Title: Effects of stress on 6-to-7-year-old children's emotional memory differs by gender

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Abstract

Understanding effects of emotional valence and stress on children's memory is important for educational and legal contexts. This study disentangles the effects of emotional content of to-be-remembered information (*i.e.,* items differing in emotional valence and arousal), stress exposure, and associated cortisol secretion on children's memory. We also examine whether girls' memory is more affected by stress induction. 143 6-to-7-year-old children were randomly allocated to the Trier Social Stress Test for Children (n = 103) or a control condition (n = 40). 25 minutes after stressor onset, children incidentally encoded 75 objects varying in emotional valence (crossed with arousal) together with neutral scene backgrounds. We found that response-bias corrected memory was worse for low arousing negative items than neutral and positive items, with the latter two categories not being different from each other. Whilst boys' memory was largely unaffected by stress, girls in the stress condition showed worse memory for negative items, especially the low arousing ones, than girls in the control condition. Girls, compared to boys, reported higher subjective stress increases following stress exposure, and had higher cortisol stress responses. Whilst a higher cortisol stress response was associated with better emotional memory in girls in the stress condition, boys' memory was not associated with their cortisol secretion. Taken together, our study suggests that 6-to-7-year-old children, more so girls, show memory suppression for negative information. Girls' memory for negative information, compared to boys, is also more strongly modulated by stress experience and the associated cortisol response.

Keywords: emotional memory; stress; cortisol secretion; children

Introduction

Understanding the mechanisms involved in children's emotional memory processing and its susceptibility to stress has implications for educational settings (*e.g.,* when to-be-learned material is emotional in nature) and legal environments (e.g., reliability of eyewitness testimony of stressful events). Yet, it remains largely elusive how emotional content of to-be-remembered information and stress at encoding contribute to children's memory. In this study, we experimentally examined how early school-aged children's memory for object content and context is modulated by emotional valence of the content, psychosocial stress exposure before encoding, and cortisol secretion. Given previous evidence that suggests girls are more reactive to acute stress than boys (Hostinar et al., 2015; Raffington et al., 2018; Räikkönen et al., 2010) (Quas et al., 2016), we further examine gender differences in children's emotional memory.

Effects of stress on memory

Experimental animal and adult research indicates that acute stress critically impacts memory in a time-sensitive way (Schwabe & Wolf, 2013). Focusing on effects of stress on the encoding phase, meta-analytic evidence from the adult literature has shown that memory is boosted if the delay between pre-encoding stress and encoding is very short or if the study materials are directly related to the stressor (Shields et al., 2017). With a longer delay between stress onset and encoding, stress begins to impair memory, particularly for content unrelated to the stressor itself (Shields et al., 2017).

In developmental studies, non-laboratory studies in children provide evidence that memory is facilitated by high levels of distress, particularly for stress-inducing experiences (*e.g.,* after medical treatments; Goodman, Hirschman, Hepps, & Rudy, 1991). Laboratory studies that examined the effects of experimentally-induced stress on memory in children are scarce. In one study, higher cortisol secretion in response to a modified Trier Social Stress Test was related to more accurate memory of the stressful event in 9-to-12-year-old's and young adults (Quas et al., 2011).

The autonomic nervous system (ANS) and hypothalamus-pituitary-adrenal (HPA) axis are believed to mediate effects of stress on memory. Stress triggers the immediate release of catecholamines (an ANS output) and the delayed release of glucocorticoids (an HPA axis output), mainly cortisol in humans (Hermans et al., 2014). According to one prominent theory (Hermans et al., 2014), the balance of stress-related hormones and neurotransmitters enhances functioning of the brain's salience system (*e.g.,* the amygdala and associated networks), which prioritizes processing of salient stimuli at the cost of non-salient stimuli. Cortisol secretion is critically involved in this process, because glucocorticoid actions can impair memory of new information unrelated to the stressor by reducing long-term potentiation in the amygdala and hippocampus (Schwabe et al., 2012).

Effects of emotional valence of to-be-remembered information

A largely separate literature has examined effects of emotional valence of to-be-remembered information on memory. In adults, memory is often (Hamann & Stevens, 2013; Schwabe et al., 2008), but not always (Brainerd et al., 2008; Dougal & Rotello, 2007; Howe et al., 2010), found to be stronger, more accurate, and enduring for emotional relative to neutral stimuli, which is commonly referred to as emotional memory enhancement. Similarly, in children, some studies report patterns of emotional enhancement of negative, but not positive, items as young as 8 years (Leventon & Bauer, 2016) or 7-9-years (Cordon et al., 2013; Stenson et al., 2019). At the same time, others have reported a lack of enhancement of positive and negative items (Leventon et al., 2014; Quas et al., 2016; Quesada et al., 2012) or a memory advantage for neutral relative to negative material in both children and adults (Howe et al., 2010). These mixed results may be indicative of interactive effects of differences of to-be-remembered information in *emotional valence* (*i.e.,* negative, neutral, or positive stimuli) and *arousal level* (*i.e.,* low or high arousing items).

Additionally, memory enhancement of emotional content can come at a cost of memory for the corresponding background (Waring & Kensinger, 2009). This effect is in line with memory narrowing effects, where memory for information that is central to an emotional event (*e.g.,* traumatic experience or emotional stories) but poorer memory for peripheral details. Such effects have been observed both in children and adults for memory of stress-inducing experience (Rush et al., 2011). However, trade-off effect between emotional content vs. background information, independent of stress experience, has not been systematically investigated in children.

Interactive effects of stress and emotional valence

It is conceivable that the valence of the to-be-remembered material interacts with the effects of stress on memory. For example, experimental adult research provides some evidence that the effects of stress on memory tend to be amplified for emotional material (Joëls et al., 2011; Shields et al., 2017). However, this effect seems to be dependent on the memory phase. In the meta-analysis by Shields et al. (2017), there is no clear evidence that stress influences encoding items of one valence more than another.

In the developmental literature, there is almost no study that examines the interaction between stress and emotional valence of memory content. Naturalistic studies of stress and memory are limited by the fact that the stress-inducing experiences are always negative. In an exceptional experimental study, Quas et al. (2016) manipulated stress levels in 7-8-year old children and then exposed them to negative, neutral, and positive word lists. They found that children's accuracy did not differ across stress conditions and word valence was unrelated to accuracy. However, increases in children's cortisol responses was related to greater accuracy for positive emotional words (Quas et al., 2016).

Interestingly, a subsequent study of 8-15-year-old's suggested that these effects may differ by gender: While girls with lower pubertal hormone levels and greater cortisol reactivity showed enhanced memory for negative information, boys with higher pubertal hormone levels and greater cortisol reactivity showed enhanced memory for positive information (Quas et al., 2018). Girls may have a higher physiological arousal response to negative pictures than boys (McManis et al., 2001) and sometimes show higher cortisol responses to stress (Hostinar et al., 2015; Quas et al., 2016; Raffington et al., 2018; Räikkönen et al., 2010). Gender differences in stress reactivity could arise from dissimilarities in behavioral and physiological development (Koss & Gunnar, 2018), previous stress exposure (Rudolph & Hammen, 1999; Turner & Avison, 2003), and gender-related socialization more generally (Eisenberg et al., 1998). Taken together, preliminary evidence suggests that cortisol may have facilitatory effects on emotional memory in children, especially in pre-pubescent girls. This may emerge as a stronger effect of emotional valence on memory (difference in memory for positive and/or negative information from neutral information) for girls than boys. Furthermore, when examined together with stress, effects of emotional valence on memory may become magnified in girls than in boys.

Present study

This study examined, in early middle childhood, the effects of experimentally-induced stress on memory for central vs. peripheral details that vary in emotional valence (and level of arousal) for the central information. Specifically, we assessed memories for objects that are emotionally valenced (positive, negative, or neutral) and their corresponding neutral scene background. 143 6-7-year-old children were randomly assigned to complete either a 15-minute stress (Trier Social Stress Test for Children; n = 103) or control task (n = 40). We assigned more children to the stress condition to examine the relationship between cortisol responses to stress and emotional memory performance. Ten minutes after stress cessation, participants encoded objects differing in both valence and arousal presented on neutral scene backgrounds. Incidental subsequent memory was probed one day later. While the empirical evidence regarding the effects of emotional valence on children's memory is not consistent, we hypothesized that children would show better memory for the emotional objects, with worse memory for the scene context that is coupled with the emotional items. These effects were expected to be enhanced by stress exposure. Additionally, we hypothesized that girls would show more emotional memory enhancement than boys under stress condition due to higher cortisol reactivity.

Method

Participants

For recruitment, research invitation letters were sent to families with 6-to-7-year-old children in Berlin. The responding 288 interested families were telephone screened for inclusion criteria, including the child attending first or second grade, no psychiatric, developmental and physical health disorders, no steroid medication use within the past two weeks, no traumatic childhood experiences (*e.g.,* maltreatment, severe illness), at least 37 weeks' gestation, and at least one fluent German-speaking parent.

A total of 147 children and parents participated in the baseline measurement of a longitudinal study, of which 5 children chose to discontinue their participation during the first session (final sample n = 143). 102 children were then randomly assigned to the Trier Social Stress Test for Children (TSST-C) and 40 children to the control condition (for procedure see section 2.3.1 and descriptive statistics in Table 1). One TSST-C child and one control child did not provide saliva samples (for assessment of salivary free cortisol concentrations) and another TSST-C child discontinued their participation in the emotional memory task.

15% of the initial sample were at-risk of poverty (monthly family net income at or below the Berlin state poverty line of that year, adjusted for family size and composition; (Statistische Ämter des Bundes und der Länder, 2018b). This is slightly less than the 19.4% of Berliners who were at-risk of poverty in 2016 (Statistische Ämter des Bundes und der Länder, 2018b). Parents were more highly educated compared to the average Berlin population. In 60% of the households at least one parent had a higher education degree compared to 39% of Berliners in 2016 (Statistische Ämter des Bundes und der Länder, 2018a). 90% of families identified their children's geographical ancestry as European only (4% as European-African, 6% as European-Asian). The study was approved by the 'Deutsche Gesellschaft für Psychologie' ethics committee (YLS_012015) and the experiment was performed in accordance with relevant guidelines.

Table 1. *Descriptive Statistics of Cortisol Levels and Memory by Gender and Stress Group.*

	Girls		Boys	
	Stress	Control	Stress	Control
N	49	18	54	22
Age [a]	7.09 (0.47)	7.33 (0.38)	7.17 (0.47)	7.33 (0.42)
Family income	3290 (1891)	4602 (2905)	3273 (1511)	4697 (2590)
Subjective stress	0.53 (0.68)	0.39 (0.61)	0.20 (0.53)	0.10 (0.31)
Cortisol Secretion				
Cortisol 1[b]	0.09 (0.04)	0.07 (0.02)	0.08 (0.04)	0.09 (0.03)
Cortisol 2	0.09 (0.05)	0.07 (0.03)	0.09 (0.04)	0.12 (0.14
Cortisol 3	0.2 (0.16)	0.07 (0.03)	0.15 (0.11)	0.11 (0.11
Cortisol 4	0.36 (0.30)	0.07 (0.04)	0.23 (0.17)	0.08 (0.04
Cortisol 5	0.37 (0.35)	0.06 (0.03)	0.22 (0.20)	0.08 (0.04)
Cortisol 6	0.28 (0.28)	0.06 (0.03)	0.17 (0.15)	0.09 (0.08)
Cortisol 7	0.22 (0.21)	0.06 (0.03)	0.14 (0.10)	0.09 (0.07)
Cortisol 8	0.17 (0.15)	-	0.12 (0.11)	-
Cortisol Intercept	0.02 (0.40)	-0.25 (0.40)	0.03 (0.37)	0.04 (0.44)
Cortisol Response Slope	0.60 (0.58)	0.36 (0.69)	0.47 (0.41)	0.05 (0.35)
Cortisol AUCi 1-7[e]	-112.82 (46.32)	-134.44 (38.51)	-119.98 (37.29)	-133.35 (32.25)
Cortisol AUCi 1-8[e]	-125.57 (52.2)	-	-137.64 (43.07)	-
Item Memory				
Corrected memory negative, high [c]	0.53 (0.25)	0.54 (0.27)	0.65 (0.25)	0.68 (0.21)
Corrected memory negative, low	0.45 (0.25)	0.55 (0.24)	0.56 (0.24)	0.58 (0.26)
Corrected memory neutral	0.63 (0.24)	0.59 (0.27)	0.62 (0.24)	0.66 (0.28)
Corrected memory positive, low	0.61 (0.25)	0.60 (0.33)	0.61 (0.25)	0.69 (0.26)
Corrected memory positive, high	0.65 (0.24)	0.60 (0.29)	0.60 (0.27)	0.68 (0.22)
Hit rate (%) negative, high	78.33 (20.61)	77.78 (14.99)	77.11 (19.41)	81.52 (12.50)
Hit rate (%) negative, low	64.58 (19.75)	72.22 (22.55)	63.90 (23.81)	68.79 (20.09)
Hit rate (%) neutral	75.97 (20.48)	72.41 (21.93)	70.69 (24.01)	79.70 (15.97)
Hit rate (%) positive, low	77.08 (17.71)	72.96 (30.20)	68.62 (21.91)	77.58 (17.03)
Hit rate (%) positive, high	80.00 (16.83)	73.33 (25.26)	76.10 (22.51)	79.39 (16.58)
FA rate (%) negative, high	22.08 (18.21)	21.11 (17.11)	18.30 (17.73)	17.73 (15.72)
FA rate (%) negative, low	19.17 (15.82)	17.22 (13.20)	13.02 (16.45)	13.18 (13.59)
FA rate (%) neutral	13.33 (14.49)	13.61 (17.13)	12.83 (14.33)	14.55 (17.31)
FA rate (%) positive, low	15.62 (18.67)	13.33 (11.38)	14.25 (16.27)	12.27 (16.02)
FA rate (%) positive, high	17.92 (16.97)	15.00 (14.25)	17.74 (19.58)	11.82 (13.68)
Scene Memory				
Scenes negative, high [d]	0.23 (0.22)	0.33 (0.21)	0.26 (0.20)	0.36 (0.20)
Scenes negative, low	0.29 (0.20)	0.35 (0.19)	0.31 (0.21)	0.35 (0.19)
Scenes neutral	0.27 (0.20)	0.31 (0.16)	0.31 (0.21)	0.34 (0.25)
Scenes positive, low	0.30 (0.24)	0.42 (0.17)	0.35 (0.21)	0.37 (0.27)
Scenes positive, high	0.25 (0.23)	0.33 (0.24)	0.30 (0.23)	0.30 (0.19)
Hit rate (%) negative, high	38.96 (23.34)	47.04 (16.41)	46.67 (22.23)	43.48 (25.79)
Hit rate (%) negative, low	45.28 (28.32)	51.85 (20.01)	41.32 (24.83)	50.91 (22.59)
Hit rate (%) neutral	43.06 (22.76)	53.70 (20.64)	42.77 (22.36)	53.33 (26.43)
Hit rate (%) positive, low	45.49 (25.48)	45.56 (18.04)	41.64 (20.96)	45.45 (23.52)
Hit rate (%) positive, high	42.64 (23.96)	51.48 (25.03)	45.66 (19.93)	46.97 (23.68)
FA rate (%) negative, high	15.94 (21.8)	15.00 (14.65)	13.58 (14.95)	16.59 (16.43)
FA rate (%) negative, low	12.08 (11.66)	17.22 (12.74)	14.43 (16.86)	12.73 (15.49)
FA rate (%) neutral	18.33 (17.79)	15.56 (9.22)	18.68 (19.71)	13.18 (14.27)
FA rate (%) positive, low	17.40 (14.73)	3.33 (11.38)	13.21 (17.41)	11.82 (16.51)
FA rate (%) positive, high	18.33 (17.08)	15.00 (15.81)	13.02 (15.01)	17.27 (11.62)

[a] Mean and standard deviations in parentheses.

[b] Cortisol levels measured twice before stress/control and 6 times post-stress and 5 times post-control. Raw values in µg/dL.

[c] Corrected memory (hit rate minus FA rate) for items. "Low" refers to low arousing items and "high" refers to high arousing items.

[d] Corrected memory (hit rate minus FA rate) for neutral scenes paired with items.

[e] AUCi 1-7 derived from the second to seventh cortisol measurement present in both stress/control groups. AUCi 1-8 derived from the second to eighth cortisol measurement available in the stress group only.

Procedure

Participants were invited to 2 sessions on consecutive weekdays scheduled between 2-6 pm. Parents were informed that their child may be invited to complete a stressful task similar to an oral examination in school and see pictures with emotional content. They were instructed not to give their children large meals or caffeine for 2 hours before the first session. Parents provided informed written consent and children gave verbal assent, and both were told they could discontinue their participation at any time. After completing two previous cognitive tasks (not reported here) that were not taxing in nature, children completed the stress or control task (approximately 1 hour after arrival). Emotional memory encoding commenced exactly 10 min after stress/control task and after children completed 6 practice encoding trials (see Fig. 1A). Encoding lasted approximately 20 min. Incidental subsequent memory was tested the next day at the beginning of the second session in the same room.

Measures

Stress versus control tasks

The TSST-C consisted of a story preparation, storytelling, and mental calculation part (5 min each) and was performed in front of 2 live female judges whom they had not met before and a video camera (Buske-Kirschbaum et al., 1997). Judges completed training of administering the TSST-C in the Kirschbaum lab in Dresden. The control task consisted of the same story preparation, storytelling, and mental calculation parts (5 min each) and was performed with the support of the experimenter whom they had met from the beginning of the session. All children reported their subjective stress response pre-and post-task by pointing to comic faces indicating 0=happy, 1=neutral, or 2=upset feelings. For the stress group only, children were kept separate from their accompanying parent before and following stress to prevent buffering effects (Hostinar et al., 2015), unless the child explicitly requested to see the parent. Excluding the 12 cases who requested to see their parents did not affect the results. At the end of the approximately 2.5-hour session, stress group children and parents were debriefed by showing them videos of the judges providing individualized, positive feedback.

Cortisol Response to Stress/Control Condition

Saliva samples for the assessment of cortisol concentrations were collected 10 min and immediately preceding the stress/control task and at 0, 10, 20, 30, and 40 min after the tasks as well as after 50 min for the stress group only. Sample 5 (+20 min) was taken in a 2 min break in the middle of the emotional memory task. Saliva swabs were frozen at -80°C until they were shipped on dry ice to the laboratory of the Institute of Medical Psychology at Charité - Universitätsmedizin Berlin and stored at -80°C until assayed. They were brought to room temperature, centrifuged at 3000 rpm for 15 min, and assayed using a highly sensitive enzyme immunoassay (Salimetrics, Suffolk, UK) with a detection range from 0,012 µg/dL - 3 µg/dL, lower sensitivity limit of 0,007 µg/dL, and average intra- and inter-assay coefficients of variation < 7%. The average of duplicate assays was used for all samples. Cortisol values were log transformed to correct for significant skew and standardized to sample 1 (pre-stress baseline).

Recently, latent growth curve models have been applied to dynamic repeated-measures of cortisol secretion instead of calculating area under the curve or multiple increase/decrease measures (Felt et al., 2017; Ji et al., 2016; Raffington et al., 2018). These have the significant benefit of modeling latent factors free of measurement error and commonly reduce the number of cortisol indices. Here, a latent growth curve structural equation model was compiled to estimate pre-stress baseline levels (intercept) and both reactivity and recovery change for both stress exposure and control children (slope is called cortisol response to stress). Notably, a two-slope model of cortisol secretion separating reactivity and recovery provided worse fit to the data, because they were very highly correlated (model-implied standardized $\rho = 0.96$, $SE = 0.01$, $p < 0.05$). The mean cortisol response slope is an indicator of the average change in cortisol per 10 min and the cortisol response variance represents between-person differences in this change. All models were fitted in MPlus 7.4 using full information maximum likelihood (FIML) estimation to accommodate missing at random data. Latent intercept and cortisol response to stress/control variables were extracted for further analyses from the final model (see Felt et al., 2017; Ji et al., 2016; Raffington et al., 2018). Given that extracted factor scores could lead to biased estimates due to factor score indeterminacy (Bagozzi, 1983; Grice, 2001), we also calculated the increase in the amount of cortisol secreted as an area under the curve measure relative to increase from the second baseline cortisol measure (AUCi; Pruessner et al., 2003) for comparison with our primary results. Factor score determinacies (ranging from 0-1) were estimated as being 0.952 for the intercept and 0.971 for the cortisol stress response. The latent growth curve model's cortisol response slope and AUCi were highly, but not perfectly correlated across both stress/control groups using the second to seventh cortisol measurement ($r = 0.788$, $p < 0.001$) as well as within the stress group only using the second to eighth cortisol measurement ($r = 0.782$, $p < 0.001$). See Table 1 for descriptive statistics by group.

Emotional Memory

During emotional memory encoding, children saw emotional (*e.g.,* a monster) and neutral (*e.g.,* a cup) items presented on neutral background scenes (Waring & Kensinger, 2009). The 125 items (Kensinger & Schacter, 2007) fell into 5 categories of each 25 items (15 target, 10 lures) differing in valence and arousal: (1) negative valence and high arousal, (2) negative valence and low arousal, (3) neutral (medium arousal, neutral in valence), (4) positive valence and low arousal, and (5) positive valence and high arousal. Emotional valence and arousal of each item was based on pre-study ratings of 45 6-to-7-year-old children, of which 21 (11 girls) rated valence and 24 (12 girls) rated arousal levels on a 9-point scale using the Self-Assessment Manikin scales (Bradley & Lang, 1994). Emotional categories were created separately for boys and girls to counteract gender differences in item categorization (e.g., a butterfly was positive and highly arousing only to boys). 32.8% of the items were in identical categories for each gender. See Figure 1 for examples and supplemental Table S1 for a full list of items, supplemental Table S2 and S3 for descriptive statistics of arousal and valence for each category and statistics showing a lack of difference in arousal/valence between task versions for girls compared to boys.

The items were individually placed on neutral backgrounds (*e.g.,* landscapes, indoor rooms without people), such that they were easily visible and did not change the emotional loading of the item. The pairing of items to backgrounds was counterbalanced in five task versions for each gender, such that across children each scene was paired with items of all emotional categories. At encoding, children saw a fixation cross for 1 sec, followed by the item-background pairing for 3 sec, after which they were asked to indicate by button press whether they would approach or avoid the item within 4 sec. Item order across emotional categories was randomized. At recognition on the following day, children saw 250 items and backgrounds displayed separately in randomized order, of which 75 items and 75 backgrounds had previously been seen and 50 items and 50 backgrounds were new. Items were counterbalanced to be both targets (old items) and lures (new items) across the 5 task versions for each gender. Children were instructed to indicate whether the item was new or old verbally to ensure task compliance, thus no reaction times were available.

Outcome measures were individual rates of hits and false alarms (FA) as well as corrected memory performance (hit rate minus FA rate). Corrected memory performance was transformed with an exponential function to correct for significant skew. There were no corrected memory outliers defined as 5 SD from the mean and no performance under the exclusion threshold of -0.10.

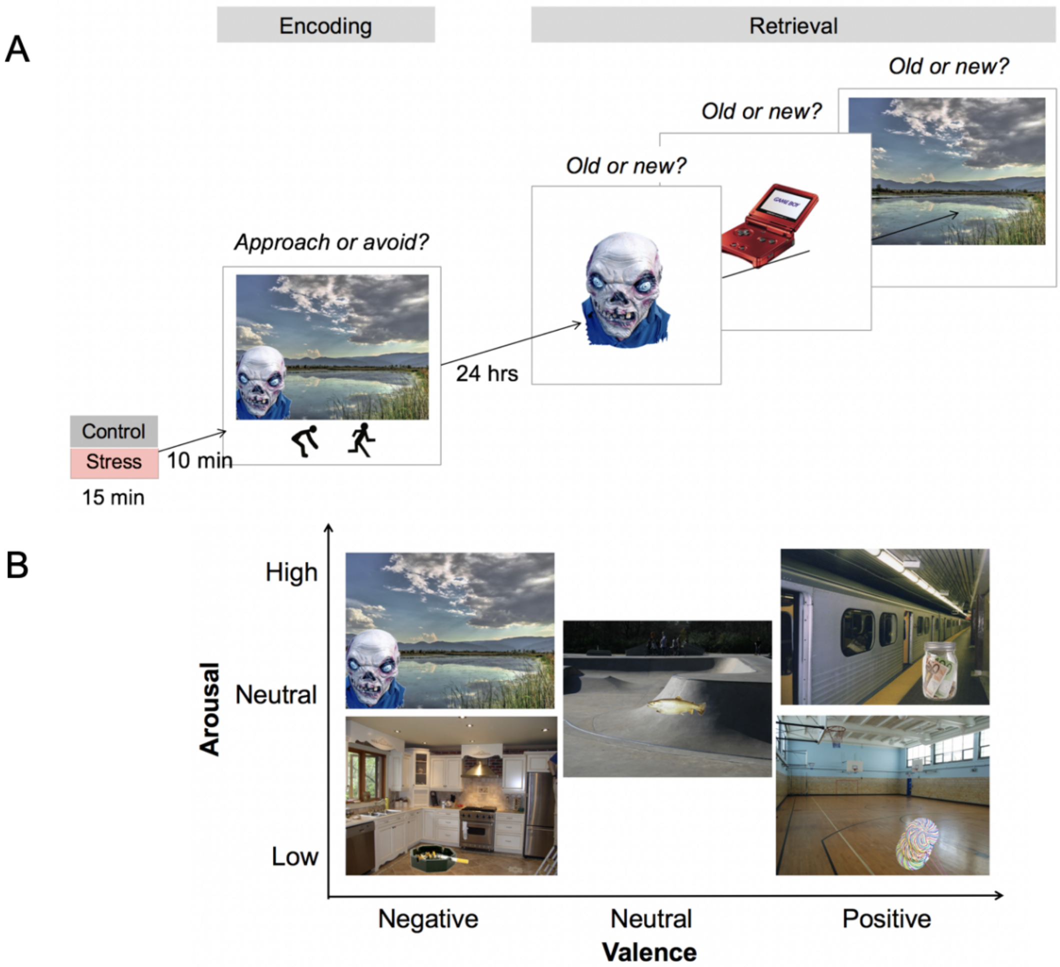

Figure 1. (A) Procedural timeline of stress/control condition and memory task. (B) Example of negative high arousing (monster), negative low arousing (ashtray), neutral (fish), positive low arousing (lollipop), and positive high arousing (money) items placed on neutral backgrounds.

Data Analysis

Our primary analyses applied linear mixed effects (LME) models, where the inclusion of a random intercept term allows clustering of the repeated measure (5 levels of emotional category) within each person. A benefit of LME models using maximum likelihood estimation compared to commonly applied repeated-measures ANOVAs is that the parameter estimates and standard errors are robust to differences in group size and can easily be extended to dichotomous dependent variables (Maas & Hox, 2005; Troncoso Skidmore & Thompson, 2013).

First, we ran LME models to validate the perception of item categories by regressing approach/avoid responses on category, gender and stress/control group (Results section 3.1).

Second, linear models evaluated our stress/control manipulation and gender differences in stress reactivity by regressing the cortisol response slope, AUCi, and subjective stress reports on group, age, gender, and a group by gender interaction (3.2).

Third, we examined whether corrected memory performance (hit rate minus false alarm rate) differed by group, emotional category, and gender in separate models for items (3.3) and scenes (3.5; defined by the emotional category of the item that each scene was paired with), allowing for interactions between these predictors and controlling for age. Importantly, linear mixed effects models estimate the effect of between-person variables with *each level* of a repeated measure, such as a parameter estimate for gender by negative low arousing items. The neutral category was deemed the reference level within all models unless specified otherwise. Thus, a significant interaction parameter of gender by negative low arousing items would indicate a significant gender difference in memory for negative low arousing items relative to neutral items. Given significant three-way interactions of emotional category, group (stress/control), and gender, post-hoc analyses ran the same model for the sample split by gender. Non-significant interaction parameters were dropped from the final model.

Fourth, we investigated whether individual differences in cortisol stress responses and children's subjective stress reports were correlated with corrected memory within the stress group only due to the high covariance of stress/control grouping and cortisol secretion (3.4 for items and 3.6 for scenes).

Finally, we ran trial-level models of hits and false alarms (individual item trials instead of corrected memory aggregates for each emotional category) to improve our understanding of corrected item memory effects (3.7). Models were implemented using the lme4 package (Bates et al., 2015) for linear mixed modeling in R and utilized maximum likelihood estimation. Group (1 = stress and -1 control) and gender (1 = female and -1 = male) were effect coded. We report standardized parameter estimates as effect size estimates. The datasets analyzed during the current study along with the R analysis scripts are available on the Open Science Framework (https://osf.io/j23ke/).

Results

Validation of emotional categories

First, approach/avoid responses validated the categorization of items based on our pre-study. Negative high arousing (mean = 30%, SD = 24; b = -0.809, SE = 0.057, $p < 0.001$) and low arousing items (mean = 36%, SD = 23; b = -0.482, SE = 0.0547, $p < 0.001$) were approached significantly less than neutral (mean = 50%, SD = 22), whereas positive low (70%, SD = 22.08; b = 0.897, SE = 0.058, $p < 0.001$) and high arousing items (mean = 72 %, SD = 21; b = 0.944, SE = 0.058, $p < 0.001$) were approached significantly more than neutral items. In addition, there were significant interactions of emotional category by gender on approach/avoid responses in all emotional category levels (negative low: b = 0.122, SE = 0.061, $p = 0.045$; negative high: b = -0.193, SE = 0.064, $p = 0.002$; positive low b = 0.166, SE = 0.064, $p = 0.01$; positive high: b = 0.177, SE = 0.065, $p = 0.006$).

Post-hoc analyses split by gender suggested that girls avoided negative high arousing items (b = -0.980, SE = 0.083) significantly more than low arousing ones (b = -0.371, SE = 0.078, paired $t = 6.60$, $p < 0.001$), whereas boys made no such differentiation (high: b = -0.636, SE = 0.078 versus low: b = -0.593, SE = 0.078, paired $t = 0.335$, $p = 0.738$). Additionally, girls approached positive items significantly more than boys, regardless of arousal (girls high: b = 1.086, SE = 0.083 and low: b = 1.043, SE = 0.083, paired $t = 0.459$, $p = 0.648$ versus boys high: b = 0.982, SE = 0.10 and low: b = 0.95, SE = 0.10, paired $t = -1.89$, $p = 0.062$). There were no main or interaction effects of group or cortisol responses to stress/control (in a separate model) on approach behaviors.

In short, behavioral response at encoding suggested that girls avoided negative items more than boys and approached positive items more. While girls differentiated low and high arousing negative items in their avoid responses (higher avoidance for high arousing than low arousing negative items), boys did not. Given the separate item sets used to elicit comparable emotion for boys and girls, we cannot rule out the possibility that these gender differences in approach/avoid responses arose somehow from differential item content (see 2.3.3.). Approach/avoid responses were unaffected by stress/control group and cortisol levels.

Validation of stress/control group and gender differences in stress reactivity

Second, the stress group had substantially higher cortisol levels in response to stress than the control group to the control condition as can be seen in Figure 2 (b = 0.551, SE = 0.070, $p < 0.001$; AUCi: b = 0.406, SE = 0.077, $p < 0.001$), but, as anticipated, they did not have significantly higher pre-stress cortisol intercepts than the control group (b = 0.113, SE = 0.084, $p = 0.184$; see Table 1 for descriptives). The stress group also reported higher subjective stress from pre- to post-stress versus control (b = 0.208, SE = 0.079, $p = 0.009$). This indicates the stress/control manipulation was successful. Within the stress group, girls had significantly higher cortisol responses than boys in the stress condition (b = 0.259, SE = 0.009, $p = 0.009$; AUCi: b = 0.173, SE = 0.098, $p = 0.080$) as well as higher subjective stress reports (b = 0.294, SE = 0.095, $p = 0.003$). No such gender differences were present in the control group (b = 0.172, SE = 0.167, $p = 0.309$; AUCi: b = -0.289, SE = 0.159, $p = 0.077$). Boys in the stress condition had higher cortisol responses to stress (b = 0.571, SE = 0.096, $p < 0.001$; AUCi: b = 0.286, SE = 0.111, $p = 0.012$) and more subjective stress reports (b = 0.235, SE = 0.111, $p = 0.038$) than control boys to the control condition. Subjective stress was not significantly related to cortisol responses to stress within the stress group (b = 0.018, SE = 0.101, $p = 0.861$; AUCi: b = -0.059, SE = 0.102, $p = 0.561$) and there was no interaction of subjective stress by gender.

In short, girls in the stress condition had higher cortisol responses to stress and higher subjective stress increases than boys in the stress condition. Although boys in the stress condition exhibited smaller cortisol responses than girls in the stress condition, the boys' responses were nonetheless significantly larger than were responses of boys in the control condition. Subjective stress was not significantly related to cortisol stress responses.

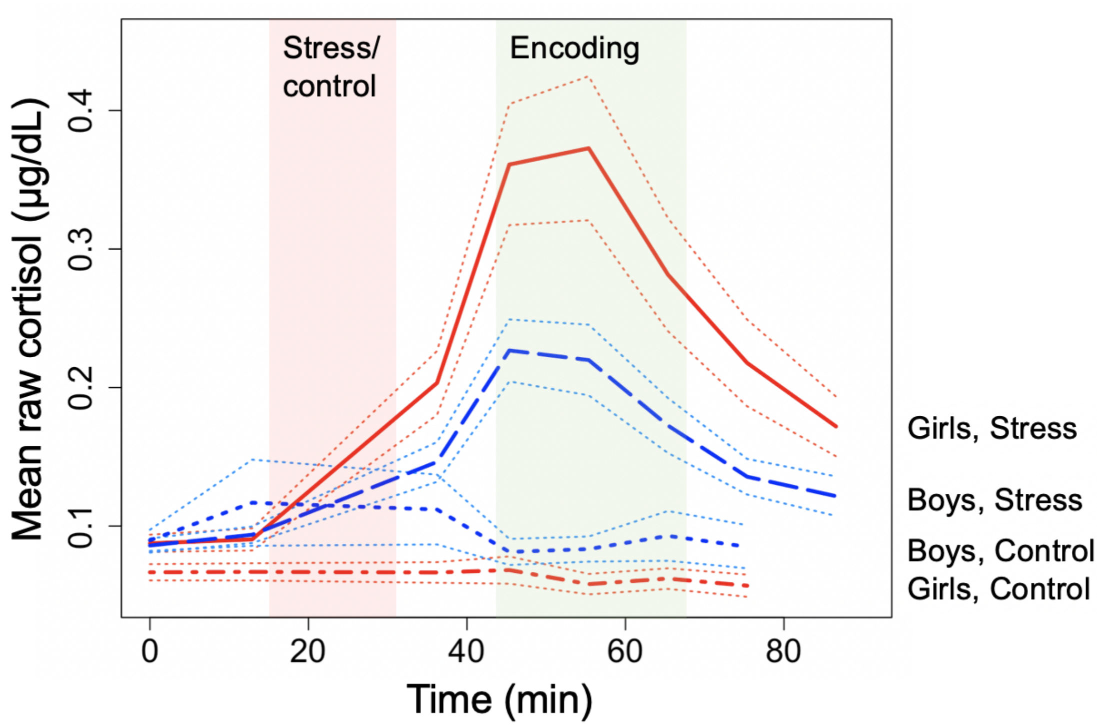

Figure 2. Raw mean cortisol levels in response to stress/control by gender. The plot depicts higher cortisol levels in girls (solid red line) following stress compared to boys (long-dashed blue line). Boys in the stress condition had higher cortisol output than control boys (short-dashed blue line) and control girls (dot-dashed red line). Within-group standard errors are represented by the dotted lines.

Stress/control group effects on corrected emotional item memory

On average, 73.88% (*SD* = 19.45) of previously seen items were correctly identified as old (hits) and 15.90% (*SD* = 13.05) of new items were inaccurately identified as old (FA). Accordingly response-bias corrected mean memory across categories and groups was 60% (*SD* = 19.45). Critically, stress/control grouping had no effect on overall memory across categories (see Table 1 for descriptives, Table 2 for parameter estimates, and Figure 3 for depiction of mean performance by group and gender).

Next, emotional category significantly predicted memory performance. A first order effect indicated that negative low arousing items were remembered less than neutral items. This effect was superimposed by a three-way interaction of negative low arousing items by gender by group. In addition, there was a two-way interaction of negative high arousing items by gender (see Table 2).

We explored these interactions by splitting the sample by gender. For girls, both low ($b = -0.165$, $SE = 0.044$, $p < 0.001$) and high arousing negative items ($b = -0.110$, $SE = 0.044$, $p = 0.012$) were remembered less than neutral[1]. Further, lower memory for low arousing negative items relative to neutral items was significantly amplified in girls in the stress condition (mean difference low arousing negative items to neutral = -0.17, SD = 0.2) than girls in the control condition (mean difference of low arousing negative items to neutral = -0.04, SD = 0.24; interaction low negative X group for girls: $b = -0.111$, $SE = 0.048$, $p = 0.020$).

In contrast, there was no effect of group or a group by emotional category interaction among boys (smallest p-value = 0.484). For boys only low arousing negative items were remembered less than neutral (albeit a smaller effect compared to the corresponding effect in girls; mean difference negative low arousing items to neutral = -0.07, SD = 0.21; $b = -0.112$, $SE = 0.039$, $p = 0.004$)[2].

In sum, there was no main effect of stress/control group on overall item memory. Girls showed worse corrected memory for negative items relative to both neutral and positive items. Boys also had worse memory for low arousing negative items than neutral and positive items, but to a significantly lesser degree than girls. In addition, boys' memory for low arousing negative items was also significantly worse than memory for high arousing negative items. More so, lower memory for low arousing negative items compared to neutral and

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[1] Defining high arousing negative items as the reference level indicated that girls remembered high arousing negative items less than both low arousing ($b = 0.116$, $SE = 0.039$, $p = 0.003$) and high arousing ($b = 0.165$, $SE = 0.039$, $p < 0.001$) positive items.

[2] Defining low arousing negative items as the reference level indicated that boys, regardless of group, also remembered low arousing negative items significantly worse than high arousing negative ($b = 0.153$, $SE = 0.035$, $p = 0.014$), high arousing positive ($b = 0.097$, $SE = 0.035$, $p = 0.022$), and low arousing positive items ($b = 0.113$, $SE = 0.035$, $p = 0.008$).

positive items was significantly more pronounced in girls in the stress condition compared to boys in the stress condition and controls.

Table 2. Linear Mixed Effects Models for Corrected Memory of Items and Scenes Predicted by Emotional Category, Group, and Gender.

	Items			Scenes		
	β [a]	SE	*p*	β [a]	SE	*p*
Age	0.121	0.071	0.089	0.133	0.071	0.063
Gender [c]	-0.058	0.090	0.523	-0.051	0.071	0.466
Group [c]	0.007	0.082	0.934	-0.102	0.071	0.153
Negative high	-0.035	0.029	0.232	-0.041	0.027	0.126
Negative low	**-0.138**	**0.029**	**0.000**	0.032	0.027	0.237
Positive high	0.017	0.029	0.567	-0.020	0.027	0.460
Positive low	0.007	0.029	0.816	**0.089**	**0.027**	**0.001**
Group x gender	0.085	0.091	0.352	–	–	–
Group x Negative high	-0.016	0.032	0.620	–	–	–
Group x Negative low	-0.049	0.032	0.124	–	–	–
Group x Positive high	-0.005	0.032	0.870	–	–	–
Group x Positive low	-0.022	0.032	0.489	–	–	–
Gender x Negative high	**-0.086**	**0.032**	**0.008**	–	–	–
Gender x Negative low	-0.032	0.032	0.318	–	–	–
Gender x Positive high	0.018	0.032	0.585	–	–	–
Gender x Positive low	-0.013	0.032	0.687	–	–	–
Group x Gender x Negative high	-0.027	0.032	0.405	–	–	–
Group x Gender x Negative low	**-0.066**	**0.032**	**0.043**	–	–	–
Group x Gender x Positive high	0.019	0.032	0.561	–	–	–
Group x Gender x Positive low	0.007	0.032	0.825	–	–	–

[a] Standardized parameter estimates.

Associations of cortisol levels and self-reported stress with corrected emotional item memory within the stress group

There was no main effect of cortisol intercept or response on overall item memory within the stress group (see Table 3 for parameter estimates and Figure 4 for depiction of cortisol response and emotional memory). Yet, there were significant two-way interactions of cortisol response and gender, cortisol response and positive high arousing items. Lastly, there was a significant three-way interaction involving cortisol response, gender, and negative low arousing items.

We explored the interactions by splitting the stress sample by gender. For girls, higher cortisol responses to stress were related to better emotional memory for high arousing positive (b = 0.244, SE = 0.070, $p < 0.001$; AUCi: b = 0.354, SE = 0.116, $p = 0.003$), low arousing negative (b = 0.165, SE = 0.70, $p = 0.019$; AUCi: b = 0.312, SE = 0.116, $p = 0.008$), and at trend for high arousing negative items (b = 0.137, SE = 0.070, $p = 0.051$; AUCi: b = 0.255, SE = 0.116, $p = 0.030$), but not low arousing positive items relative to neutral (b = 0.111, SE = 0.070, $p = 0.112$; AUCi: b = 0.203, SE = 0.116, $p = 0.083$, see Figure 4). No significant associations of cortisol stress responses and memory were seen in boys in the stress condition (lowest *p*-value = 0.155).

Next, there was a significant positive main effect of self-reported stress on overall item memory that was superimposed by an interaction with gender. We explored the interaction by splitting the stress sample by gender. For boys (b = 0.350, SE = 0.106, $p = 0.006$), but not girls (b = 0.002, SE = 0.117, $p = 0.984$), higher self-reported stress was associated with better overall item memory and there were no interactions with emotional category.

Thus, higher cortisol responses to stress were related to better emotional memory amongst girls in the stress condition for high arousing positive, low arousing negative, and at trend (though significant with AUCi) for high arousing negative items relative to neutral. In contrast, cortisol stress responses were unrelated to boys' memory. Results were very similar across the latent growth model and AUCi measures of cortisol stress response. Further, higher self-reported stress increases following stress exposure was associated with better overall item memory in boys in the stress condition, whereas self-reported stress was unrelated to girls' item memory.

Table 3. Linear Mixed Effects Models for Corrected Memory of Items and Scenes Predicted by Emotional Category, Gender, and Cortisol Responses in the Stressed Group.

	Items			Scenes		
	β [a]	SE	*p*	β [a]	SE	*p*
Age	0.164	0.084	0.053	**0.167**	**0.083**	**0.048**
Gender	0.260	0.146	0.076	-0.106	0.085	0.217
Cortisol intercept	0.023	0.083	0.784	-0.019	0.083	0.820
Cortisol response	0.048	0.105	0.647	0.166	0.086	0.056
Negative high	-0.083	0.046	0.073	**-0.069**	**0.031**	**0.028**
Negative low	**-0.208**	**0.046**	**0.000**	0.031	0.031	0.322
Positive high	-0.078	0.046	0.095	-0.011	0.031	0.736
Positive low	-0.052	0.046	0.264	**0.076**	**0.031**	**0.016**
Cortisol response x gender	**-0.323**	**0.155**	**0.038**	–	–	–
Cortisol response x Negative high	0.040	0.052	0.439	–	–	–
Cortisol response x Negative low	0.019	0.052	0.721	–	–	–
Cortisol response x Positive high	**0.106**	**0.052**	**0.042**	–	–	–
Cortisol response x Positive low	0.045	0.052	0.385	–	–	–
Gender x Negative high	**-0.174**	**0.052**	**0.001**	–	–	–
Gender x Negative low	**-0.190**	**0.052**	**0.000**	–	–	–
Gender x Positive high	-0.060	0.052	0.250	–	–	–
Gender x Positive low	-0.051	0.052	0.324	–	–	–
Cortisol response x Gender x Negative high	0.080	0.055	0.148	–	–	–
Cortisol response x Gender x Negative low	**0.128**	**0.055**	**0.021**	–	–	–
Cortisol response x Gender x Positive high	0.106	0.055	0.054	–	–	–
Cortisol response x Gender x Positive low	0.052	0.055	0.348	–	–	–

[a] Standardized parameter estimates.

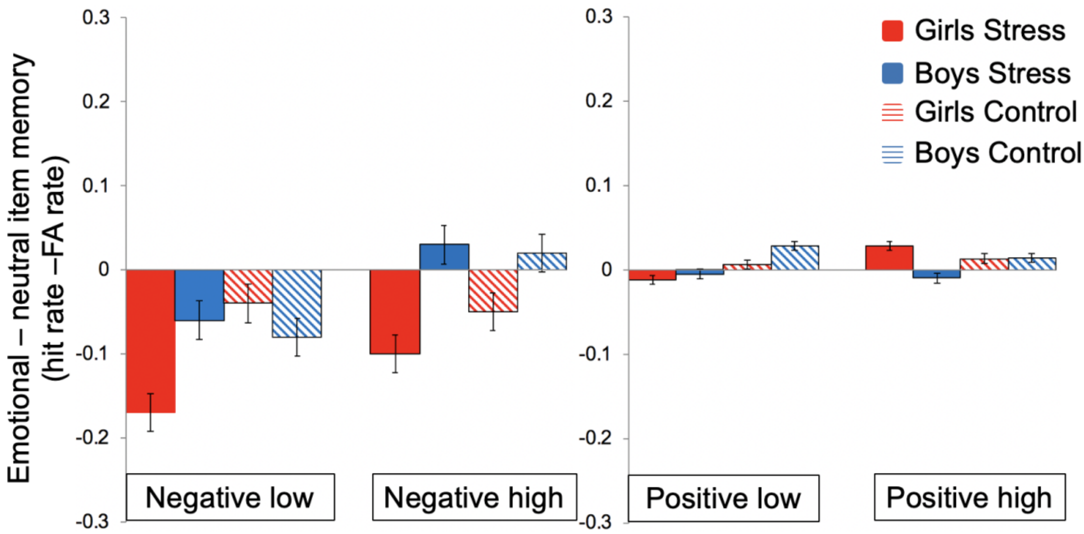

Figure 3. Raw means of response-bias corrected memory performance (hit rate - FA rate) by group (stress/control) and gender for each emotional category relative to memory for neutral

items (emotional - neutral). Zero line indicates equivalent memory for emotional relative to neutral memory. Error bars indicate within-group standard errors of the mean.

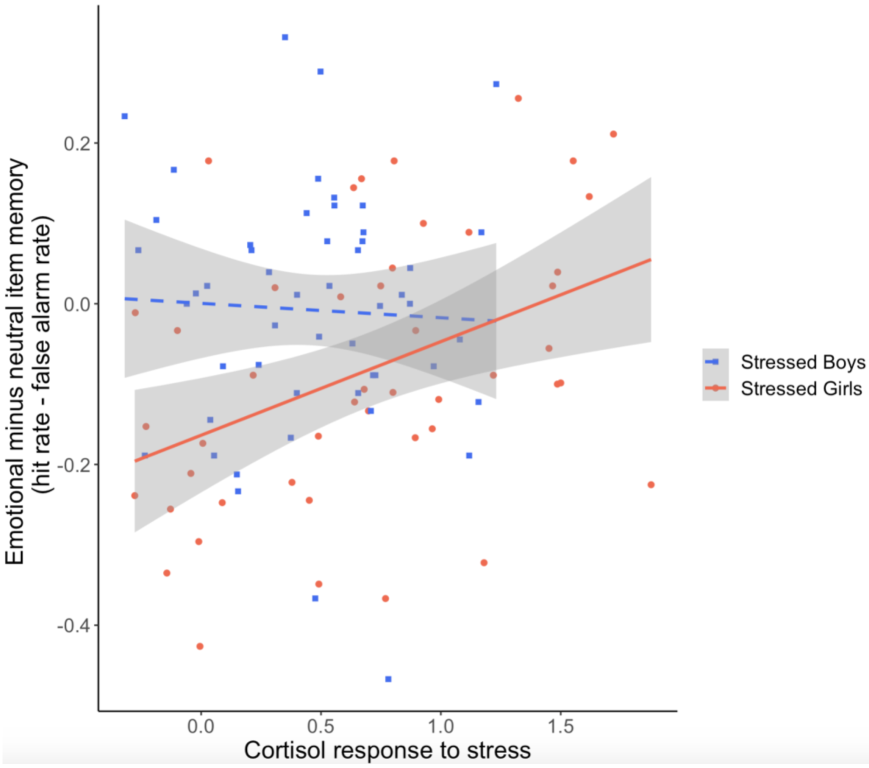

Figure 4. Cortisol secretion in response to stress predicting corrected memory performance (hit rate minus FA rate) for emotional (positive high arousing, low arousing negative, and high arousing negative items) minus neutral items in girls in the stress condition (solid red line) and boys in the stress condition (dashed blue line). The zero point indicates neutral memory performance. The plot depicts the positive association of higher cortisol stress responses and emotional memory present in girls in the stress condition, but not boys in the stress condition, who had lower average cortisol responses to stress.

Stress/control group effects on corrected emotional scene memory

On average, 44.93% (*SD* = 9.49) of previously seen scenes were correctly identified as old (hits) and 15.25 % (*SD* =12.17) of new scenes were inaccurately identified as old (FA). Accordingly corrected mean memory across categories and groups was 30% (*SD* = 18.00).

Overall scene memory was not significantly affected by stress/control group (see Table 2). Yet, scene memory was improved by a pairing with low arousing positive items relative to a pairing with neutral items (see Table 2). Defining low arousing positive items as the reference level indicated that scenes paired with low arousing positive items were also remembered significantly better than scenes paired with high arousing negative (b = -0.131, SE = 0.027, $p < 0.001$), low arousing negative (b = -0.058, SE = 0.027, $p = 0.032$), and high arousing positive items (b = -0.109, SE = 0.027, $p < 0.001$). There were no significant interactions with gender, group, or emotional category. Thus, no interaction terms were retained in the final scene memory model.

Associations of cortisol levels and self-reported stress with corrected emotional scene memory within stress group

In a separate model of cortisol and scene memory for the stress group, there was a nonsignificant trend (see Table 3, $p = 0.056$; AUCi: b = 0.126, SE = 0.086, $p = 0.143$) for a higher cortisol stress response to be associated with better scene memory. In addition to the aforementioned effect that scene memory was improved by a pairing with positive low arousing items, it was also significantly reduced by a pairing with negative high arousing items relative to neutral in the stress group (see Table 3). The corresponding interaction of group by negative high arousing items was marginally nonsignificant (b = -0.060, SE = 0.032, $p = 0.065$). Defining high arousing negative items as the reference level within the stress group indicated that memory for scences paired with high arousing negative items was also significantly worse compared to a pairing with low arousing negative (b = 0.100, SE = 0.031, $p = 0.001$) and low arousing positive items (b = 0.145, SE = 0.031, $p < 0.001$), but not high arousing positive items (b = 0.058, SE = 0.031, $p = 0.062$) .

Next, there was no association of self-reported stress with overall scene memory within the stress group (b = 0.022, SE = 0.087, $p = 0.806$) and no interactions with category or gender.

In sum (of 3.5 and 3.6), there was no main effect of group on overall scene memory. Memory for scenes paired with low arousing positive items was facilitated in both groups compared to all other emotional categories, and memory for scenes paired with high arousing negative items was impaired compared to neutral and low arousing items of both positive and negative valence in the stress group only. Self-reported stress was unrelated to scene memory.

Hits and false alarm item memory

Trial-level models of hits and FA indicated that high arousing negative items had more hits (b = 0.087, SE = 0.039, $p = 0.028$), but also more FA (b = 0.736, SE = 0.161, $p < 0.001$) than neutral items. In contrast, low arousing negative items had less hits (b = -0.168, SE = 0.040, $p < 0.001$), but no more or less FA than neutral items (b = 0.292, SE = 0.168, $p = 0.082$). There was a non-significant trend that high arousing positive items had more hits (b = 0.071, SE = 0.039, $p = 0.070$), but they also showed significantly more FA than neutral items (b = 0.389, SE = 0.167, $p = 0.019$). There were no main or interaction effects of group or gender. Looking at the stress group only, cortisol responses did not predict hits or FA. There were no interactions of cortisol response with gender or emotional category (lowest p-value = 0.271).

In short, although high arousing items evinced more hits than neutral, they also had more false alarms. In contrast, low arousing negative items had less hits and unaffected false alarms compared to neutral. Notably, there were no significant group or gender differences in hits or false alarms.

Discussion

The current study systematically examined how the effects of experimentally-induced stress on memory for central vs. peripheral details vary as a function of the emotional valence (and level of arousal) of the central information.

Effects of emotional valence

We found that emotional valence did not enhance 6-7-year-old children's item memory, after correcting for response bias (due to increased false alarms) to emotional items. Similarly, three previous developmental studies have reported a lack of emotional enhancement under the age of 8 years (Leventon et al., 2014; Quas et al., 2016; Quesada et al., 2012). To our knowledge, this study is the first to examine this question exploring items bound to contexts, where object items were presented in front of background context. Interestingly, EEG evidence suggests that 5-7-year-old's show emerging emotional enhancing effects neurophysiologically but not behaviorally (Leventon et al., 2014), whereas 8-year-old's (Cordon et al., 2013; Leventon & Bauer, 2016) and adolescents (Krauel et al., 2007; Quas et al., 2016; Vasa et al., 2011) show behavioral emotional enhancement effects as well. Potentially, emotional memory enhancement effects at the behavioral level may emerge in middle childhood at a developmental period that is later than the age of the children tested in our study.

On the other hand, even adults do not always show emotional enhancement effects. This is especially the case for negative items, to the degree that corrected memory for negative items or words is sometimes found to be worse than neutral in both children and adults (Brainerd et al., 2008; Howe et al., 2010), and potentially when items are bound to contexts (Doerksen & Shimamura, 2001; Dougal & Rotello, 2007; Mather & Nesmith, 2008; Waring & Kensinger, 2009). Our study corroborates those findings: Response-bias corrected memory was worse for low arousing negative items relative to neutral and positive items across groups. Girls also had worse corrected memory for high arousing negative items relative to both neutral and positive items. In contrast, low and high arousing positive items were remembered just as accurately as neutral items.

The mechanisms underlying the effects of emotional content on memory are not fully understood. It is currently unclear whether arousal and/or valence directly affects memory accuracy or creates more gist-based, generalizable memory that increases the resemblance between false and true memories, which would increase false alarms (Brainerd et al., 2008; Howe et al., 2010). For example, ERP evidence suggests the frontal cortex may be involved in relaxing retrieval criteria for negative stimuli to ensure that emotional events are not as easily forgotten as neutral events (Windmann & Kutas, 2001), and the amygdala, in interaction with the hippocampus, modulates memory for arousing experiences (Adolphs et al., 2005). We find evidence that high arousal may increase generalizability in children, since both negative and positive high arousing items evinced more hits than neutral items, but also had more false alarms. However, low arousing negative items had *less* hits and unaffected false alarms. This could suggest that high arousal increases generalizability or changes retrieval criteria, but negative valence in the absence of high arousal could affect memory accuracy in children. We speculate that children in the age range of our study, especially girls, may tend to suppress memory of negative items. This suppression is stronger for negative content that is low in arousal, potentially because they are easier to process and regulate. Future studies are needed to test this interpretation, for example by using eye tracker to probe children's processing of emotional stimuli (across valence and arousal) at encoding.

Effects of stress exposure and associations with cortisol

We found that the effects of exposure to the same psychosocial stressor differed by gender. First, girls were more reactive to stress than boys: They reported higher subjective stress increases following stress exposure, and had higher cortisol stress responses. Several previous studies have reported higher cortisol stress responses in girls than boys, although the evidence overall is mixed and should be explored meta-analytically (Gunnar et al., 2009;

Hatzinger et al., 2007, 2013; Hostinar et al., 2015; Quesada et al., 2012; Raffington et al., 2019; Räikkönen et al., 2010; Stroud et al., 2009; Yim et al., 2010).

Second, memory for low arousing negative items was significantly lower in girls in the stress condition than boys in the stress condition, as well as than girls in the control condition. We speculate that children are generally less stressed by psychosocial public speaking tasks than adolescents/adults, and therefore do not show as reliable memory impairments of pre-encoding stress as them (Shields et al., 2017). For instance, one previous developmental study reports a lack of stress condition effect on 7-8-year-old children's memory after an approximately 15-min delay post stressor onset, whereas stressed adolescents showed improved hits (Quas et al., 2016). Yet, because girls were significantly more stressed than boys, as indicated by their subjective responses and cortisol secretion, stress had an effect on their memory for low arousing negative items. In contrast, boys' memory did not differ due to exposure to psychosocial stress. While girls in the control group were already showing generally worse (or suppressed) memory for negative items, psychosocial stress might have led girls in the TSST condition to engage in even stronger suppression, particularly for low arousal items that were easier to regulate.

Third, amongst girls in the stress condition, but not boys, a higher cortisol stress response was associated with better corrected memory for low and high arousing negative items, and high arousing positive items relative to neutral items. However, keeping in mind that girls in the stress condition showed memory suppression for negative items, we noted that cortisol response was not related to a true enhancement of the negative items relative to the neutral items, but a reduced difference between them. In other words, we postulate that girls who showed higher cortisol response may have had a harder time to suppress their memory for negative items. For example, for the low arousing negative items, only 7 girls (out of 48 girls in the stress group) showed better memory for these items than the neutral ones. This stands in contrast to the high arousing positive items, where 23 girls (out of 48) showed better memory for these items than the neutral ones (*i.e.,* true enhancement). Interestingly, our results resemble those of Quas et al. (2018), where girls (as well as boys) with higher cortisol responses to stress showed better corrected memory for negative images. However, as there was no control group in that study, it is unclear whether the positive relationship existed with the backdrop of a suppression effect in the stress group. Our study provides novel insight by documenting a strong suppression effect in the girls of stress group compared to control group for the negative items. Nevertheless, across studies, one may speculate that girls with higher cortisol stress responses may, depending on age, either have more difficulties in suppressing or more susceptible to remembering stressful or emotional events, which could come at a cost for mental health.

Finally, for both girls in the stress condition and boys, background scene memory was impaired by a pairing with high arousing negative items compared to neutral and low arousing items of both positive and negative valence. In contrast, background scene memory was facilitated by a pairing with low arousing positive items across stress/control groups. These findings may imply that while mildly emotional stimuli themselves do not in general produce background trade-off in children, prior exposure to stress seems to reduce memory for backgrounds paired with high arousing negative items. Future studies would benefit from manipulating the relatedness of item and background stimuli and contrasting memory for stressor-unrelated emotional items with naturalistic memory of the stressor itself.

Data Availability

The datasets analyzed during the current study along with the R analysis scripts are available on the Open Science Framework (https://osf.io/j23ke/). Task code and items will be shared upon request.

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Conflicts of interest: None.

References

Adolphs, R., Tranel, D., & Buchanan, T. W. (2005). Amygdala damage impairs emotional memory for gist but not details of complex stimuli. *Nature Neuroscience*, *8*(4), 512–518. https://doi.org/10.1038/nn1413

Bagozzi, R. P. (1983). Issues in the Application of Covariance Structure Analysis: A Further Comment. *Journal of Consumer Research*, *9*(4), 449. https://doi.org/10.1086/208939

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). *Package 'Ime4.'*

Bradley, M. M., & Lang, P. J. (1994). Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry*, *25*(1), 49–59. https://doi.org/10.1016/0005-7916(94)90063-9

Brainerd, C. J., Stein, L. M., Silveira, R. A., Rohenkohl, G., & Reyna, V. F. (2008). How does negative emotion cause false memories? *Psychological Science*, *19*(9), 919–925. https://doi.org/10.1111/j.1467-9280.2008.02177.x

Buske-Kirschbaum, A., Jobst, S., Wustmans, A., Kirschbaum, C., Rauh, W., & Hellhammer, D. H. (1997). Attenuated free cortisol response to psychosocial stress in children with atopic dermatitis. *Psychosomatic Medicine*, *426*, 419–426. https://doi.org/10.1097/00006842-199707000-00012

Cordon, I. M., Melinder, A. M. D., Goodman, G. S., & Edelstein, R. S. (2013). Children's and adults' memory for emotional pictures: Examining age-related patterns using the Developmental Affective Photo System. *Journal of Experimental Child Psychology*, *114*(2), 339–356.

Doerksen, S., & Shimamura, A. P. (2001). Source Memory Enhancement for Emotional Words. *Emotion*, *1*(1), 5–11. https://doi.org/10.1037/1528-3542.1.1.5

Dougal, S., & Rotello, C. M. (2007). "Remembering" emotional words is based on response bias, not recollection. *Psychonomic Bulletin and Review*, *14*(3), 423–429. https://doi.org/10.3758/BF03194083

Eisenberg, N., Cumberland, A., & Spinrad, T. L. (1998). Parental socialization of emotion. *Psychological Inquiry*, *9*(4), 241–273. https://doi.org/10.1207/s15327965pli0904_1

Felt, J. M., Depaoli, S., & Tiemensma, J. (2017). Latent Growth Curve Models for Biomarkers of the Stress Response. *Frontiers in Neuroscience*, *11*(JUN), 1–17. https://doi.org/10.3389/fnins.2017.00315

Grice, J. W. (2001). Computing and evaluating factor scores. *Psychological Methods*, *6*(4), 430–450. https://doi.org/10.1037/1082-989X.6.4.430

Gunnar, M. R., Wewerka, S., Frenn, K., Long, J. D., & Griggs, C. (2009). Developmental changes in hypothalamus-pituitary-adrenal activity over the transition to adolescence: Normative changes and associations with puberty. *Development and Psychopathology*, *21*(1), 69–85. https://doi.org/10.1017/S0954579409000054

Hamann, S., & Stevens, J. S. (2013). Memory for Emotional Stimuli in Development. In *The Wiley Handbook on the Development of Children's Memory* (pp. 724-742 Verfasser:).

Hatzinger, M., Brand, S., Perren, S., Von Wyl, A., Stadelmann, S., von Klitzing, K., & Holsboer-Trachsler, E. (2013). In pre-school children, cortisol secretion remains stable over 12 months and is related to psychological functioning and gender. *Journal of Psychiatric Research*, *47*(10), 1409–1416. https://doi.org/10.1016/j.jpsychires.2013.05.030

Hatzinger, M., Brand, S., Perren, S., von Wyl, A., von Klitzing, K., & Holsboer-Trachsler, E. (2007). Hypothalamic–pituitary–adrenocortical (HPA) activity in kindergarten children: Importance of gender and associations with behavioral/emotional difficulties. *Journal of Psychiatric Research*, *41*(10), 861–870. https://doi.org/10.1016/j.jpsychires.2006.07.012

Hermans, E. J., Henckens, M. J. A. G., Joëls, M., & Fernández, G. (2014). Dynamic adaptation of large-scale brain networks in response to acute stressors. *Trends in Neurosciences*, *37*(6), 304–314. https://doi.org/10.1016/j.tins.2014.03.006

Hostinar, C. E., Johnson, A. E., & Gunnar, M. R. (2015). Parent support is less effective in buffering cortisol stress reactivity for adolescents compared to children. *Developmental Science*, *18*(2), 281–297. https://doi.org/10.1111/desc.12195

Howe, M. L., Candel, I., Otgaar, H., Malone, C., & Wimmer, M. C. (2010). Valence and the development of immediate and long-term false memory illusions. *Memory*, *18*(1), 58–75. https://doi.org/10.1080/09658210903476514

Ji, J., Negriff, S., Kim, H., & Susman, E. J. (2016). A study of cortisol reactivity and recovery among young adolescents: Heterogeneity and longitudinal stability and change. *Developmental Psychobiology*, *58*(3), 283–302. https://doi.org/10.1002/dev.21369

Joëls, M., Fernandez, G., & Roozendaal, B. (2011). Stress and emotional memory: A matter of timing. *Trends in Cognitive Sciences*, *15*(6), 280–288. https://doi.org/10.1016/j.tics.2011.04.004

Kensinger, E. A., & Schacter, D. L. (2007). Remembering the specific visual details of presented objects: Neuroimaging evidence for effects of emotion. *Neuropsychologia*, *45*(13), 2951–2962. https://doi.org/10.1016/j.neuropsychologia.2007.05.024

Koss, K. J., & Gunnar, M. R. (2018). Annual Research Review: Early adversity, the hypothalamic-pituitary-adrenocortical axis, and child psychopathology. *Journal of Child Psychology and Psychiatry*, *59*(4), 327–346. https://doi.org/10.1111/jcpp.12784

Krauel, K., Duzel, E., Hinrichs, H., Santel, S., Rellum, T., & Baving, L. (2007). Impact of Emotional Salience on Episodic Memory in Attention-Deficit/Hyperactivity Disorder: A Functional Magnetic Resonance Imaging Study. *Biological Psychiatry*, *61*(12), 1370–1379. https://doi.org/10.1016/j.biopsych.2006.08.051

Länder, S. A. des B. und der. (2018a). *Internationale Bildungsindikatoren im Ländervergleich*.

Länder, S. A. des B. und der. (2018b). *Sozialberichterstattung – Armutsgefährdungsquoten 2005-2017*.

Leventon, J. S., & Bauer, P. J. (2016). Emotion regulation during the encoding of emotional stimuli: Effects on subsequent memory. *Journal of Experimental Child Psychology*, *142*, 312–333. https://doi.org/10.1016/j.jecp.2015.09.024

Leventon, J. S., Stevens, J. S., & Bauer, P. J. (2014). Development in the neurophysiology of emotion processing and memory in school-age children. *Developmental Cognitive Neuroscience*, *10*, 21–33. https://doi.org/10.1016/j.dcn.2014.07.007

Maas, C. J. M., & Hox, J. J. (2005). Sufficient sample sizes for multilevel modeling. *Methodology*, *1*(3), 86–92. https://doi.org/10.1027/1614-2241.1.3.86

Mather, M., & Nesmith, K. (2008). Arousal-enhanced location memory for pictures. *Journal of Memory and Language*, *58*(2), 449–464.

McManis, M. H., Bradley, M. M., Berg, W. K., Cuthbert, B. N., & Lang, P. J. (2001). Emotional reactions in children:Verbal, physiological, and behavioral responses to affective pictures. *Psychophysiology*, *38*, 222–231.

Pruessner, J. C., Kirschbaum, C., Meinlschmid, G., & Hellhammer, D. H. (2003). Two formulas for computation of the area under the curve represent measures of total hormone concentration versus time-dependent change. *Psychoneuroendocrinology*, *28*(7), 916–931. https://doi.org/10.1016/S0306-4530(02)00108-7

Quas, J. A., Castro, A., Bryce, C. I., & Granger, D. A. (2018). Stress physiology and memory for emotional information: Moderation by individual differences in pubertal hormones. *Developmental Psychology*, *54*(9), 1606–1620. https://doi.org/10.1037/dev0000532

Quas, J. A., Rush, E. B., Yim, I. S., Edelstein, R. S., Otgaar, H., & Smeets, T. (2016). Stress and emotional valence effects on children’s versus adolescents’ true and false memory. *Memory*, *24*(5), 696–707. https://doi.org/10.1080/09658211.2015.1045909

Quas, J. A., Yim, I. S., Edelstein, R. S., Cahill, L., & Rush, E. B. (2011). The role of cortisol reactivity in children's and adults' memory of a prior stressful experience. *Developmental Psychobiology*, *53*(2), 166–174.

Quesada, A. A., Wiemers, U. S., Schoofs, D., & Wolf, O. T. (2012). Psychosocial stress exposure impairs memory retrieval in children. *Psychoneuroendocrinology*, *37*(1), 125–136. https://doi.org/10.1016/j.psyneuen.2011.05.013

Raffington, L., Malanchini, M., Grotzinger, A. D., Madole, J. W., Engelhardt, L. E., Sabhlok, A., Youn, C., Patterson, M., Harden, K. P., & Tucker-Drob, E. M. (2019). Changing environments reveal innovative genetic variation in children's cortisol responses. *BioRxiv [Preprint]*, 1–21. https://doi.org/10.1101/856658

Raffington, L., Prindle, J., Keresztes, A., Binder, J., Heim, C. M., & Shing, Y. L. (2018). Blunted cortisol stress reactivity in low–income children relates to lower memory function. *Psychoneuroendocrinology*, *90*, 110–121. https://doi.org/10.1016/j.psyneuen.2018.02.002

Räikkönen, K., Matthews, K. A., Pesonen, A.-K., Pyhälä, R., Paavonen, E. J., Feldt, K., Jones, A., Phillips, D. I. W., Seckl, J. R., Heinonen, K., Lahti, J., Komsi, N., Järvenpää, A.-L., Eriksson, J. G., Strandberg, T. E., & Kajantie, E. (2010). Poor sleep and altered hypothalamic-pituitary-adrenocortical and sympatho-adrenal-medullary system activity in children. *The Journal of Clinical Endocrinology & Metabolism*, *95*(5), 2254–2261. https://doi.org/10.1210/jc.2009-0943

Rudolph, K. D., & Hammen, C. (1999). Age and gender as determinants of stress exposure, generation, and reactions in youngsters: A transactional perspective. *Child Development*, *70*(3), 660–677. https://doi.org/10.1111/1467-8624.00048

Rush, E. B., Quas, J. A., & Yim, I. S. (2011). Memory narrowing in children and adults. *Applied Cognitive Psychology*, *25*(6), 841–849. https://doi.org/10.1002/acp.1757

Schwabe, L., Bohringer, A., Chatterjee, M., & Schachinger, H. (2008). Effects of pre-learning stress on memory for neutral, positive and negative words: Different roles of cortisol and autonomic arousal. *Neurobiology of Learning and Memory*, *90*(1), 44–53. https://doi.org/10.1016/j.nlm.2008.02.002

Schwabe, L., Joëls, M., Roozendaal, B., Wolf, O. T., & Oitzl, M. S. (2012). Stress effects on memory: An update and integration. *Neuroscience & Biobehavioral Reviews*, *36*(7), 1740–1749. https://doi.org/10.1016/j.neubiorev.2011.07.002

Schwabe, L., & Wolf, O. T. (2013). Stress and multiple memory systems: From 'thinking' to 'doing.' *Trends in Cognitive Sciences*, *17*(2), 60–68. https://doi.org/10.1016/j.tics.2012.12.001

Shields, G. S., Sazma, M. A., McCullough, A. M., & Yonelinas, A. P. (2017). The effects of acute stress on episodic memory: A meta-analysis and integrative review. *Psychological Bulletin*, *143*(6), 636–675. https://doi.org/10.1037/bul0000100

Stenson, A. F., Leventon, J. S., & Bauer, P. J. (2019). Emotion effects on memory from childhood through adulthood: Consistent enhancement and adult gender differences. *Journal of Experimental Child Psychology*, *178*, 121–136. https://doi.org/10.1016/j.jecp.2018.09.016

Stroud, L., Foster, E., Papandonatos, G., Handwerger, K., Granger, D. A., Kivlighan, K., & Niaura, R. (2009). Stress response and the adolescent transition: Performance versus peer rejection stressors. *Development Psychopathology*, *21*(1), 47–68.

Troncoso Skidmore, S., & Thompson, B. (2013). Bias and precision of some classical ANOVA effect sizes when assumptions are violated. *Behavior Research Methods*, *45*(2), 536–546. https://doi.org/10.3758/s13428-012-0257-2

Turner, R. J., & Avison, W. R. (2003). Status variations in stress exposure: Implications for the interpretation of research on race, socioeconomic status, and gender. *Journal of Health and Social Behavior*, *44*(4), 488. https://doi.org/10.2307/1519795

Vasa, R. A., Pine, D. S., Thorn, J. M., Nelson, T. E., Spinelli, S., Nelson, E., Maheu, F. S., Ernst, M., Bruck, M., & Mostofsky, S. H. (2011). Enhanced right amygdala activity in adolescents during encoding of positively valenced pictures. *Developmental Cognitive Neuroscience*, *1*(1), 88–99. https://doi.org/10.1016/j.dcn.2010.08.004

Waring, J. D., & Kensinger, E. (2009). Effects of emotional valence and arousal upon memory trade-offs with aging. *Psychology and Aging*, *24*(2), 412–422. https://doi.org/10.1037/a0015526

Windmann, S., & Kutas, M. (2001). Electrophysiological correlates of emotion-induced recognition bias. *Journal of Cognitive Neuroscience*, *13*(5), 577–592. https://doi.org/10.1162/089892901750363172

Yim, I. S., Quas, J. A., Cahill, L., & Hayakawa, C. M. (2010). Children's and adults' salivary cortisol responses to an identical psychosocial laboratory stressor.

Psychoneuroendocrinology, *35*(2), 241–248.

https://doi.org/10.1016/j.psyneuen.2009.06.014

Supplementary Material

Table S1. Emotional memory items.

Valence	Positive		Neutral	Negative	
Arousal	High	Low	Neutral	Low	High
			Girls		
	Banana sundae	**Birthday cake**	**Alligator toy**	**Blood**	Alien
	Bow	**Candy present**	**Beetle**	Coffee machine	**Angry woman**
	Butterfly	**Chips**	**Blood 2**	**Crying baby**	Arrest
	Cinnamon rolls	**Chocolates**	**Bongo**	**Crying baby 2**	**A knife-like tool**
	Cupcakes	**Cocktails**	**Bowling pin**	Eggplant	**Bee 2**
	Diamond ring	Crown	Camel	**Forceps**	**Cockroaches**
	Dice	**Gift**	**Frog**	**Grenade**	Cut
	Easter	Gold coins	Geode	**Hammer**	Disgusted man
	Ice cream	**Horse**	**Globe**	**Helicopter**	**Fist**
	Leaves	**Lollipop**	**Gumball machine**	**Hippopotamus**	Handcuffs
	Muffin	**Mixer**	**Lawnmower**	**Hockey fight**	Handgun
	Palette	Money jar	**Lizard**	**Hygienist**	Holdup
	Pretzels	**Noisemaker**	**mummy**	**Oxygen tank**	Hook
	Propeller	**Party supply**	**Rat**	**Patient**	Knife
	Puppy	Pot of gold	**Rollerblade**	**Sardines**	Mace
	Rhino	**Pumpkin**	**Screwdriver**	**School bus**	**Monster 2**
	Ribbon	**Rabbit2**	**Seagull**	**Semiautomatic**	**Mosquito**
	Rose	Ribbon	**Shackles 2**	**Staples**	Pistol
	Rug	**Santa Claus**	**Swing set**	**Stretcher**	Rifle
	Soccer ball	**Sled**	**Tattoo artist**	**Sword**	**Saber**
	Sponge bob	**Soldier**	**Thermometer**	**Teakettle**	Saber 2
	Sports car	Tiger	**Tie**	**Tongs**	Shackles
	Sunflower	Treasure chest	**Tombstone**	**Vulture**	Spider
	Toaster	Trophy	**Wheel**	**Whistle**	**Suicide**
	Toy parrot	**Unicycle**	Yacht	**Wrench**	**Tarantula**
			Boys		
	Banana sundae	Cheetah	Axe	Ashtray	Alien
	Butterfly	Controller	Beetle 2	Ballerina	Arrest
	Candy bar	Crown	Brooch	Beehive	Tool
	Candy chest	Game boy	Camel	Carpentry accident	Blood
	Cannolis	Gold coins	Crossbones	Clogs	Chemical splash suit
	Cinnamon rolls	Gumball machine	Dental tray	Cockroaches	Cut
	Dice	Lion	Evidence	Coffee machine	Disgusted man
	Dog toy	Man soccer	Firetruck	Eggplant	Gasmask
	Giraffe	Meat	Gargoyle	Fall leaf	Glass eye
	Ice cream	Medal	Geode	Hair dryer	Gorilla
	Leaves	Money jar	Hang glider	Handgun 2	Handcuffs
	Leopard	Polar bear	Plane toy	Hypodermic needle	Handgun
	Lollipop	Pot of gold	Potato man	Iron	Holdup
	Muffin	Rattlesnake	Scream	Metal toy	Hook
	Penguin	Ribbon	Skull	Oxygen tank	Knife
	Pretzels	Rocket	Skull 2	Pills	Mace
	Puppy	Scuba diver	Stuffed bear	Sardines	Monster

Rose	Speedboat	Toy horse	Scream2	Mummy
Rug	Tabby cat	Tropical fish	Scythe	Pistol
Santa Claus	Tiger	Trout	Smile sit	Prisoner
Skip	Toboggan	Wade pool	Springs	Rifle
Slinky	Treasure chest	Wasp	Staples	Saber 2
Sponge bob	Trophy	Water bug	Suit	Shackles
Sports car	Turtle	Whistle	Syringe	Smiling hat
Toucan	Zebra	Yacht	Vest	Spider

[a] List of items (Kensinger & Schacter, 2007) contained in each emotional categories for girls and boys. Bold items differ by gender.

Table S2. Mean valence and arousal rating for each category.

Category	Dimension	Boys mean (*sd*)	Girls mean (*sd*)	*t*-test (*p*)
Positive high arousal	valence	2.14 (0.56)	2.05 (0.55)	.581
	arousal	3.17 (1.45)	2.95 (1.10)	.545
Positive low arousal	valence	2.14 (0.51)	2.00 (0.50)	.340
	arousal	7.29 (1.02)	7.05 (1.06)	.419
Neutral	valence	4.49 (0.63)	4.42 (0.36)	.597
	arousal	4.92 (0.52)	4.98 (0.52)	.625
Negative low arousal	valence	7.08 (0.94)	6.89 (0.86)	.419
	arousal	6.97 (0.67)	6.71 (0.95)	.282
Negative high arousal	valence	7.44 (0.86)	7.20 (0.90)	.581
	arousal	2.92 (1.27)	2.63 (1.18)	.545

T-test comparing boy and girl task versions on arousal and valence ratings.

Table S3.

Category		Positive high arousal		Positive low arousal		Neutral		Negative low arousal	
		Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Positive low arousal	valence	.967	.769						
	arousal	<.001	<.001						
Neutral	valence	<.001	<.001	<.001	<.001				
	arousal	<.001	<.001	<.001	<.001				
Negative low arousal	valence	<.001	<.001	<.001	<.001	<.001	<.001		
	arousal	<.001	<.001	.195	.244	<.001	<.001		
Negative high arousal	valence	<.001	<.001	<.001	<.001	<.001	<.001	.166	.776
	arousal	.391	.323	<.001	<.001	<.001	<.001	<.001	<.001

Two-tailed t-test assuming unequal variance comparing arousal and valence between different categories. For example, the top left panel compares the items of positive high arousal to items of positive low arousal on valence.