the completion of data collection. At the time of analysis, samples were brought to room temperature and were subjected to a radioimmunoassay using Corti-Cote RIA kits from MP Biomedicals (www.mpbio.com). Samples were assayed in duplicate, and the mean cortisol concentration in nmol/L served as the dependent measure. The inter-assay and intra-assay coefficients of variability were 15.82% and 10.33%, respectively. Because several participants provided insufficient saliva samples, the subsequent analyses were limited to 25 older adults (13 control, 12 stress).

Statistical Analyses

Mixed-model ANOVAs and *t* tests were used to examine our dependent measures. Alpha was set at 0.05 for all analyses, and significant results were followed up with effect size calculations and Bonferroni-corrected post-hoc tests (when appropriate). Effect sizes were calculated using η_p^2 ($SS_{effect}/(SS_{effect} + SS_{error})$) and Cohen's *d* ($(M_2 - M_1) / SD_{pooled}$). When comparing two within-subjects means, we adjusted Cohen's *d* using Morris and DeShon's (2002) equation 8, which incorporates the correlation between repeated measures.

Results

Physiological Arousal

Day 1. We conducted a 2 (TSST Group: control, stress) x 2 (Time: baseline, during the TSST) mixed ANOVA on average BPM to determine whether the stress group experienced an increase in heart rate during the TSST. Indeed, we found a significant TSST Group x Time interaction as stressed participants demonstrated higher BPM during the TSST (*M* = 85.32) than during baseline (*M* = 73.88), whereas those in the control group showed no difference between the baseline (*M* = 76.82) and TSST (*M* = 78.52) measurements, *F*(1, 43) = 10.71, *p* = .002, η_p^2 = .20.

Because our cortisol samples were reduced in number, we next conducted separate paired-samples *t* tests for the stress and control groups, comparing baseline average cortisol concentrations to those taken after the TSST. As expected, the stress group demonstrated significantly higher post-TSST cortisol (*M* = 17.30 nmol/L) as compared to baseline (*M* = 5.21 nmol/L), *t*(11) = 1.86, *p* = .045, *d* = 0.61. The control group demonstrated no such differences between baseline (*M* = 8.49 nmol/L) and post-TSST (*M* = 10.84 nmol/L) cortisol, *t*(12) = 1.06, *p* = .309.

Day 2. To validate our assumption that participants were not stressed when they returned to the lab on the second day for memory testing, we examined participants' baseline heart rate, STICSA scores, and cortisol on day 2. Independent samples *t* tests comparing the control group to the stress group confirmed that there were no differences in average BPM, *t*(38) = 0.83, *p* = .413, STICSA scores, *t*(48) = 0.59, *p* = .558, or cortisol, *t*(36) = 0.49, *p* = .624, between the two groups.

Self-reported Stress

We conducted a 2 (TSST Group: control, stress) x 2 (Time: baseline, post-TSST) mixed ANOVA to test whether the TSST tasks differentially increased subjective anxiety for the stress and control groups. In contrast to our predictions, the TSST Group x Time interaction was not significant. Rather, the only significant result was a main effect of Time, such that participants reported higher pre-TSST (*M* = 27.0) than post-TSST (*M* = 26.0) STICSA scores across groups, *F*(1, 47) = 11.32, *p* = .002, η_p^2 = .19. These results are not entirely surprising, as older adults sometimes do not report feeling stressed even when measures of physiological arousal suggest otherwise (e.g., Pulopulos et al., 2015).

Image Recall

We conducted a 2 (TSST Group: control, stress) x 2 (Learning Session: immediately post-TSST, 25 min post-TSST) mixed ANOVA to determine whether image recall differed as a function of when images were learned after the onset of stress. We found a main effect of Learning Session, $F(1, 48) = 4.45$, $p = .040$, $\eta_p^2 = .09$, showing that participants recalled fewer images from the learning session that occurred 25 min after the onset of the TSST ($M = 5.4$) than the learning session that occurred immediately after the TSST ($M = 6.4$). No other effects were significant, suggesting that stress induction did not influence recall performance. Means and standard errors are presented in Table 1.

Video Recall

Accuracy. We examined the average proportion of accurate responses on the video cued recall test via a 2 (TSST Group: control, stress) x 3 (Item Type: consistent, neutral, misleading) mixed ANOVA. We found a main effect of Item Type, $F(2, 47) = 257.08$, $p < .001$, $\eta_p^2 = .92$. Participants demonstrated the highest rates of accurate recall for details from the synopsis that were presented in a manner consistent with the video ($M = .84$), followed by neutral details that were not specified in the synopsis ($M = .31$) and misleading details that presented false information ($M = .21$). All pairwise comparisons among the item types were significant (consistent-neutral: $t(49) = 18.60$, $p < .001$, $d = 2.66$; consistent-misleading: $t(49) = 20.92$, $p < .001$, $d = 2.97$; neutral-misleading: $t(49) = 3.50$, $p = .001$, $d = 0.50$). All other effects were non-significant. See Table 2 for means and standard errors.

Misinformation production. In the misinformation paradigm, the production of misinformation from the synopsis is expected on misleading trials. However, on consistent and neutral trials, participants sometimes inadvertently guess the misleading answer even though they were not exposed to it in the synopsis. We thus examined whether the production of misleading details would differ across the three trial types, with the expectation that production would be highest on misleading trials. We conducted a 2 (TSST Group: control, stress) x 3 (Item Type: consistent, neutral, misleading) mixed ANOVA with average proportion of misinformation produced as the dependent variable. This analysis found a main effect of item type, $F(2, 47) = 86.51$, $p < .001$, $\eta_p^2 = .79$. As expected, participants produced the most misinformation on misleading trials ($M = .40$), followed by neutral ($M = .11$) and consistent ($M = .00$) trials (consistent-neutral: $t(49) = 6.49$, $p < .001$, $d = 0.92$; consistent-misleading: $t(49) = 12.66$, $p < .001$, $d = 1.79$; neutral-misleading: $t(49) = 8.60$, $p < .001$, $d = 1.24$). All other effects were non-significant. See Table 2 for means and standard errors.

Errors of Omission. We next examined the influence of stress on errors of omission (i.e., when answers were left blank). Recent research examined how being confronted with ageist stereotypes about memory influences misinformation production in older adults (Thomas, Smith, & Mazerolle, 2018). While accuracy and production were unaffected by stereotyping, Thomas et al. (2018) found that older adults were more likely to leave answers blank after being confronted with ageist stereotypes about memory. Because the act of giving a speech and solving math problems in front of a young adult experimenter could induce stereotype threat, we aimed to determine whether older adults would similarly withhold responses in the TSST stress paradigm.

Average proportions of omission errors were subjected to a 2 (TSST Group: control, stress) x 2 (Item Type: neutral, misleading) mixed ANOVA. Note that consistent items were not examined in this analysis because errors of omission on consistent trials were at floor levels. Most notably, the analysis on errors of omission found a significant interaction between Item Type and TSST Group, $F(1, 48) = 6.40$, $p = .015$, $\eta_p^2 = .12$. As depicted in Figure 2, stressed participants left more items blank on neutral trials ($M = .39$) than on misleading trials ($M = .21$), whereas those in the control group demonstrated no differences on neutral ($M = .25$) versus misleading trials ($M = .19$). We also found a main effect of Item Type, $F(1, 48) = 20.70$, $p < .001$, $\eta_p^2 = .30$, as participants left more answers blank on neutral trials ($M = .32$) than on misleading trials ($M = .20$). All other effects were non-significant.

To further examine whether the effects of stress on errors of omission were due to changes in cortisol, we conducted bivariate correlations (Pearson's *r*) to examine the relationship between participants' cortisol reactivity to the TSST (delta cortisol) and errors of omission on neutral and misleading trials. Participants did not demonstrate a relationship between change in cortisol and errors of omission on neutral trials, $r(25) = -0.12$, $p = .564$, or misleading trials, $r(25) = -0.25$, $p = .227$. However, given our reduced number of cortisol samples, this analysis should not be considered conclusive evidence that cortisol did not influence the pattern of omission results.

Discussion

In the present study, we investigated the influence of acute psychological stress on the encoding of a witnessed criminal event and a series of images in a sample of older adults. Consistent with our hypothesis, our results suggest that stress had a minimal impact on encoding. We did not observe any effects of pre-encoding stress on free recall of images and, with the exception of the analysis on errors of omission, did not find stress effects on the cued recall test for the video. It should be noted that measures of heart rate and cortisol suggest that participants in the stress group did experience a physiological stress response, and thus these findings likely are not due to an ineffective stress induction procedure.

The minimal impact of stress on encoding in the present study is well-supported by previous literature. In the few experiments that have been conducted with older adults, null effects of stress have commonly been found both when stress was induced prior to a combined encoding/retrieval task (Bohnen et al., 1990; Domes et al., 2002) and when stress was induced after encoding but prior to retrieval (Hidalgo et al., 2015; Pulopulos et al., 2013). The present results are the first to extend these null findings to a paradigm in which stress was only present during encoding. Further, this study is the first to demonstrate null effects of stress in the context of a complex eyewitness event.

The misinformation paradigm offered a unique opportunity to examine the influence of stress on learning. Encoding the criminal events depicted in the video is a more complex and potentially more emotionally arousing experience than studying the wordlists that are typically used in experiments on stress and memory. Because stress can bias attention toward emotionally salient stimuli (see Christianson, 1992), in the misinformation paradigm, stress prior to encoding has the potential to enhance learning of the information in the video. Further, by enhancing memory for the video, pre-encoding stress could help improve subsequent source monitoring and reduce susceptibility to misinformation from the synopsis. Consistent with this idea, in studies with young adults, researchers have found that stress prior to a witnessed event both improved memory accuracy (Hoscheidt, LaBar, Ryan, Jacobs, & Nadel, 2014) and reduced susceptibility to post-event misinformation (Hoscheidt et al., 2014; Zoladz et al., 2017). However, no such effects were found in the present study. As previously discussed, aging is associated with neural changes that result in reduced sensitivity to stress (Bhatnagar et al., 1997; Heffelfinger &

Newcomer, 2001; Mizoguchi et al., 2009; Newcomer et al., 1995). While the young adult brain may benefit from stress that occurs prior to witnessing a criminal event, the older adult brain may no longer feature the neural connections that facilitate that enhancement. In light of age-related neural changes and the null results of previous studies examining stress in older adults, it is not surprising that stress did not influence memory accuracy or misinformation production in the present experiment.

Interestingly, stress did influence errors of omission on the video cued recall test. This finding is consistent with recent research in which older adults who were exposed to negative stereotypes about aging withheld more answers on an eyewitness memory test than those who were not stereotyped (Thomas et al., 2018). In an eyewitness paradigm, acute psychological stress and stereotype threat may work via similar mechanisms. Socio-evaluative threats such as being stereotyped or judged on one's public speaking abilities may not necessarily impair eyewitness memory in older adults, but may encourage individuals to exercise caution when recounting witnessed events.

As Figure 2 depicts, the interaction between stress group and item type on errors of omission was driven by stressed participants leaving a disproportionate number of items blank on neutral trials. This pattern of withholding responses suggests that pre-encoding stress influenced participants' ability to remember the information from neutral trials and/or influenced their certainty in their memory for these trials. Of relevance to this hypothesis is the fact that the video synopsis that was presented prior to the cued recall test prompted participants to remember details associated with consistent and misleading items, but did not provide detailed information for neutral items. This is a crucial design element in misinformation studies, because memory for items that are not presented in the narrative demonstrate memory for the original event in the absence of restudy or interference. The fact that stressed participants left more items blank on neutral trials suggests that, in the absence of a reminder like that which was given for consistent trials, they were either less able to recall information from the video or were less willing to report their memory for the video. Although we cannot distinguish between these two possibilities, we argue that it is more likely that stressed participants intentionally withheld responses. Consider that stress occurred prior to encoding of the video, and that only information from consistent trials was accurately recounted in the synopsis the next day. If stress had impaired encoding of the video, then high errors of omission on both neutral and misleading trials should have resulted. Further, stress-related memory inaccessibility should have yielded an increase in incorporation of the misinformation from the synopsis into memory on misleading trials. Since this was not the case, it is more plausible that pre-encoding stress reduced participants' certainty in their memories on trials in which the synopsis did not prompt them to recall specific details from the video. Though this interpretation is speculative, it raises the question of whether the detrimental effects of pre-encoding stress on free recall that have been reported in the young adult literature (e.g., Maheu et al., 2005; Quaedflieg et al., 2013; Zoladz et al., 2012) were due to encoding deficiencies, as has been reported, or intentional withholding at retrieval. Future research is necessary to disentangle the influence of pre-encoding stress on memory accessibility and response withholding in both young and older adults.

Although the mechanism underlying the limited influence of stress on encoding is not yet fully understood, one theory posits that stress initially places the brain into a "memory formation mode" that enhances the encoding and consolidation of information that is relevant to the stressor (Schwabe, Joels, Roozendaal, Wolf, & Oitzl, 2012; see also Shields et al., 2017). This mode is characterized by neural processing that prioritizes storing memories of the recent stressful episode, while suppressing neural pathways involved in the retrieval of irrelevant information. When stress precedes an unrelated learning event (i.e., a video of a crime), it is possible that the memory formation mode neither enhances nor impedes encoding of that event because the event is neither relevant to the stressor nor subject to the deleterious impact of stress on retrieval. An important next step in research will be to examine whether stress influences how older adults learn information that is relevant to the stressor. This would be particularly important to examine in the context of an eyewitness memory paradigm, since the source of stress (i.e., the crime) is directly relevant to the encoded event.

The results of the present study are limited by a moderate-sized sample and a lack of cortisol data for all participants. A few previous studies examining the impact of stress on cognition in older adults have reported a moderating influence of gender that resulted from differences in cortisol reactivity to stress (Almela et al., 2011; Pulopulos et al., 2015). Future researchers should make an effort to recruit large, gender-diverse older adult samples so that these effects can be examined in the context of a pre-encoding stress paradigm. The present study was also limited by a relatively short habituation phase when participants first entered the laboratory for each experimental session. Ideally, participants could relax and habituate to the lab environment for up to 90 min (Gagnon & Wagner, 2016) to ensure that cortisol levels could return to baseline prior to experimentation. That said, any cortisol-elevating events that older adults experienced prior to experimentation were likely equated across the stress and control groups through random assignment. A final limitation to note is the lack of a young adult comparison group in this experiment. A young adult group would be beneficial for validating our modified version of the TSST and for making cross-generational comparisons.

In conclusion, in the first study to isolate the influence of psychological stress on the encoding of information in older adults, we found a minimal impact of stress. Pre-encoding stress did not influence memory for pictures or the typical measures of memory accuracy and production in the misinformation paradigm. However, stress may have made older adults more cautious when reporting their memories of the witnessed event. The present study examined the effects of pre-encoding stress in the context of just two paradigms. Thus, future research is necessary to establish a consensus regarding the influence of stress on encoding in older adults. Of further importance is to establish whether laboratory stressors affect encoding differently than real-world stressors, given that these forms of stress have been shown to differentially affect physiological arousal (Segerstrom & Miller, 2004). Understanding how stress and age impact our ability to learn new information is important for both advancing scientific knowledge and informing the broader public about the potential consequences of stress.

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Table 1

Average numbers of images accurately recalled on day 2. Fifteen images were learned immediately after the TSST and 15 images were learned 25 min after the TSST on day 1. Standard errors of the mean are in parentheses.

	Immediately Post-TSST	25 Min Post-TSST
Control	6.68 (*.51*)	5.20 (*.70*)
Stress	6.16 (*.70*)	5.68 (*.71*)

Table 2

Average proportions of accurate responses and misinformation production on the cued recall test on day 2. Responses are organized by question type. Questions were presented in the synopsis in a manner that was consistent, neutral, or misleading with respect to the video. Standard errors of the mean are in parentheses.

	Accuracy			Production		
	Consistent	Neutral	Misleading	Consistent	Neutral	Misleading
Control	.87 (*.02*)	.32 (*.03*)	.20 (*.03*)	.00 (*.00*)	.11 (*.02*)	.39 (*.04*)
Stress	.81 (*.04*)	.31 (*.04*)	.23 (*.04*)	.00 (*.00*)	.12 (*.03*)	.41 (*.05*)

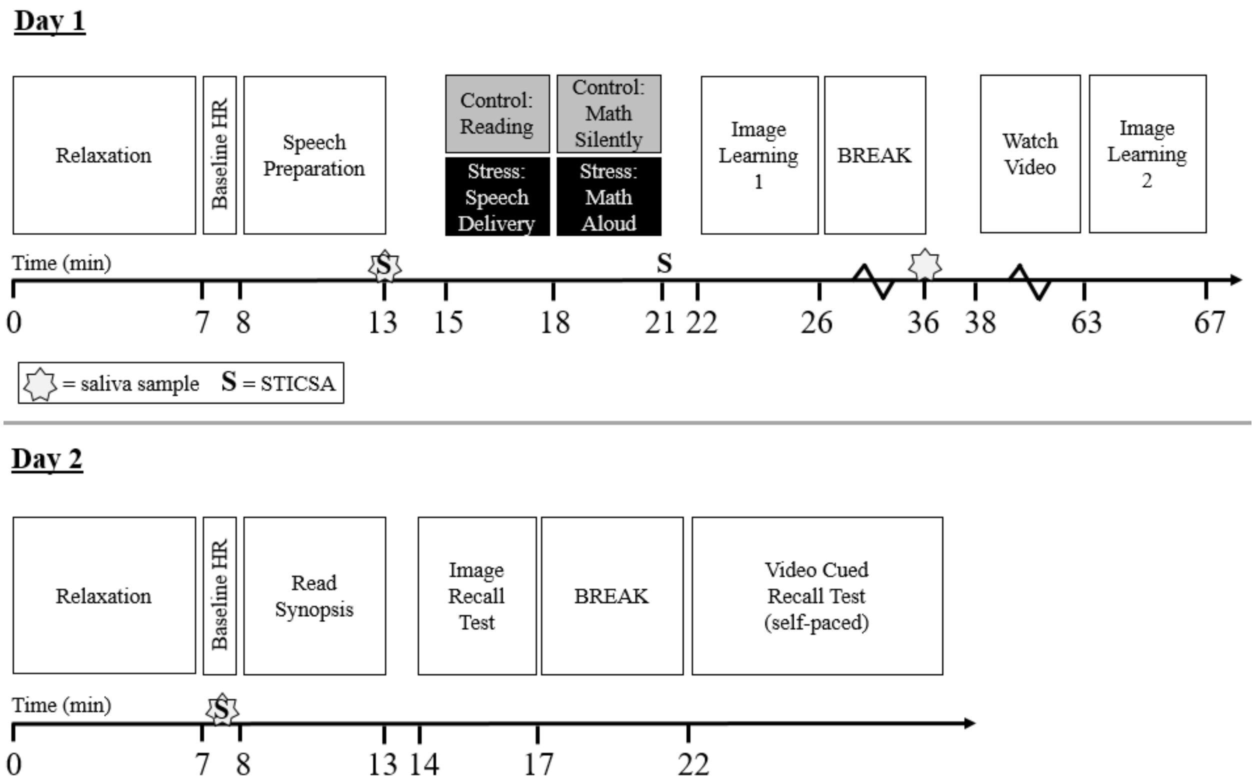

Figure 1. A graphic depiction of the experimental procedure. Heart rate is denoted as HR.

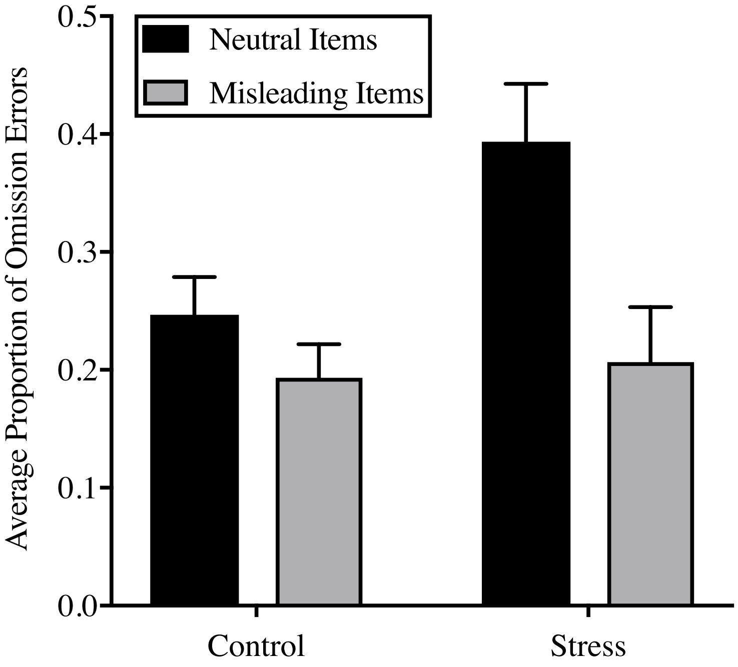

Figure 2. Average proportions of omission errors on neutral and misleading trials for participants in the control and stress groups. Means represent data collapsed across age group, and error bars represent *SEM*. Note that consistent items are not depicted because errors of omission were at floor levels on consistent trials.