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Positive memory retrieval generates pleasant feelings that can counteract negative affective states and improve mood. However, not all positive memories are created equal. Our most treasured memories are likely experiences we shared with other people (e.g., birthday party) rather than something we did alone (e.g., receiving good grades). Here, we explored whether the social context within a positive memory enhanced its subjective value and contributed to an individual's well-being. In Study 1, participants were asked how much they would be willing to pay to reexperience positive memories that occurred with socially close others (high-social), with acquaintances (low-social) or alone (nonsocial). When controlling for the memory's positivity, participants were still willing to pay 1.5 times as much for high-social than for low-social or nonsocial memories. Likewise, participants chose to reminisce about high-social memories more frequently than less social ones of equal positive feeling. In Study 2, recalling memories rich in social context recruited regions previously implicated in mentalizing and reward (e.g., caudate), which further correlated with greater ability to savor positive emotions in daily life. Finally, we examined the benefit of social context by asking participants to recall positive memories that varied in social context after acute stress exposure. In Study 3, recalling memories that included higher social context led to a greater dampening of the physiological stress response (i.e., cortisol). Taken together, these findings suggest that social context inherent in a positive memory enhances its value, providing a possible mechanism by which positive reminiscence aids stress coping and enhances well-being.

Keywords: social rewards, autobiographical memory, positive emotion, stress, neuroimaging

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Reminiscing about happy autobiographical memories generates pleasant feelings that can counteract negative affect and improve mood (Bower, 1981). While there is behavioral and neural evidence that thinking about the past in a positive light is intrinsically rewarding (Speer, Bhanji, & Delgado, 2014), not all positive memories are created equal. We often reflect more fondly or nostalgically on experiences we shared with other people (e.g., celebrating a birthday) than experiences we had alone (e.g., receiving good grades). This is even prevalent in our everyday conversations. We enjoy recounting our shared histories with loved ones at the dinner table or rehashing the good times when reconnecting with old friends. Given this intuition, do we place a higher value on reminiscing about positive memories that are rich in social context?

An emerging literature on the rewarding nature of social interactions may shed some light. Much like receiving primary and secondary rewards such as food or money (Haber & Knutson, 2010), social acts like giving to charity (Hare, Camerer, Knoepfle, & Rangel, 2010) or receiving positive feedback or approval (Sherman, Payton, Hernandez, Greenfield, & Dapretto, 2016) are perceived as rewarding and similarly activate the neural reward system (e.g., striatum, medial prefrontal cortex; Wake & Izuma, 2017). These kinds of social rewards are also reflected in the positive experiences we share with other people. Eating delicious food (Boothby, Clark, & Bargh, 2014) or viewing images or photographs (Kawamichi et al., 2016; Wagner et al., 2015) together with a familiar individual generates greater positive emotions and striatal activation than solo experiences or sharing with unfamiliar others. Importantly, the behavioral and neural indices of social rewards scale with their frequency and are magnified by how close we feel to the individual(s) with whom we are interacting (Boothby, Smith, Clark, & Bargh, 2016; Fareri, Niznikiewicz, Lee, & Delgado, 2012). In the context of memory, this invites an intriguing question: While it is no secret that it feels good to remember past positive events, is reminiscing especially valuable *when* it is rich in social context? Further, how is the "social value" of a positive memory represented in the brain?

This research explored the subjective value associated with the social context of positive autobiographical memories across three studies. In Study 1, we assessed individual preference to reminisce about memories that occurred with socially close others (high-social), with acquaintances (low-social), or alone (nonsocial). We also sought to quantify the subjective value of a memory's social context by asking participants how much hypothetical money they

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would spend for the opportunity to reexperience positive memories that varied in social context. Using functional MRI (fMRI), Study 2 investigated the neural circuitry associated with a memory's social context over and above the positive emotion it elicits. We hypothesized that regions classically associated with reward processing (e.g., striatum) and mentalizing about other people (e.g., medial prefrontal cortex [PFC], temporoparietal junction) would be sensitive to the social context of memory.

Finally, we tested the potential benefit of reminiscing about positive social memories. In Study 3, individuals underwent an acute stressor and then reminisced about positive memories that varied in social context. While interventions that increase positive emotions have been shown to counteract the effects of stress (Tugade & Fredrickson, 2004), including positive memories (Speer & Delgado, 2017), here we hypothesized that socially rich memories would bolster this effect, leading to greater reductions in cortisol than memories experienced solo or with unfamiliar individuals, even when divorced from positive emotion.

Study 1: Decision-Making

Method

Participants.   Fifty-two healthy individuals participated. We determined our sample size using pilot data that indicated a small to medium effect size ($d = .35$). G*power calculated target recruitment to be 52 (to achieve 80% power). Five participants were excluded prior to data analysis for not reporting enough memories that met criteria (see Procedure). Final sample included 47 participants (17 males, $M_{age} = 21.2$, $SD = 5.56$). Participants provided informed consent in accordance with the Rutgers Institutional Review Board (IRB).

Procedure.

Autobiographical Memory Questionnaire.   Participants wrote about real positive memories from their past prompted by 62 common life event cues (e.g., playing in the snow), similar to prior studies (Markowitsch, Vandekerckhove, Lanfermann, & Russ, 2003; Speer et al., 2014). Memories had to occur at a specific place and time, and the participant had to be personally involved. For each positive memory, they provided a description, date, emotion ratings for feeling (How does this memory make you feel in the present moment? 1–4: 1 = *neither good nor bad,* 4 = *very good*) and intensity (How intense is the memory? 1–4: 1 = *not intense,* 4 = *very intense*), and a social context rating (Who else was present in the memory? 1–3: 1 = *nonsocial* [alone], 2 = *low-social* [with acquaintances], 3 = *high-social* [with close others]).

Based on these responses, event cues corresponding to 28 memories were selected on an individualized basis for use in a memory choice task (online supplemental Table S1). Specifically, 10 pairs of memories (20 total) were selected for experimental trials. Each pair contained one memory high in social context (rating of "3") and one rated as either nonsocial or low-social (rating of "1" or "2"). Importantly, while the memories differed in social context, they were equated for feeling rating (e.g., both generated a feeling rating of "2"). For these feeling-matched memory pairs, we used the full range of the feeling rating scale ranging from low (1) to high (4) in positivity, when possible, based on each participant's Autobiographical Memory Questionnaire (AMQ). Only participants who had at least eight memory pairs who met criteria were

included in final data analysis. Four additional memory cue pairs (8 memories total) not equated for feeling were used as "catch" trials in the memory choice task, reaching 28 cues/memories total. These same 28 cues along with 8 additional cues (to comprise 36 memories total, 12 high-social, 12 low-social, and 12 nonsocial) were selected for use in the willingness-to-pay (WTP) task. We added these eight additional cues to the WTP task so that each social context condition would have an equal number of memories, as the memory choice task had more high-social than low-social or nonsocial memories. See online supplemental Table S2 for descriptive statistics of memories recalled in these tasks.

Memory choice task.   Participants made a choice between recalling two different positive memories on each of 14 trials (10 experimental, 4 catch). For the 10 experimental trials, participants chose between two positive memories of equal feeling rating that only differed in social context: One was rated as high-social, whereas the other was low-social or nonsocial. For the four catch trials, participants chose between two positive memories that were not of equal feeling and did not necessarily differ in social context. Catch trials were included to ensure participants were paying attention. On each trial, participants first saw the two cues corresponding to two different memories. They had 6 s to make their choice by making a button press. After a 2-4 s delay, participants saw the memory cue they selected and had 14 s to reminisce about it. They made button presses to indicate recall duration (i.e., beginning and end of the memory), followed by a 4-6 s delay. The position of the high-social memory on the screen (left or right) was counterbalanced across trials.

WTP to reexperience task.   In a typical WTP task, the value of a stimulus is assessed by the willingness of participants to forgo their own resources (e.g., money) in exchange for another good (e.g., food). In previous versions of WTP tasks, stimuli have ranged from consumable goods such as food (e.g., Hare, Camerer, & Rangel, 2009) to more abstract rewards like self-disclosure to others (Tamir & Mitchell, 2012) or recalling positive memories (Speer et al., 2014). Here, we asked participants how much they would hypothetically be willing to pay to relive a prior experience. On each of 36 trials, participants saw one event cue corresponding to one positive memory and these instructions: "Imagine that you have $1,000. On a scale of $0–$1,000, how much would you be willing to pay to re-live this experience?" On each trial, they always had $1,000 to spend, and their spending amount on one trial did not affect subsequent trials. They typed in their chosen monetary value without time restrictions, followed by a 2-4 s delay. The 36 trials (12 of each social context) were presented in random order.

Data analysis.   To measure choice behavior, we calculated the percentage of time participants chose high-social memories (relative to low-social/nonsocial memories) during the choice task. We then performed a one-sample t test in comparison to chance (50%). To examine how WTP related to social context while controlling for feeling ratings, we first calculated the mean WTP value for each type of memory separately (high-social, low-social, and non-social). We then performed a hierarchical regression analysis with memory feeling ratings entered as the first variable, followed by social context ratings as the second variable and WTP value as the dependent variable. We followed up significant effects with pairwise t tests across levels of social context.

Results

Effect of social context on positive memory choice. Participants made choices between memories of higher social context (with socially close others) and memories of lower social context (with acquaintances/alone; Figure 1a). As expected, participants chose to reminisce about high-social memories more frequently (56.2% of the time) than low-social or nonsocial memories (43.8% of the time), even though the memories were of equal feeling (Figure 1b). The percentage of time they chose high-social memories was significantly greater than chance ($t_{46} = 2.32$, $p = .025$, $d = 0.35$, 95% CI [0.01, 0.12], achieved power = 76.4%). There were no reaction time differences when making choices to recall memories of higher or lower social context ($t_{46} = 1.33$, $p = .19$).

Effect of social context on WTP to reexperience a positive memory. Our hypothesis was that social context predicts the value of a memory over and above feeling ratings. To test this, we performed a hierarchical regression analysis with memory feeling ratings entered as the first variable, followed by memory social context ratings as the second variable and WTP value as the dependent variable. In Step 1, the model was only trending in its prediction of value when considering feeling ratings alone ($F_{1, 137} = 3.70$, $p = .056$, $R^2 = .026$). Consistent with our hypothesis, the model in Step 2 was significantly improved when including social context ratings ($F_{2, 136} = 9.55$, $p < .001$, $R^2 = .123$, R^2 change = .097). This further indicated that social context was the most important predictor as it uniquely explained 9.7% of the variance associated with WTP value ($\beta = .320$, $t_{90} = 3.88$, $p < .001$, 95% CI [38.3, 118.2]), whereas feeling was no longer a predictor ($\beta = .087$, $t_{90} = 1.05$, $p = .297$, 95% CI [−24.6, 80.0]). Specifically, when controlling for feeling ratings, participants were

willing to pay 1.5 times more for high-social memories than for low-social memories ($t_{90} = 2.73$, $p = .008$, $d = 0.57$, 95% CI [31.0, 196.8], achieved power = 96.9%) and 1.8 times more than for nonsocial memories ($t_{92} = 4.33$, $p < .001$, $d = 0.89$, 95% CI [90.2, 242.8], achieved power = 99.9%; Figure 2). There was no difference in WTP value between low-social and nonsocial memories ($t_{90} = 1.36$, $p = .176$, 95% CI [−24.0, 129.5]). We also tested whether the interaction of social context and feeling predicted WTP, but the interaction did not contribute to WTP over and above social context and feeling ($\beta = −.224$, $t_{90} = −.563$, $p = .574$).

Study 2: Neural Correlates

Study 1 revealed that positive memories experienced with socially close others carry additional value, as individuals preferentially chose to reminisce about them and spent more hypothetical money for the opportunity to reexperience them. We were next interested in the neural mechanisms associated with the social context of positive memory retrieval, over and above positive feeling. In Study 2, participants reminisced about social and nonsocial positive memories while undergoing functional MRI (fMRI) scanning and made subjective emotion ratings. We hypothesized that socially rich positive memories would engage regions previously implicated in reward valuation (e.g., striatum) and mentalizing about other people.

Method

Participants. Forty healthy individuals participated. To determine sample size, we used a combination of effect sizes from Study 1 behavioral analyses and a previous fMRI study that used
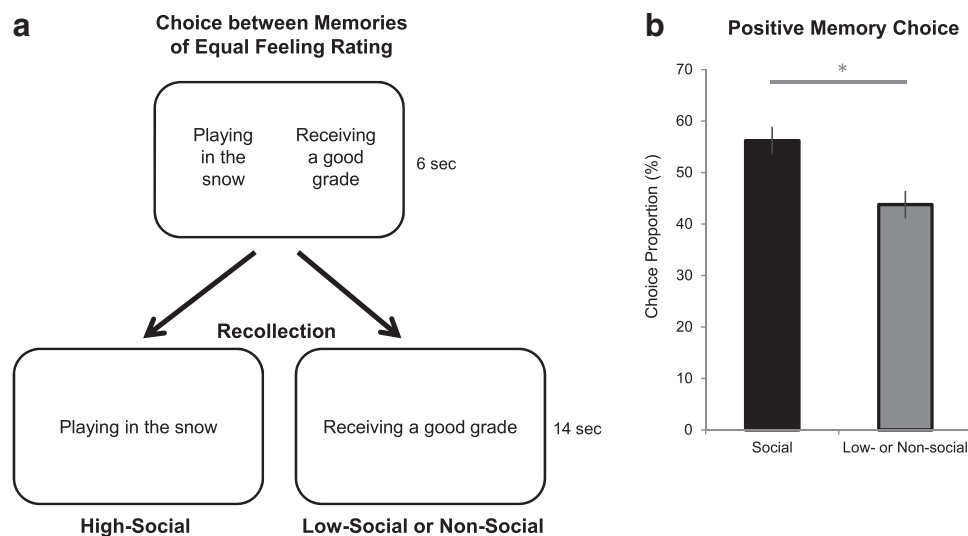
Figure 1. Positive memory choice task. (a) On each trial, participants made a choice between two life event cues that would each trigger a specific positive memory from their past. The two memory choices were always of equal feeling rating and only differed in social content. Specifically, one choice represented a high-social memory, and the other choice represented either a low-social or nonsocial memory. After making their choice, participants recalled the memory elicited by the selected event cue for 14 s and made button presses to indicate the beginning and end of recall. (b) Across the sample, participants chose to recall high-social memories (56.2%) more frequently than low- or nonsocial memories (43.8%). Error bars represent ± 1 SEM. * $p < .05$.
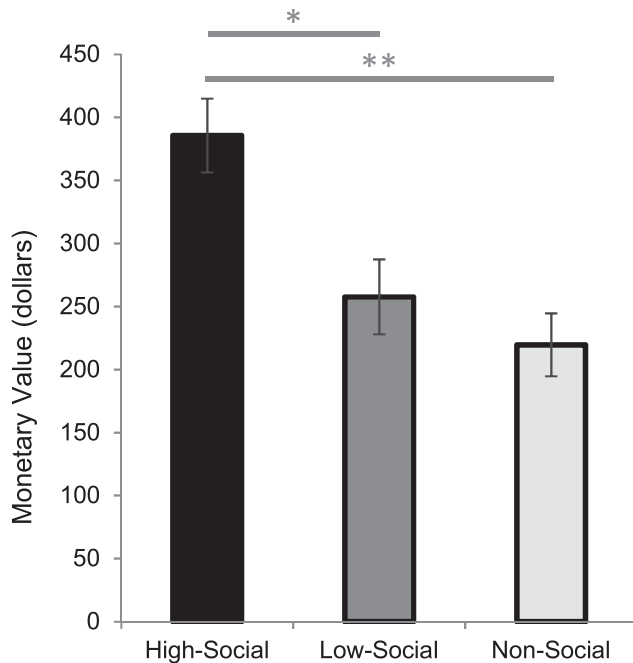
Figure 2. Willingness to pay to reexperience a positive memory. In this task, participants were asked how much they would be willing to pay to reexperience positive memories from their past (12 high-social, 12 low-social, 12 nonsocial). On each trial, they saw one life event cue and were told they had up to $1,000 to spend. On average, participants were willing to pay more for high-social memories ($M = \$386$, $SD = \$200$) than for low-social ($M = \$275$, $SD = \$200$) or nonsocial memories ($M = \$220$, $SD = \$171$), even when controlling for positive feeling ratings. Error bars represent $\pm$ 1 SEM. * $p < .01$. ** $p < .001$.

the same memory recall task, which yielded an effect size of .556 for region of interest (ROI) analyses of feeling ratings during positive > neutral recall (Speer et al., 2014). Because the present ROI analyses would examine a more nuanced aspect of recall—social context while controlling for feeling ratings—we expected a slightly smaller effect size ($d = .45$). G*power calculated the target sample to be 40 (to achieve 80% power). Exclusions included excessive head motion (>4 mm in any direction; $n = 3$), leaving a final sample of 37 participants (14 males; $M_{age} = 21.8$, $SD = 3.0$). All participants met criteria for scanning (right-handed, no implanted metal, not pregnant, no neurological or psychiatric disorders) and were not taking any medications. Participants provided informed consent in accordance with the Rutgers IRB.

Procedure. Participants first completed questionnaires asking about depressive and anxiety symptoms (Mood and Anxiety Symptom Questionnaire; Watson et al., 1995) and ability to savor positive emotions in daily life (Emotion Regulation Profile–Revised [ERP-R]; Nelis, Quoidbach, Hansenne, & Mikolajczak, 2011).

During fMRI scanning, participants performed a cued memory recollection task in which they reminisced about 24 positive memories. The 24 event cues were selected from the AMQ data from Study 1. They were cues for which (a) most participants tended to have a memory triggered by that particular cue and (b) that included a variety of social and nonsocial memories (see online

supplemental method for list of event cues). On each trial, participants saw one written life event cue (e.g., going to the beach) and thought about one specific positive memory associated with that event. During a 14 s time window, they made button presses indicating the "beginning" and "end" of recollection. After 2–4 s, they rated the memory for feeling and social closeness (3.5 s each). The feeling rating was the same as in Study 1. Social closeness ratings asked how close they felt to the individuals present in the memory (1–4: 1 = *low* [alone], 4 = *high* [with significant other, family, best friend]). Each trial included a different life event cue and all participants saw the same 24 cues. The length of one trial was 24 s, and the inter-trial interval was 6–10 s. Participants were debriefed and compensated for their time.

fMRI data acquisition and preprocessing. Neuroimaging data were acquired using a 3T Siemens Magnetom Trio scanner. We collected T1-weighted MPRAGE structural images in 176 sagittal slices measuring 1 mm (256 × 256 matrix, field of view (FOV) = 256 mm) and functional images in 35 contiguous oblique-axial slices (3-mm × 3-mm × 3-mm voxels) prescribed parallel to the anterior commissure - posterior commissure plane with a single-shot gradient echo-planar imaging (EPI) sequence (repetition time = 2 s, echo time = 25 ms, FOV = 192, flip angle 90°, bandwidth = 2,232 Hz/Px, echo spacing = 0.51).

Images were preprocessed using SPM12. We motion-corrected each time series to its first volume and then performed spatial unwarping to minimize geometric distortions due to susceptibility artifacts (Andersson, Hutton, Ashburner, Turner, & Friston, 2001). We coregistered the mean functional image to the anatomical scan and normalized the anatomical scan using the unified segmentation model (Ashburner & Friston, 2005). The normalized anatomical scan was subsequently used to reslice the functional data to standard stereotaxic space defined by the Montreal Neurological Institute. We then applied spatial smoothing using a Gaussian kernel of 5 mm full width half maximum.

We applied additional preprocessing steps using Functional Magnetic Resonance Imaging for the Brain Software Library (FSL) to minimize the impact of head motion on the neuroimaging data. We detected motion spikes using the FSL tool *fsl_motion_outliers*. The motion spikes were evaluated with two metrics: (a) root-mean-square (RMS) intensity difference of each volume relative to the reference volume obtained from the first time point and (b) frame-wise displacements calculated as the mean RMS change in rotation/translation parameters relative to the same reference volume. We subjected the metric values within a run to a boxplot threshold (75th percentile plus 1.5 times the interquartile range) and labeled volumes as spikes, which were subsequently removed via regression (Power, Schlaggar, & Petersen, 2015; Satterthwaite et al., 2013). Across all participants, this method removed 9.6% of volumes (range: 2.2% to 17%). Following the removal of motion spikes, we extracted brain material from the functional images and normalized the entire four-dimensional data set using a single scaling factor (grand-mean intensity scaling). We also passed the images through FSL's SUSAN (Smallest Univalue Segment Assimilating Nucleus) noise reduction filter using a 2-mm kernel (Smith & Brady, 1997), which allowed for greater signal-to-noise ratio while preserving the image structure. Lastly, we applied a high-pass temporal filter with a 100-s cutoff to remove low-frequency drift in the magnetic resonance signal. Applying the

temporal filter after the removal of motion spikes helps to minimize ringing artifacts (Satterthwaite et al., 2013).

fMRI data analysis. Functional data were analyzed using a random-effects general linear model in FSL. The memory task was modeled with regressors representing social memory and nonsocial memory. Given the variability in ratings across individuals, we defined nonsocial memory as ratings of 1–2 and social memory as ratings of 3–4. To control for positive emotion, two parametric regressors were included for feeling ratings (one for social and one for nonsocial memories) that were mean-centered and orthogonalized with respect to the memory regressors. A regressor representing missed trials was also included (i.e., no rating given, 4.1% missed trials, ranging from 0 to 5 missed trials out of 24). Recall duration was defined by participants' button presses during the 14-s recall period. Our key analysis was a contrast of social > nonsocial memory, controlling for feeling ratings on a trial-by-trial basis.

We performed ROI analyses to test our specific hypothesis that regions implicated in reward and mentalizing would be sensitive to the social context of memory. Reward-related ROIs included nucleus accumbens and caudate (both bilateral), defined by the peak coordinates of activation for positive > neutral autobiographical memory in prior studies (Speer et al., 2014; Speer & Delgado, 2017). The mentalizing network was defined by brain regions that are preferentially activated for the term *mentalizing* via a meta-analysis of 151 studies on Neurosynth (association test map; Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011). This included the medial PFC, temporal parietal junction, superior temporal sulcus, and temporal pole, among other regions. Given that regions comprising the mentalizing network (e.g., medial PFC) can serve a variety of functions beyond mentalizing and even social context, we investigated the mentalizing network in its entirety rather than testing individual ROIs within this network. Importantly, because we tested five different ROIs, $p < .01$ was considered significant to control for multiple comparisons. See the online supplemental results for exploratory whole-brain and connectivity analyses.

Results

Effect of social context on neural responses during memory recall. During the memory recollection task, on average, participants reminisced about 14.4 social memories ($SD = 2.46$; $M_{Feeling} = 3.37$, $SD = 0.28$) and 8.65 nonsocial memories ($SD = 2.45$; $M_{Feeling} = 2.70$, $SD = 0.48$; $t_{35} = 8.92$, $p < .001$, $d = 1.64$). We performed targeted ROI analyses to examine neural responses associated with the social context of positive memory retrieval over and above positive feeling. We found greater activity for social relative to nonsocial memory retrieval in one reward-related ROI (left caudate; $t_{36} = 2.73$, $p = .01$, $d = .449$, 95% CI [0.15, 1.04], achieved power = 85.0%; Figure 3a) and the mentalizing network ($t_{36} = 2.64$, $p = .012$, $d = .435$, 95% CI [0.10, 0.73], achieved power = 82.9%; Figure 3b). Importantly, memory onset ($t_{36} = -1.55$, $p = .130$) and recall duration ($t_{36} = 0.69$, $p = .495$) did not differ between social and nonsocial memories and thus the ease/difficulty of recalling and the time spent reminiscing cannot explain these findings. Although participants recalled more social than nonsocial memories, this did not drive our results as there was no relationship between the quantity of social relative to nonsocial

memories recalled and activity in the left caudate ($r_{36} = -0.03$, $p = .856$) or mentalizing network ($r_{36} = 0.26$, $p = .116$). When considering individual differences, greater caudate activity was further associated with greater ability to savor positive emotions in daily life, as measured by the ERP-R ($r_{36} = .341$, $p = .039$; Figure 3c). Whole-brain analyses did not find any significant effects when controlling for multiple comparisons (see online supplemental materials).

Study 3: Coping With Acute Stress

Study 2 revealed that recalling social relative to nonsocial memories was associated with reward-related activity (caudate) and the mentalizing network, complementing evidence from Study 1 that social memories may carry additional value. We also previously reported that recalling positive memories dampens cortisol levels after stress, whereas recalling neutral memories leads to the typical heightened stress response (Speer & Delgado, 2017). This led to the intriguing question of whether retrieving memories richer in social context would confer additional protective benefits under stress. In Study 3, participants underwent an acute stressor and then recalled positive memories that varied in social context. We hypothesized that positive reminiscence including socially close others would lead to lower cortisol levels after stress than recalling similarly positive memories but of lower social context.

Method

Participants. Participants were 25 individuals from a larger sample of 50 healthy young adults who underwent an acute stress procedure followed by memory recollection (data from full sample described in Speer & Delgado, 2017). We utilized this subsample because they were individuals randomly selected to recall only positive memories, whereas the other half ($n = 25$) recalled only neutral memories. Thus, sample size was based on available data from a previous study. Exclusions included extreme or insufficient saliva for neuroendocrine response ($n = 4$) and missing data on social context for the present analyses ($n = 1$), resulting in a final sample of 20 participants (8 males; age = 22.6, $SD = 3.39$). Participants provided informed consent in accordance with the Rutgers IRB.

Procedure.

Day 1: AMQ. On Day 1, participants performed the same AMQ as described in Study 1, except it contained 84 event cues instead of 70. To be included in Day 2, participants must have reported at least 24 positive memories (based on valence and feeling ratings).

Day 2: Acute stress induction and memory recall. The second session (2–4 days later) occurred between 1 p.m. and 5:30 p.m. to account for diurnal variations in cortisol levels (Kirschbaum & Hellhammer, 1994). Day 2 included (a) salivary cortisol collection $s1$ (baseline), (b) stress induction via the socially evaluated cold pressor task (SECPT; Schwabe, Haddad, & Schachinger, 2008), (c) salivary cortisol $s2$, (d) positive memory recollection task, (e) salivary cortisol $s3$ (+24 min, peak), (f) salivary cortisol $s4$ (+58 min, recovery), and (g) memory ratings.

Stress induction. During the SECPT, participants immersed their hand in ice water (1–3 °C) for 2 min while under social threat (videotaped by an experimenter wearing a lab coat who acted

a   **L. Caudate**

b   **Mentalizing Network**

c
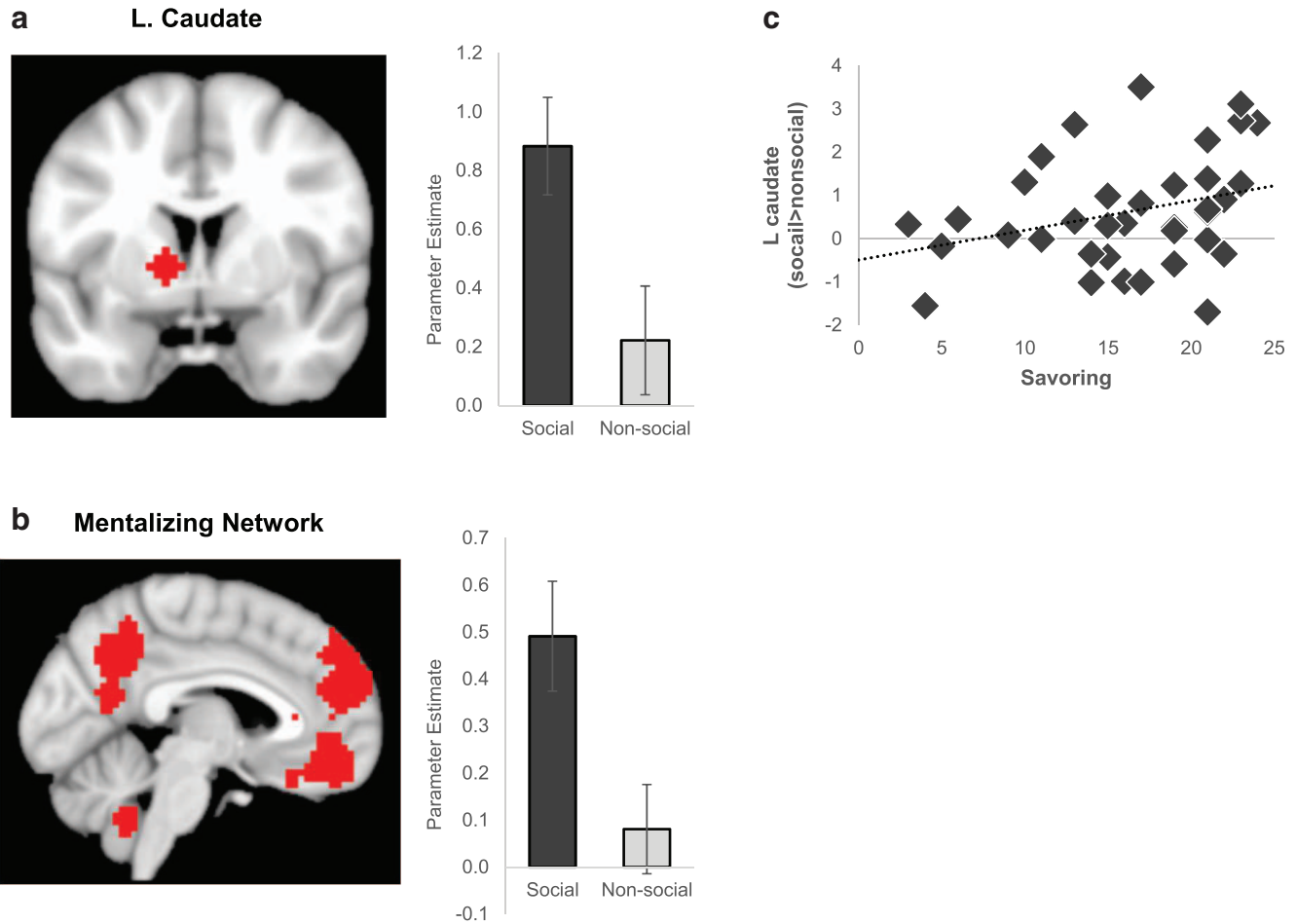
Figure 3.   Neural mechanisms associated with the social context of positive memory. An ROI analysis revealed greater activity for the contrast of Social > Nonsocial memory, controlling for positive feeling, in the left caudate (a) and the mentalizing network (b; corrected $p < .05$). (c) Greater ability to savor positive emotions in everyday life was associated with greater caudate activity for social relative to nonsocial memory reminiscence. Error bars represent ± 1 SEM. See the online article for the color version of this figure.

neutral and were told their recording would be analyzed later). Skin conductance responses were collected during the stressor to measure their physiological arousal. Afterward, participants rated the stressor for unpleasantness, stress, and pain (0–100: 0 = *not at all,* 100 = *very much*), which created a subjective stress rating (max = 300).

   Memory recall task.   Participants performed the same memory recall task as in Study 2, except common life event cues were individualized for each participant based on their AMQ, and emotion ratings included feeling and emotional intensity (1–4 scale). This task began about 5–6 min following the acute stressor.

   Social closeness memory ratings.   Afterward, participants saw each of the 24 event cues corresponding to memories they retrieved in the scanning task and were asked to make additional ratings about each memory including: vividness, richness, social closeness, and frequency of recall in everyday life. Social closeness ratings mirrored that of Study 2, except was on a 5-point scale (1–5: 1 = *alone/not close,* 5 = *extremely close*). Vividness, richness, and recall frequency were also on a 5-point scale (1–5: 1 = *low,* 5 = *high*), and this questionnaire was untimed.

   Neuroendocrine assessment and analysis.   We collected salivary cortisol concentrations via a swab placed under the tongue for 2 min. Swabs were kept in cold storage (-10 °C) until sent for biochemical assay analysis. To assess cortisol change across time, we calculated the difference from baseline ($s1$) to peak ($s3$, $+24$ min after stressor; $s3 - s1$).

   To assess sympathetic nervous system arousal during the 2-min stressor, we measured skin conductance via electrodes placed on the participant's left index and middle fingers, sampled at 200 Hz using an MP100 Data Acquisition Module (Biopac Systems). Skin conductance levels (SCLs) were measured as the mean tonic activity. Data were preprocessed by low-pass filtering (25-Hz cutoff) and mean-value smoothing using a three-sample window.

   Data analysis.   We used one-sample t tests for skin conductance and stress ratings to examine the efficacy of the SECPT in inducing stress. We used a correlation analysis to test the relationship between social context of memory and cortisol change over time across individuals. We examined confounds such as age and gender, but neither of these factors impacted the relationship between social context and cortisol response (age: $F_{1, 16} = 0.31,$

$p = .587$; gender: $F_{1, 16} = 0.00$, $p = .986$). There was also no difference in social context of memory ($t_{10} = -1.11$, $p = .293$) or cortisol response ($t_{10} = 0.20$, $p = .849$) across menstrual cycle phase (luteal phase = 6; follicular phase = 6).

Results

Manipulation check for stress induction. We first assessed the effectiveness of the stress procedure. Physiological responses during the stressor and subjective stress ratings afterward were both elevated above baseline, suggesting that the SECPT effectively induced stress (SCL: $t_{19} = 10.5$, $p < .001$; ratings: $t_{19} = 14.6$, $p < .001$).

Effect of social context on neuroendocrine stress responses. We were interested in whether the social context of positive memory recollection would predict cortisol levels after acute stress. Thus, we tested for correlation between mean social closeness ratings of positive memories recalled after stress exposure and the change in cortisol levels from baseline (cort *s*1, before stress) to after memory recall (cort *s*2, peak, +24 min after stress). We focused on the peak cortisol response, because (a) our prior work demonstrated reduced cortisol response after an acute stressor after recalling positive but not neutral memories (Speer & Delgado, 2017), and (b) we hypothesized our social positive memory manipulation to have the most meaningful impact on peak cortisol response given our experimental design (recall occurs between baseline and peak).

As predicted, recalling positive memories richer in social context led to lower cortisol levels after stress exposure, even when controlling for positive feeling (partial $r_{17} = -.494$, $p = .032$;

achieved power = 81.3%; Figure 4a). Importantly, this correlation remained even when we additionally controlled for other aspects of memory that could have influenced our results, such as a memory's vividness (partial $r_{16} = -.503$, $p = .033$), richness (partial $r_{17} = -.488$, $p = .04$), frequency of recall (partial $r_{17} = -.538$, $p = .021$), memory onset (partial $r_{17} = -.511$, $p = .03$), or recall duration (partial $r_{17} = -.471$, $p = .049$; online supplemental Tables S3 and S4). SCL during the acute stressor and subjective stress ratings afterward were unrelated to cortisol change ($r_{19} = -.100$, $p = .679$; $r_{19} = .254$, $p = .280$) or the social context of memory ($r_{19} = -.276$, $p = .238$; $r_{19} = -.223$, $p = .344$), suggesting that individual differences in response to the stressor itself did not influence our findings or the accessibility of social memories during the subsequent recall task. For better visualization of cortisol response as a function of social context during memory recall, we also report baseline-corrected cortisol levels across time for all participants, median split into low-social closeness ($n = 10$) and high-social closeness groups ($n = 10$; see Figure 4b).

Discussion

Social experiences imbue our lives with meaning. Here, we found that when reminiscing about the positive past, we prefer to think about experiences we shared with other people rather than ones we experienced alone. This was true even though people reported feeling similarly positive about both kinds of memories. Likewise, people were willing to pay at least 1.5 times more (of hypothetical money) for the opportunity to relive memories of higher social context than lower social context. Consistent with
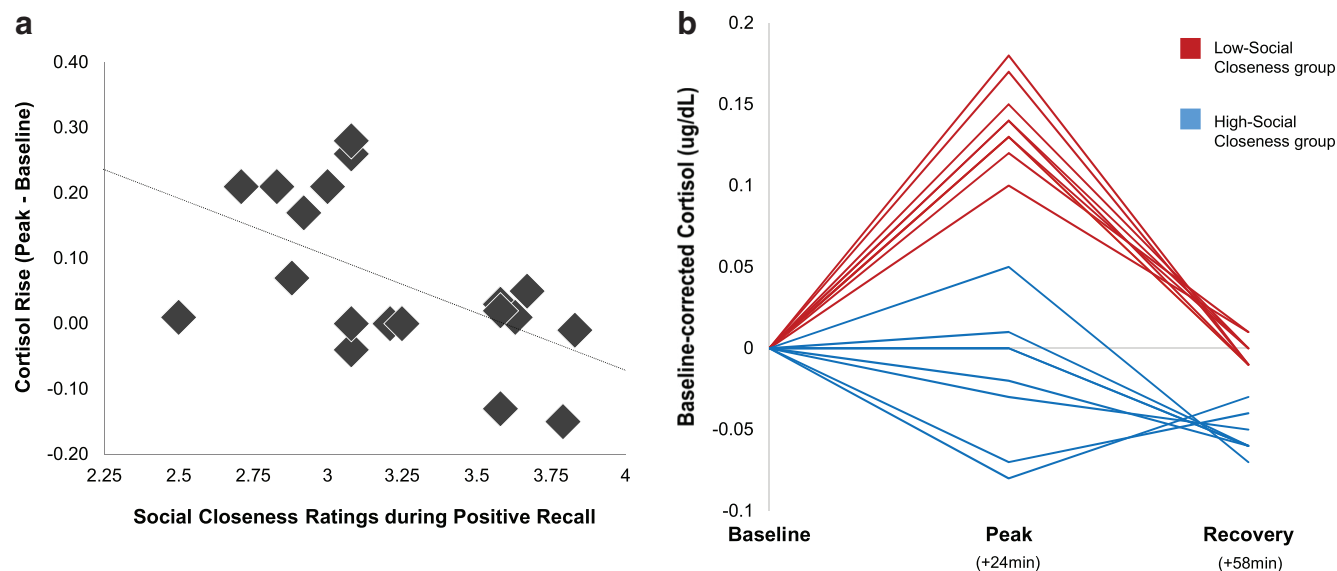
Figure 4. Greater social closeness during positive recall is associated with lower cortisol response after acute stress exposure. (a) Participants were exposed to acute stress and then recalled positive autobiographical memories that varied in social closeness. Participants who recalled positive memories with higher social context (e.g., with close others) showed a greater dampening of cortisol rise, even when controlling for positive feeling. (b) Baseline-corrected cortisol levels at baseline, peak (24 min poststressor), and recovery (58 min poststressor) for all participants. For better visualization, the sample was median split into low-social closeness ($n = 10$, red) and high-social closeness groups ($n = 10$, blue). See the online article for the color version of this figure.

this, memories rich in social context engaged regions previously implicated in mentalizing about other people and the neural systems of reward (i.e., caudate). Finally, recalling positive memories that more frequently included socially close others led to a greater reduction in cortisol response after stress exposure, revealing a potential benefit of the social context of memory.

That we would choose to think about or pay more money to relive socially rich over socially poor memories, even when they do not provide a positive emotion boost, suggests that we may place a higher value on them. Research showing that it is rewarding to be social lends support to this. Viewing photographs or winning a reward is more exciting when you share it with a close other than with a stranger or solo (Fareri et al., 2012; Kawamichi et al., 2016; Wagner et al., 2015). These findings also build on prior work demonstrating that reminiscing about happy memories (regardless of social context) is intrinsically valuable, leading individuals to forgo monetary rewards for the opportunity to savor them, and engages reward-related circuits (striatum, medial prefrontal cortex (mPFC); Speer et al., 2014). In the present study, it is intriguing that the mentalizing network—commonly engaged during tasks requiring theory of mind or making inferences about others (Van Overwalle & Baetens, 2009)—and the caudate—a dorsal striatum region critical to processing rewards (Balleine, Delgado, & Hikosaka, 2007; Knutson, Adams, Fong, & Hommer, 2001), particularly in relation to social contexts (e.g., Delgado, Frank, & Phelps, 2005; King-Casas et al., 2005; Wake & Izuma, 2017)—were also sensitive to the social context of memory, even when divorced from positive emotion. Striatal activity during social reminiscence was further correlated with a greater ability to savor positive emotions in everyday life. Savoring is associated with enhanced life satisfaction and can foster resilience to future adversity (Fredrickson, 2001; Tugade & Fredrickson, 2004). Future research could address how daily savoring and reward sensitivity to personally relevant social stimuli, such as memory, collectively impact one's well-being.

Our results suggest that how we value our past may not be solely determined by the positivity of the event itself but also by whether we had the opportunity to share those happy experiences with other people. But *why* might this be the case? One possibility is that social memories are a reminder that we are connected to other people. An extensive psychological literature has shown that humans are motivated to connect. This is likely because social relationships satisfy our fundamental need to belong (Baumeister & Leary, 1995). A lack of social ties is linked to reduced self-esteem (Leary, Tambor, Terdal, & Downs, 1995), the onset of mental health disorders such as anxiety and depression (Heinrich & Gullone, 2006), and increased risk of mortality akin to smoking or alcohol abuse (Holt-Lunstad, Smith, & Layton, 2010). In the present research, social memories may provide the coveted opportunity to feel connected, even in the physical absence of other people, which is adaptive for well-being.

In a similar vein, autobiographical memory is thought to serve a social function (Alea & Bluck, 2003). Sharing one's own experiences with another person can generate warmth and connection that facilitates social bonds, while learning about someone else's past history can nurture new relationships (Gable, Reis, Impett, & Asher, 2004; Lambert et al., 2013). More broadly, the simple opportunity to share information about oneself with other people is intrinsically rewarding (Tamir & Mitchell, 2012), so much so that

people sacrifice money for it, even when it provides no personal or social benefit (i.e., improved reputation; Tamir, Zaki, & Mitchell, 2015). Thus, beyond making us feel more connected, social reminiscence may also be rewarding because it inspires valuable opportunities to socially engage with other people. An interesting question for future research pertains to the direction of these relationships—whether feeling connected biases memory to be more social or if thinking about social memories fosters feelings of connection.

We also found that social memories may be especially adaptive when experiencing stress. While there is prior evidence that positive reminiscence can dampen negative affect and physiological stress responses (Speer & Delgado, 2017), here we observed that the social context of a memory bolsters these effects. This finding is reminiscent of the social support literature. Holding the hand of a partner or writing a supportive note to a friend can reduce subjective (Coan, Schaefer, & Davidson, 2006) and sympathetic responses to stress (e.g., blood pressure; Inagaki & Eisenberger, 2016). In addition, mental training that was socially based (incorporating compassion and perspective-taking) rather than attention based was far better at reducing cortisol stress reactivity over the course of 9 months (Engert, Kok, Papassotiriou, Chrousos, & Singer, 2017), highlighting the significance of support that is social in nature. In the present research, perhaps remembering positive events that included socially close others may serve as a similar means of social support. This is adaptive when close others are not present during a stressful event, as we can draw on our past positive social experiences instead. One intriguing hypothesis is that positive social memories may be especially beneficial when dealing with social (e.g., rejection) rather than physical stressors (e.g., overexertion, illness). Although we cannot untangle this here, future work could explore the efficacy of social memories for reducing socially induced stress in particular.

There are limitations about this research that warrant mention. Although we tested both the positivity and social context of memory, there are other factors that potentially contribute to the value of a memory, such as vividness and richness. The only study where we collected these ratings (Study 3) showed this to be unlikely, as neither differed across social and nonsocial memories (see online supplemental results). Similarly, social memories may be easier to retrieve, which could inflate how valuable they seem. However, across all three studies, social and nonsocial memories did not differ in their onset or recall duration, making this alternative unlikely as well.

Another outstanding question is how the social context of memory might function when considering events that were not positive to begin with. Do we value memories that are socially rich over socially poor when they were neutral or negative? Although we only measured positive memories here, both types of emotional experiences are amplified by the presence of others, making positive experiences more positive and negative experiences more negative (Boothby et al., 2014, 2016). Anecdotally, some negative circumstances may be more embarrassing when experienced with another person than alone (e.g., slipping and falling). On the other hand, reflecting on past negative social experiences can also lead to learning and personal growth (e.g., learning that a friend is trustworthy). Thus, the social value of a negative memory may be more context dependent. Finally, there are likely individual differences in how much one values socially rich experiences. Because

individuals with depression have difficulty recalling specific positive memories (Young, Bellgowan, Bodurka, & Drevets, 2013) and report fewer social ties (Teo, Choi, & Valenstein, 2013), social positive reminiscence may be more effortful and thus less rewarding. Individuals with social anxiety or low social motivation (e.g., autism spectrum disorder; Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012) may have fewer positive social experiences to draw from, making it less appealing. Whether or not increasing the frequency of social positive reminiscence enhances well-being in these populations is an important future inquiry.

Together, this research provides compelling evidence that socially rich positive memories may be adaptive, motivating us to savor them more often and leveraging them to serve as social support in the face of adversity. Social memories may be a pleasant and comforting reminder that we have social connections and people who support us, even if, just in this moment, it is only in our mind.

Context Paragraph

Here we find converging evidence across three experiments using various techniques—decision-making behavior, neuroimaging, and neuroendocrine responses to acute stress—that people place a higher subjective value on positive memories that are rich in social context than memories experienced solo. These findings shed light on a common observation—that the positive memories we most often think about and enjoy retelling to other people are likely social in nature (e.g., birthday party) rather than something we did alone (e.g., good grades). These results extend our prior work by demonstrating that the social context of a memory may help explain *why*, in fact, remembering past positive experiences is intrinsically rewarding to an individual (Speer et al., 2014) and can aid coping with stress (Speer & Delgado, 2017). Social positive reminiscence may be particularly adaptive by providing us the coveted opportunity to feel connected to other people, even in the absence of their physical presence. Further, it may be an efficacious strategy for dealing with stressors in everyday life with potential clinical significance in the treatment of mental health disorders.

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