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ANTYPA, Argyro-Despoina, VUILLEUMIER, Patrik, RIMMELE, Ulrike

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Suppressing but not intensifying emotion decreases arousal and subjective sense of recollection

Despina Antypa, Patrik Vuilleumier, and Ulrike Rimmele

University of Geneva, Switzerland

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Author Note

Despina Antypa, Department of Basic Neurosciences, University of Geneva, Switzerland, Swiss Center for Affective Sciences, University of Geneva, Switzerland; Patrik Vuilleumier, Department of Basic Neurosciences, Geneva, Switzerland, Swiss Center for Affective Sciences, University of Geneva, Switzerland, Department of Clinical Neurology, Geneva University Hospitals, Switzerland; Ulrike Rimmele, Department of Basic Neurosciences, University of Geneva, Switzerland

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Correspondence concerning this article should be addressed to Ulrike Rimmele,
Laboratory for Neurology and Imaging of Cognition, Dept. of Basic Neurosciences, University of Geneva, Campus Biotech, Chemin des Mines 9, CH-1202, Geneva, Switzerland. E-mail: Ulrike.Rimmele@unige.ch
Abstract

Emotional memories are commonly recalled with an increased subjective sense of recollection but not necessarily with more accurate context recollection, depending on the type of context. Response-focused emotion regulation techniques, such as suppressing and intensifying emotion expression, can alter subjective arousal and later memory and confidence about memory. Here, we investigated if emotion suppression affects later subjective sense of recollection as well as context recollection for different types of details. In order to disentangle the contribution of arousal modulation vs. potential cognitive costs of emotion suppression effects on later subjective sense of recollection, we further explored if intensifying emotion expression similarly affects later subjective sense of recollection and actual context recollection as emotion suppression. We found that emotion suppression decreases the subjective sense of recollection, while intensifying emotion expression has no effect on the subjective sense of recollection. In contrast, suppressing emotion did not affect the recollection of extrinsic and intrinsic contextual details, while intensifying emotion expression decreased recollection of intrinsic item features of emotional scenes. In conclusion, response-focused emotion regulation techniques with distinct effects on subjective arousal differentially affect the subjective sense of recollection and memory for contextual details.

Keywords: Emotion, Memory, Subjective sense of recollection, Remember/Know, Emotion regulation
Suppressing but not intensifying emotion decreases arousal and subjective sense of recollection.

Compared to neutral events, emotional events are more often recalled with a distinctive relatedness, i.e. the feeling that these events are embedded in personal experience and interwoven with contextual details about the world and the self in the past (Ochsner, 2000; Kensinger & Corkin, 2003). This feeling is described as *subjective sense of recollection* and commonly assessed with subjective recollection judgments (Tulving, 1985; Yonelinas, 2002). The increased subjective sense of recollection for emotional events has also been associated with higher confidence about memory accuracy (Talarico & Rubin, 2003; Sharot, Verfaellie, & Yonelinas, 2007) but not necessarily more accurate context recollection (Sharot & Yonelinas, 2008; Rimmele, Davachi, Petrov, Dougal, & Phelps, 2011; Rimmele, Davachi, & Phelps, 2012), in contrast to the relation observed between subjective sense of recollection and context recollection for neutral events (Huron et al., 1995; Perfect, Mayes, Downes, & Van Eijk, 1996; Gardiner, Ramponi, & Richardson-Klavehn, 1998).

This dissociation between subjective sense of recollection and accuracy for details for emotional events has been hypothesized to relate to the arousal dimension of emotional experience. In particular, subjective sense of recollection has been found to increase with arousal either in a positive linear relation or following an inverted U-shaped function. Data underlying the positive linear relation show that highly arousing vs. intermediately arousing stimuli induce an increased subjective sense of recollection and arousing vs. non-arousing stimuli are likewise recalled with an increased sense of recollection (Ochsner, 2000; Kensinger & Corkin, 2003). Data underlying the inverted U-shaped relation show that stimuli of very high arousal are either recollected with a similar higher subjective sense of recollection as arousing stimuli or even with a decreased subjective sense of recollection (Boywitt, 2015). Recollection of contextual details is
likewise affected by arousal, albeit in different ways depending on the type of detail (Rimmele et al., 2011; Rimmele et al., 2012; Boywitt, 2015). For example, even though emotionally arousing vs. neutral stimuli are remembered with an increased subjective sense of recollection, memory for the color of a frame surrounding the recollected scenes is actually lower for emotionally arousing in contrast to neutral scenes (Rimmele et al., 2011). In another study with stimuli of three distinct levels of arousal, context memory for the color of the frame of recollected scenes decreased linearly with increasing arousal while subjective context recollection followed an inverted U-shape relation to arousal (Boywitt, 2015). In contrast, subjective recollection judgments as well as memory of the location of a scene were found to be higher for arousing material (Rimmele et al., 2012), and equally increased for stimuli of medium and high levels of arousal (Boywitt, 2015). These findings are consistent with two theoretical frameworks, in which arousal does not affect or even decreases memory for the color of the frame, considered as between-item feature (Mather, 2007) or extrinsic contextual detail (Kensinger, 2009b), but does increase memory for the location of a scene, considered as within-item (Mather, 2007) or intrinsic item feature (Kensinger, 2009b). In particular, the color of the frame can be described here as background or extrinsic contextual information, since a colored frame could be theoretically removed from the object of interest without changing the stimulus itself. In contrast, location has been considered a within-item or intrinsic item feature, since it is a constituent feature of any item, as any item necessarily has a location (Mather, 2007; Kensinger, 2009b).

Given previous findings that the increased subjective sense of recollection for emotional material is accompanied by better memory for location, but not the color of a frame, it is possible that the enhanced subjective sense of recollection for emotional stimuli is linked to better memory for intrinsic, but not extrinsic contextual details.
The subjective arousal of an emotional experience can be lowered behaviourally by emotion suppression, an emotion regulation technique that requires a conscious modulation of one’s own expressive behaviour (Gross & Levenson, 1993; Gross, 1998). Employing emotion suppression has been shown to decrease the self-reported intensity of an experienced emotion (Dillon, Ritchey, Johnson, & LaBar, 2007; Goldin, McRae, Ramel, & Gross, 2008; Binder et al., 2012). Emotion suppression during encoding is also known to affect memory formation as evidenced by decreased later retrieval of both item and contextual information (Richards & Gross, 1999, 2000; Binder et al., 2012). In particular, emotion suppression at encoding decreased item memory as well as the level of confidence about memory performance for both emotional and neutral stimuli (Richards & Gross, 1999, 2000; Binder et al., 2012). Similarly, emotion suppression during encoding impaired memory for contextual information for stimuli of low and high levels of negative emotion (Richards & Gross, 1999, 2000). However, while the effects of emotion suppression on item and contextual memory and on confidence about memory have been examined, it is unknown whether emotion suppression affects the subjective sense of recollection of emotional and neutral stimuli and its relation to the actual recollection for different types of contextual details.

Here, in a within-subject counter-balanced design we tested the effects of suppressing vs. naturally experiencing one’s emotion during encoding of emotional and neutral scenes on later subjective sense of recollection (tested with the Remember/Know paradigm), on confidence about memory for the scenes, as well as on memory of two contextual details, the color of frame around the scene (in Experiment 1) and the location of the scene on the screen (in Experiment 2). We hypothesized that emotion suppression decreases arousal ratings during encoding and consequently weakens the subjective sense of recollection and confidence about memory, but
differentially affects memory for extrinsic contextual details and intrinsic item features. In particular, if emotion suppression affects memory by decreasing arousal, the arousal-dependent subjective sense of recollection and associated confidence about memory should be decreased for emotional scenes, but not neutral scenes (Ochsner, 2000; Kensinger & Corkin, 2003); analogously memory for intrinsic item features should be decreased, while memory for extrinsic contextual details should be either not affected or increased (Mather, 2007; Kensinger, 2009b).

Instead of a result of arousal modulation, a main effect of emotion suppression vs. naturally experiencing one’s emotion on memory in Experiment 1 and 2 could be interpreted in terms of a depletion of attentional and cognitive resources associated with emotion suppression (Johns, Inzlicht, & Schmader, 2008; Ortner, Zelazo, & Anderson, 2012; Franchow & Suchy, 2015). In particular, it is thought that emotion suppression is a late modulation of emotional processing and therefore more cost intense in comparison to naturally experiencing one’s emotions (Richards & Gross, 1999, 2000; Binder et al., 2012). Another emotion regulation technique with similar cost intensity, because of its late intervention to emotional processing, is intensifying ongoing emotion expression (Gross, 1998). Indeed probably due to increased cognitive load, it has been found that intensifying emotion expression impairs later memory (Bonanno, Papa, Lalande, Westphal, & Coifman, 2004; Robinson & Demaree, 2009). Because intensifying emotion expression induces cognitive costs, but does not decrease subjective arousal as emotion suppression (Demaree et al., 2006; Robinson & Demaree, 2009), it is the ideal technique to disentangle the contribution of a suppressing-induced decrease of arousal vs. potential cognitive costs of emotion suppression effects on later memory.

In a within-subject counter-balanced design, Experiment 3 therefore tested the effects of intensifying vs. naturally experiencing the expression of one’s emotion on later subjective sense
of recollection, confidence about memory, as well as memory for location of the scene on the screen. We hypothesized that intensifying emotional expression is cost intense but does not decrease arousal, and therefore should not weaken the subjective sense of recollection, confidence about memory and memory for the original location of each scene. Alternatively, if intensifying emotional expression decreases the subjective sense of recollection, confidence about memory and memory for the original location of each scene as a result of the increased cognitive load associated with the implementation of a response-focused emotion regulation strategy, findings in Experiments 1 and 2 might not be due to arousal modulation at all, but only due to the cost intensity of the intervention.

Experiment 1

Method

Participants. The study sample consisted of 23 participants ($M = 23.44$, $SE = .99$ years, 13 female). Intended sample size for all three experiments was decided before data collection ($20 \leq n \leq 25$), based on previous studies with a similar amount of trials and design (Ochsner, 2000; Sharot & Yonelinas, 2008; Rimele et al., 2011; Rimmlele et al., 2012). Participants for Experiments 1 and 2 were recruited in parallel and randomly assigned to one of the two experiments and therefore exact sample size was defined by the availability of volunteers for the pre-defined data acquisition period (before all data analyses). All participants provided written informed consent approved by the local ethics committee and were paid for their participation.

Stimuli. Four sets of 30 neutral and 30 negative scenes were created. Two sets were presented at the two encoding sessions. For the two recognition tests, the encoded scenes were intermixed with a set of 60 novel scenes (30 neutral, 30 negative). The photo sets presented at
encoding and recognition were counterbalanced across conditions and subjects. The emotional scenes were higher in their normative ratings of arousal ($M = 5.71 \ SD = .74$; $1 = \text{calm}, \ 9 = \text{excited}$) and lower in valence ($M = 2.67 \ SD = .83$; $1 = \text{unhappy}, \ 9 = \text{happy}$) compared to the neutral scenes (arousal: $M = 3.81, \ SD = .89$, valence: $M = 5.78, \ SD = .99$). All scenes were selected from the International Affective Picture Set (Lang, Bradley, & Cuthbert, 2008). Each scene was presented inside a colored frame (blue, green, yellow or red). Colors were counterbalanced across neutral and negative scenes and across conditions. The stimuli were presented using E-Prime® software on a 17 inch computer monitor scaled to screen size.

**Design and Procedure.** A randomized within-subject design was used. Each participant was tested in two conditions (Look vs. Suppress during encoding) on two different days with the order of condition balanced across subjects. Each condition included an encoding session followed by a recognition test one hour later (Figure 1). All data acquisition took place in the Brain and Behaviour Laboratory at the University of Geneva, Switzerland. Data were acquired by two female experimenters, trained by the principal investigator to provide the same instructions and feedback during the practice round. There was an English and a French version of all tasks and were provided to participants according to their preference (English version was translated to French, by a native French speaker).

Scene Encoding: During the encoding session, the 30 negative and 30 neutral scenes were presented with a colored frame pseudo-randomly in three blocks of 20 scenes with no more than three consecutive negative or neutral scenes. Each scene (4000 ms) was preceded by a white fixation cross (1000 ms) and followed by a 5000 ms blue screen. Participants were instructed to judge whether the color of the frame appeared in the scene or not by pressing one of two response keys during presentation of the blue screen. They were instructed to maintain the
Figure 1. Design and procedure of the three experiments.
On two different days, participants encoded 30 negative and 30 neutral scenes under either Look or Regulate instructions (Suppress in Experiments 1 and 2; Express in Experiment 3), with the order of conditions balanced across participants. One hour after the encoding session, participants were tested in a recognition session.

At encoding, in Experiment 1 scenes were presented in a colored frame, followed by participant’s judgment whether the color of the frame appeared in the scene. In Experiments 2 & 3, scenes were presented at one of the four corners of the screen, followed by participant’s indication in which corner the scene was presented; then each scene was rated for arousal and valence.

At recognition, participants were shown the encoded scenes intermixed with 30 new negative and 30 new neutral scenes. For each scene, participants were asked their confidence about memory, remember/know judgments and the detail of interest (color of the frame for Experiment 1; location for Experiments 2 and 3).

condition (Look vs. Suppress) during the presentation of each scene and the following blue screen. In the Look condition participants were instructed to look at the scenes as long as they were presented and naturally experience their emotions. In contrast, in the Suppress condition, participants were instructed to look at the scenes as long as they were presented and to suppress
their emotions elicited by each scene (Robinson & Demaree, 2009; Hayes et al., 2010; Binder et al., 2012), in order to induce expressive emotion suppression (Richards & Gross, 1999, 2000). The specific instructions for the Suppress condition were: “Please, suppress your emotions during the presentation of each scene and during the blue screen. Please, try not to express your emotions on your face, so that someone watching at you would not be able to tell how you feel (poker face). We know that for some scenes this can be more difficult than others but it is very important for the success of the study that you try to suppress your emotions for each scene” (Binder et al., 2012). After the blue screen, participants were asked to rate their emotions in terms of arousal and valence with the original Self-Assessment Manikin (SAM; Bradley & Lang, 1994) scale (1 = excited, 9 = calm; 1 = happy, 9 = unhappy; for the presentation of the tasks and the analyses, these scores will be reversed to 1 = calm, 9 = excited; 1 = unhappy, 9 = happy) with no time restriction.

A practice version of the task was administered to each participant beforehand to ensure that she or he understood the task and the specific instructions for each condition. During the practice, the experimenter asked the participants to either suppress or maintain their emotions during the presentation of the scenes and during the following blue screen.

Scene recognition: One hour after encoding, a self-paced recognition memory test was administered to assess the effect of Suppress vs. Look instruction during encoding on confidence about memory and subjective sense of recollection for the presented scenes, as well as on frame color recognition for scenes identified as formerly presented. For the recognition task, participants saw again the 60 scenes from the encoding without the colored frame, together with 60 new scenes (30 neutral, 30 negative). The scenes were presented pseudo-randomly with no more than three consecutive negative or neutral scenes, in overall six blocks of 20 scenes. Each
scene was presented for 2000 ms and was followed by a self-paced confidence and Remember/Know judgments of their recognition memory.

For the confidence judgment, participants had to judge their confidence in having seen or not having seen the specific scene during the encoding session on a scale from one to six (6 = *I am sure I have seen this scene before*; 5 = *I am not sure I have seen this scene before*; 4 = *I guess I have seen this scene before*; 3 = *I guess I have not seen this scene before*; 2 = *I am not sure I have not seen this scene before*; 1 = *I am sure I have not seen this scene before*).

To distinguish the subjective sense of recollection from familiarity, participants were given a detailed definition of the Remember/Know paradigm, including examples (Rajaram, 1993): they were instructed to provide a Remember response (R) when the scene brought back to mind a specific detail and/or association from the context in which the viewing of the scene had been experienced, such as a thought, a feeling or a contextual detail. In contrast, they were asked to provide a Know response (K), when the scene evoked a feeling of familiarity without episodic recollection of its occurrence. Participants were then asked to describe the meaning of Remember and Know in their own words and administered a practice round, during which participants were asked to explain why they chose to respond with Remember or Know for each of their choices and their correct understanding of the Remember/Know paradigm was verified.

Frame color recognition: If the participant has recognized the scene as previously seen (i.e. provided a Remember/Know response), the participant was asked to identify the color of the frame that the scene was originally surrounded during encoding, given four color choices and the option “I don’t know”. For this question, the original scene was presented again with the multiple choices of keystroke responses (1-5).
Data Analysis. Memory performance was analysed with a 2(emotional/neutral) x 2(Suppress/Look condition) mixed-design analyses of variance (ANOVA). Confidence about memory was analysed with a 2(emotional/neutral) x 2(Suppress/Look condition) x 3 (confidence levels) mixed-design analyses of variance (ANOVA) and with 2(emotional/neutral) x 2(Suppress/Look condition) mixed-design analyses of variance (ANOVA) separately for hit rate with low, medium and high confidence. To control for potential order effects, we ran a 2 (emotional/neutral) x 2 (Suppress/Look condition) mixed-design analyses of variance (ANOVA) with session order as a between-subject factor. Where it was appropriate, Greenhouse–Geisser corrections of degrees of freedom were used. Significant ANOVA effects were specified by pairwise contrasts using t tests. All tests were two-tailed and the level of significance was set at p ≤ .05. All analyses were performed with IBM SPSS Statistics for Windows, Version 21.0.

Results

Encoding. Participants rated negative scenes more arousing than neutral scenes ($M_{emo} = 4.78, SE = .36$ vs. $M_{neut} = 2.57, SE = .24$; main effect of emotion: $F(1, 22) = 73.754, p < .001, \eta^2 = .770$). Critically, in the Suppress condition participants succeeded to decrease their experienced arousal ($M_{Look} = 3.98, SE = .28$ vs. $M_{Suppress} = 3.38, SE = .32$; main effect of condition: $F(1, 22) = 6.564, p = .018, \eta^2 = .230$). There was a trend for emotion by condition interaction ($F(1, 22) = 3.446, p = .077, \eta^2 = .135$; Fig. 2A).

Participants rated the emotional vs. neutral scenes more negative than neutral scenes ($M_{emo} = 3, SE = .23$ vs. $M_{neut} = 5.74, SE = .14$; main effect of emotion for valence: $F(1, 22) = 139.142, p < .001, \eta^2 = .863$). There was no main effect of condition on valence ratings ($F(1, 22) = .228, p = .638, \eta^2 = .010$), but an emotion by condition interaction ($F(1, 22) = 6.520, p = .018$,
In particular, in Suppress condition participants rated emotional scenes marginally less negative ($M_{\text{Look}} = 2.86$, $SE = .23$ vs. $M_{\text{Suppress}} = 3.15$, $SE = .25$; $t(22) = -1.897$, $p = .071$, $r = .368$, 95% CI [-.61, .03]) but neutral scenes more positive ($M_{\text{Look}} = 5.85$, $SE = .15$ vs. $M_{\text{Suppress}} = 5.63$, $SE = .14$; $t(22) = 2.379$, $p = .026$, $r = .444$, 95% CI [.03, .40]; Fig. 2D).

**Figure 2.** Emotion regulation effects on emotional ratings at encoding. Emotion suppression decreased subjective arousal ratings in Experiments 1 and 2 (Panels A & B; main effect of condition). Intensifying emotion did not affect subjective arousal in Experiment 3 (C). Arousal ratings were higher for emotional vs. neutral scenes in all three experiments (main effect of emotion). Under emotion suppression emotional scenes were rated less negative in Experiment 1 (D) and in Experiment 2 (E) and neutral scenes were rated as more positive in Experiment 1 (D; emotion by condition interaction in Experiments 1 & 2; main effect of condition in Experiment 2). In all three experiments emotional scenes were rated as more negative in comparison to neutral scenes (D, E & F; main effect of emotion). Error bars indicate SEM and * $p < .05$, ** $p < .01$, *** $p < .001$. 

$\eta^2 = .229$.
Memory

Effect of session order: There were no main effects or interactions of the session order with the condition or emotion for overall recognition scores, subjective sense of recollection and familiarity scores (all p > .223).

Overall recognition memory scores for scenes (RK_{hit rate} - RK_{fa rate}): Overall recognition scores did not differ between emotional and neutral scenes \( (F(1, 22) = .209, p = .652, \eta^2 = .009 \) for main effect of emotion). There was no main effect of condition \( (F(1, 22) = 1.531, p = .209, \eta^2 = .065 \), but a significant emotion by condition interaction \( (F(1, 22) = 4.27, p = .051, \eta^2 = .163 \). In particular, suppression lowered overall recognition scores for emotional scenes \( (MLook = .93, SE = .01 \) vs. Suppress: \( M = .86, SE = .03; t(22) = 2.261, p = .034, r = .426, 95\% CI [.01, .13]\) but not for neutral scenes \( (MLook = .89, SE = .03 \) vs. M_{Suppress} = .89, SE = .02; \( t(22) = .000, p = 1.000, r = 0, 95\% CI [-.07, .07]; \) Fig. 3A).

Subjective sense of recollection (R_{hit rate} - R_{fa rate}): Subjective sense of recollection was higher for emotional vs. neutral scenes \( (M_{emo} = .80, SE = .04 \) vs. M_{neut} = .72, SE = .05; main effect of emotion: \( F(1, 22) = 5.857, p = .024, \eta^2 = .210 \). There was no main effect of condition \( (F(1, 22) = .007, p = .932, \eta^2 = .001 \), but a significant emotion by condition interaction \( (F(1, 22) = 4.411, p = .047, \eta^2 = .167 \). Importantly, an emotional enhancement in the subjective sense of recollection was found in the Look condition \( (M_{emo} = .82, SE = .04 \) vs. M_{neut} = .71, SE = .06; \( t(22) = 3.069, p = .006, r = .539, 95\% CI [.03, .18]\) but not in the Suppress condition \( (M_{emo} = .78, SE = .05 \) vs. M_{neut} = .74, SE = .05; \( t(22) = 1.225, p = .234, r = .248, 95\% CI [-.03, .11]; \) Fig. 3D; for \( R_{hit rate} \) and \( R_{fa rate} \) separately see Fig. 1A & 1G and Table 1 in Supplementary).
Familiarity (Khit rate - Kfa rate): Familiarity was lower for emotional vs. neutral scenes ($M_{emo} = .1, SE = .04$ vs. $M_{neut} = .16, SE = .05$; main effect of emotion: $F(1, 22) = 8.418, p = .008, \eta^2 = .277$). There was neither a main effect of condition ($F(1, 22) = 1.696, p = .206, \eta^2 = .072$) nor an emotion by condition interaction ($F(1, 22) = 0.004, p = .949, \eta^2 = .001$) for familiarity (Fig. 3G; for separate K_hit rate and K_fa rate see Fig.1D & 1J and Table 1 in Supplementary).

Confidence about memory: Hit rate with high confidence ($6 = \text{I am sure I have seen this scene before}$) was higher for emotional vs. neutral scenes ($M_{emo} = .88, SE = .02$ vs. $M_{neut} = .81, SE = .03$; main effect of emotion: $F(1, 22) = 9.768, p = .005, \eta^2 = .307$). There was neither a main effect of condition ($F(1, 22) = 0.854, p = .366, \eta^2 = .037$) nor an emotion by condition interaction ($F(1, 22) = 2.576, p = .123, \eta^2 = .105$; Fig. 4A).

Across conditions, on average there was only 1.18 ($SE = .35$) correctly recognized scene with medium confidence ($5 = \text{I am not sure I have seen this scene before}$) and less than one ($M = .71, SE = .24$) with low confidence ($4 = \text{I guess I have seen this scene before}$; for presentation and analyses on low and medium confidence hit rates see Figure 2A & 2D and Tables 2 & 3 in Supplementary).

Memory for the color of the frame: The proportion of R_hits with correct memory for the color of the frame to total R_hits ($R_{hits}$ with accurate detail recognition/ $R_{hits}$) was higher for neutral vs. emotional scenes ($M_{emo} = .36, SE = .05$ vs. $M_{neut} = .42, SE = .05$; main effect of emotion: $F(1, 22) = 11.706, p = .002, \eta^2 = .347$). There was no main effect of condition ($F(1, 22) = 0.665, p = .424, \eta^2 = .029$) or emotion by condition interaction ($F(1, 22) = 0.097, p = .758, \eta^2 = .004$; Fig. 5A).
Neither emotion nor condition had an effect on the proportion of high confidence judgments associated with correct memory for the color of the frame (all $p > .606$).

**Discussion**

In Experiment 1, we replicated previous findings by showing that emotion suppression decreases subjective arousal during encoding (Dillon et al., 2007; Binder et al., 2012). Moreover, emotion suppression impaired overall recognition memory rates ($R_{hit} - R_{fa}$) for emotional scenes, as it has been previously shown (Richards & Gross, 1999, 2000; Binder et al., 2012). However, emotion suppression did not significantly decrease high confidence hit rate, in contrast to previous findings in overall confidence about memory (Richards & Gross, 1999, 2000).

By asking participants to distinguish at recognition if their memory was characterized by subjective sense of recollection or familiarity, in our Look condition we observed that emotional scenes were more often recalled with subjective sense of recollection ($R_{hit} - R_{fa}$) in comparison to neutral scenes, replicating previous findings (Ochsner, 2000; Sharot, Delgado, & Phelps, 2004). Most importantly, we found that emotion suppression blunted the typically observed enhanced subjective sense of recollection for emotional vs. neutral scenes, but did not affect the reverse pattern in familiarity judgments. Since the emotional enhancement in subjective sense of recollection has been robustly found to be arousal-dependent (Ochsner, 2000; Kensinger & Corkin, 2003), the observed effect of emotion suppression on lowering the emotional enhancement in subjective sense of recollection suggests that arousal modulation may be a crucial component of how emotion suppression affects memory.
While there was a strong enhancement for the subjective sense of recollection ($R_{hit rate} - R_{fa rate}$) in the Look condition, overall recognition memory rates ($RK_{hit rate} - RK_{fa rate}$) were only marginally enhanced for emotional vs. neutral images in the Look condition. This finding is consistent with the notion that emotional enhancement of the subjective sense of recollection is more robust than emotional enhancement on overall recognition scores (Phelps and Sharot 2008). Indeed the emotional enhancement is not necessarily found for overall recognition memory rates (Kensinger & Corkin, 2003; Sharot et al., 2004; Sharot & Yonelinas, 2008). In our experiment, the long presentation of the scenes during encoding, in order to allow sufficient emotion regulation time, might have boosted overall recognition scores for both emotional and neutral scenes. Such ceiling effects do undermine the detection of differences in memory measures (Uttl, 2005) and therefore the high overall recognition scores might have circumvented an emotional memory enhancement to emerge. Moreover, previous studies found that emotion slows forgetting, i.e. the emotional memory enhancement becomes greater over time (Sharot & Yonelinas, 2008). The relatively short interval between encoding and recognition task in our study (one hour) might not have allowed the emotional enhancement in memory performance to emerge.

Across the Look and the Suppress conditions, the proportion of $R_{hits}$ associated with correct recollection for the color of the frame was higher for neutral scenes in comparison to emotional scenes, as previously shown for this type of detail (Rimmele et al., 2011; Boywitt, 2015). Interestingly, there was no main effect or interaction of emotion suppression on memory for a contextual detail. This finding accords with the theoretical frameworks proposed to distinguish the arousal effects on memory for within- and between-item features (Mather, 2007) and intrinsic and extrinsic details (Kensinger, 2009b): memory for the color of the frame around
a scene, being a between-item feature or an extrinsic contextual detail, would either remain unaffected or even improve with a decrease in subjective arousal, such as after emotion suppression.

To further understand the effects of emotion suppression on the subjective sense of recollection in relation to actual context recollection, in Experiment 2 we set out to examine the hit rate linked with accurate recollection for a different type of detail, i.e. the location where each scene was originally presented on the screen. In contrast to the color of the frame in Experiment 1, spatial location is considered as a within-item (Mather, 2007) or intrinsic item feature (Kensinger, 2009b) and memory for an item’s location has been found to benefit from emotional arousal (D’Argembeau & Van der Linden, 2004; Mather & Nesmith, 2008; Rimmelen et al., 2012).

Experiment 2

Method

Participants. The study sample consisted of 20 participants ($M = 23.42, SE = 1.42$ years, 10 female). See Experiment 1 how sample size was determined. All participants provided written informed consent approved by the local ethics committee and were paid for their participation. Two participants were excluded from analysis, due to false alarm rates higher than 2 standard deviations in at least one of the 2 conditions ($n = 1$, female and $n = 1$, male).

Stimuli. The same scenes as in Experiment 1 were used. Instead of a colored frame around each scene, we presented each scene in one of the four corners of the screen. The four locations were equally distributed across emotional and neutral scenes between conditions.
**Design and Procedure.** As in Experiment 1, participants were tested in two conditions (Suppress vs. Look) in balanced order across subjects (Fig. 1). At the encoding session, participants were instructed to either naturally experience (Look condition) or to suppress their emotions (Suppress condition) during the presentation of each scene and the following blue screen (for specific instructions, see Experiment 1). They were asked to indicate the screen location of each scene (one of the four corners of the screen) by pressing one of four response keys during the blue screen following the presented scene. After the blue screen, they were asked to rate the arousal and valence that each scene had evoked. At the recognition session one hour after encoding, participants were asked to judge their recognition confidence, provide Remember/Know judgments and indicate in which corner of the screen they had seen the recognized scene during encoding (i.e. after Remember/ Know response had been provided for the scene, participants were given four options for scene location and the additional option: “I don’t know”).

**Data Analysis.** Same as in Experiment 1.

**Results**

**Encoding.** Replicating Experiment 1, participants rated negative scenes more arousing than neutral scenes ($M_{emo} = 4.7$, $SE = .39$ vs. $M_{neu} = 2.4$, $SE = .36$; $F(1, 17) = 53.076$, $p < .001$, $\eta^2 = .757$ for main effect of emotion). As in Experiment 1, there was a main effect of condition for arousal ratings ($M_{Look} = 3.98$, $SE = .35$ vs. $M_{Suppress} = 3.12$, $SE = .38$; $F(1, 17) = 9.320$, $p = .007$, $\eta^2 = .354$). Moreover, there was significant emotion by condition interaction ($F(1, 17) = 6.824$, $p = .018$, $\eta^2 = .286$). In particular, suppression significantly decreased arousal ratings for emotional ($M_{Look} = 5.36$, $SE = .39$ vs. $M_{Suppress} = 4.04$, $SE = .48$; $t(17) = 3.005$, $p = .008$, $r = .578$, 95% CI...
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[.39, 2.24]) and neutral scenes ($M_{\text{Look}} = 2.61, SE = .39$ vs. $M_{\text{Suppress}} = 2.19, SE = .35$; $t(17) = 2.465, p = .025, r = .502, 95\% \text{ CI } [.06, .77]$; Fig. 2B).

As in Experiment 1, participants rated the emotional vs. neutral scenes more negative ($M_{\text{emo}} = 3.2, SE = .18$ vs. $M_{\text{neu}} = 5.81, SE = .14$; main effect of emotion: $F(1, 17) = 95.092, p < .001, \eta^2 = .848$). In Experiment 2, there was a main effect of condition for valence ratings ($M_{\text{Look}} = 4.4, SE = .09$ vs. $M_{\text{Suppress}} = 4.61, SE = .10$; $F(1, 17) = 6.984, p = .017, \eta^2 = .291$) in addition to the emotion by condition interaction ($F(1, 17) = 5.875, p = .027, \eta^2 = .257$). Under Suppression, participants rated emotional scenes less negative ($M_{\text{Look}} = 2.94, SE = .17$ vs. $M_{\text{Suppress}} = 3.47, SE = .23$; $t(17) = -2.728, p = .014, r = .502, 95\% \text{ CI } [-.94, -.12]$), while there was no significant difference in valence ratings of neutral stimuli between conditions ($M_{\text{Look}} = 5.86, SE = .13$ vs. $M_{\text{Suppress}} = 5.76, SE = .16$; $t(17) = 1.053, p = .307, r = .241, 95\% \text{ CI } [-.10, .31]$; Fig. 2E).

**Memory**

Effect of session order: There were no main effects or interactions of the session order with the condition or emotion for overall recognition scores, subjective sense of recollection and familiarity scores (all $p > .146$).

Overall recognition memory scores for scenes ($RK_{\text{hit rate}} - RK_{\text{fa rate}}$): While there was no main effect of emotion on overall recognition scores in Experiment 1, overall recognition memory rates were higher for emotional vs. neutral scenes in Experiment 2 ($M_{\text{emo}} = .91, SE = .02$ vs. $M_{\text{neu}} = .86, SE = .04$; main effect of emotion: $F(1, 17) = 5.729, p = .028, \eta^2 = .252$). In Experiment 2, there was a main effect of condition on overall recognition scores ($M_{\text{Look}} = .91, SE = .03$ vs. Suppress: $M = .87, SE = .03$; $F(1, 17) = 5.048, p = .038, \eta^2 = .229$) but no emotion by condition interaction ($F(1, 17) = .000, p = 1, \eta^2 = .000$; Fig. 3B).
Emotion regulation effects on Overall Recognition Rate, Subjective Recollection and Familiarity.

Figure 3. Emotion regulation effects on Overall Recognition Rate, Subjective Recollection and Familiarity.

Emotion suppression did not affect overall recognition memory scores ($R_{hit} - R_{fa}$) for emotional scenes in Experiment 1 (Panel A; note there was a trend for emotion by condition interaction), but decreased overall recognition memory scores in Experiment 2 (B; main effect of condition). There was no effect of intensifying emotion in Experiment 3 (C). Overall recognition rates were higher for emotional vs. neutral scenes in Experiments 2 and 3 (B & C; main effect of emotion).

Emotion suppression blunted the emotional enhancement in subjective sense of recollection ($R_{hit} - R_{fa}$) in Experiment 1 (D; emotion by condition interaction) and decreased subjective sense of recollection in Experiment 2 (E; main effect of condition). Intensifying emotion had no effect in Experiment 3 (F). In all three experiments emotional scenes were recalled with increased
subjective sense of recollection in comparison to neutral scenes (D, E & F; main effect of emotion).
Emotion regulation did not affect familiarity (Khit rate - Kfa rate) in all three experiments. In Experiment 1, familiarity rates were higher for neutral in comparison to emotional scenes in both conditions (G) but did not differ in Experiments 2 & 3 (H & I). Error bars indicate SEM and * p < .05, ** p < .01, *** p < .001.

Subjective sense of recollection (Rhit rate - Rfa rate): As in Experiment 1, the subjective sense of recollection was higher for emotional vs. neutral pictures (Memo = .84, SE = .03 vs. Mneut = .78, SE = .05; main effect of emotion: F(1, 17) = 5.886, p = .027, η² = .257). In Experiment 2, there was a main effect of condition (MLook = .83, SE = .04 vs. Suppress: M = .79, SE = .04; F(1, 17) = 10.232, p = .005, η² = .376) but no emotion by condition interaction (F(1, 17) = .539, p = .473, η² = .031; Fig. 3E; for separate Rhit rate and Rfa rate see Fig. 1B & 1H and Table 1 in Supplementary).

Familiarity (Khit rate - Kfa rate): Familiarity did not differ between emotional and neutral scenes (F(1, 17) = 1.480, p = .240, η² = .080 for main effect of emotion), unlike in Experiment 1. As in Experiment 1, there was neither a main effect of condition on familiarity (F(1, 17) = .289, p = .598, η² = .017) nor an emotion by condition interaction (F(1, 17) = .822, p = .377, η² = .046; Fig. 3H; for separate Khit rate and Kfa rate see Fig 1E & Fig. 1K and Table 1 in Supplementary).

Confidence about memory: As in Experiment 1, hit rate with high confidence (6 = I am sure I have seen this scene before) was higher for emotional vs. neutral pictures (Memo = .86, SE = .03 vs. Mneut = .80, SE = .04; main effect of emotion: F(1, 17) = 6.048, p = .025, η² = .262). In addition suppression decreased high confidence hits in Experiment 2 (MLook = .86, SE = .03 vs. Suppress: M = .80, SE = .04; main effect of condition: F(1, 17) = 15.248, p = .001, η² = .473). As in Experiment 1, in Experiment 2 there was no emotion by condition interaction (F(1, 17) = .003, p = .959, η² = .001; Fig. 4B).
Across conditions, on average there was only 1.11 ($SE = .34$) correctly recognized scene with medium confidence ($5 = I \text{ am not sure I have seen this scene before}$) and less than one ($M = .83, SE = .30$) with low confidence ($4 = I \text{ guess I have seen this scene before}$; for presentation and analyses on low and medium confidence hit rates see Fig. 2B & 2E and Tables 2 & 3 in Supplementary).

Memory for the location of the scene: There was a marginal difference in the rate of $R_{\text{hits}}$ with correct memory for location between emotional and neutral scenes ($M_{\text{emo}} = .42, SE = .05$ vs. $M_{\text{neut}} = .48, SE = .06$; main effect of emotion: $F(1, 17) = 4.041, p = .061, \eta^2 = .191$). There was no main effect of condition ($F(1, 17) = .006, p = .939, \eta^2 = .001$) and no emotion by condition interaction ($F(1, 17) = .516, p = .482, \eta^2 = .029$; Fig. 5B).

Neither emotion nor condition had an effect on the proportion of high confidence rates associated with correct memory for original location of each scene (all $p > .107$).

**Discussion**

Consistent with Experiment 1 and previous findings, Experiment 2 showed that emotion suppression decreases subjective arousal during encoding (Dillon et al., 2007; Binder et al., 2012) and lowers later overall recognition memory scores (Richards & Gross, 1999, 2000; Binder et al., 2012). This decrease in overall recognition was observed also for neutral scenes in Experiment 2. In addition to Experiment 1 findings, emotion suppression decreased high confidence hit rate in Experiment 2, replicating previous studies (Richards & Gross, 1999, 2000).

As in Experiment 1, we replicated the typical enhancement in subjective sense of recollection ($R_{\text{hit rate}} - R_{\text{fa rate}}$) for emotional vs. neutral scenes in the Look condition in Experiment 2 (Ochsner, 2000; Sharot et al., 2004). Crucially, in Experiment 2, emotion
suppression decreased the subjective sense of recollection. In addition, emotion suppression did not affect familiarity judgments.

Considering context memory, R_{hit} with correct memory for location did not significantly differ between emotional and neutral scenes, replicating a previous study (Rimmele et al., 2012; but see: Boywitt, 2015). Moreover, while emotion suppression decreased arousal, it did not affect memory for the location of a scene, in contrast to previous studies that report memory for intrinsic details to be higher for arousing material (D'Argembeau & Van der Linden, 2004; Mather & Nesmith, 2008).

In Experiment 2, there was a main effect of emotion suppression on subjective sense of recollection in contrast to Experiment 1, where emotion suppression specifically lowered the subjective sense of recollection for emotional but not neutral scenes. The distinct effects of emotion suppression in the two experiments may stem from the subtle differences of the two tasks during encoding (i.e. scenes presented in coloured frame in Experiment 1 and on one of the four corners of the screen in Experiment 2), which may have affected the encoding processes. Moreover, in addition to emotion suppression modulating arousal in Experiment 1, it may be that emotion suppression is a cost-intensive process resulting in a decrease in overall subjective sense of recollection, as found in Experiment 2.

In order to disentangle the contribution of arousal modulation vs. potential cognitive costs linked to emotion suppression (e.g. dual task conditions), in Experiment 3 we asked our participants to intensify instead of suppress their emotion expression during memory formation and consequently tested subjective sense of recollection in relation to actual recollection of the original location of each scene. We set out to test the hypothesis that intensifying emotional
expression is a cost-intense process but does not decrease arousal and therefore it should not weaken the subjective sense of recollection and the recollection of this intrinsic item feature of each scene.

Experiment 3

Method

Participants. The study sample consisted of 25 participants ($M = 24.35$, $SE = .8$ years, 13 female), who did not participate in either Experiment 1 or Experiment 2. Intended sample size for all three experiments was decided before data collection ($20 \leq n \leq 25$), based on previous studies with a similar amount of trials and design (Ochsner, 2000; Sharot & Yonelinas, 2008; Rimmele et al., 2011; Rimmele et al., 2012). Participants for Experiment 3 were recruited after completion of Experiment 1 and 2 (before data analysis for Experiment 3). All participants provided written informed consent approved by the local ethics committee and were paid for their participation.

Stimuli. The same scenes and presentation of these scenes (at one of the four corners of the screen) were used as in Experiment 2.

Design and Procedure. The experimental procedure was identical to Experiment 2 with few modifications (Fig. 1).

As in Experiment 2, participants were tested in two conditions (Express vs. Look) in balanced order across subjects. Instead of a Suppress condition as in Experiments 1 and 2, participants were asked to intensify the expression of their emotions elicited by each scene
(Express condition), whereas in the Look condition instructions were the same as in Experiments 1 and 2.

The specific instructions for the Express condition were: “Please, try to experience and intensify the emotions each image makes you feel. Try to express your emotions the most you can. For the success of the study it is essential that you follow the instructions and try to express your emotions the most you can during the presentation of each scene and during the blue screen” (Bonanno et al., 2004; Demaree et al., 2006; Robinson & Demaree, 2009).

To circumvent ceiling effects in the case the Express condition would improve memory performance (as pilot data suggested), the presentation time of the scenes during encoding was decreased to 2500 ms.

**Data Analysis.** Same as in Experiment 1.

**Results**

**Encoding.** Consistent with Experiment 1 and Experiment 2, emotional scenes were rated as more arousing than the neutral scenes ($M_{emo} = 5.47, SE = .22$ vs. $M_{neu} = 3.53, SE = .22$; $F(1, 24) = 54.221, p < .001, \eta^2 = .693$ for main effect of emotion). In Experiment 3, there was neither a main effect of condition ($F(1, 24) = 2.198, p = .151, \eta^2 = .084$) nor an emotion by condition interaction ($F(1, 24) = 1.343, p = .258, \eta^2 = .053$; Fig. 2C) on arousal ratings.

As in Experiments 1 and 2, participants rated the emotional scenes as more negative than the neutral scenes ($M_{emo} = 3.16, SE = .13$ vs. $M_{neu} = 5.57, SE = .14$; main effect of emotion: $F(1, 24) = 113.46, p < .001, \eta^2 = .825$). In Experiment 3, there was neither a main effect of condition
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(F(1, 24) = .059, \( p = .810, \eta^2 = .002 \)) nor an emotion by condition interaction \((F(1, 24) = .672, \ p = .421, \eta^2 = .027; \) Fig. 2F) on valence ratings.

Memory

Effect of session order: There were no main effects or interactions of the session order with the condition or emotion for overall recognition scores, subjective sense of recollection and familiarity scores (all \( p > .087 \)).

Overall recognition memory scores for scenes (\( R_{hit\ rate} - R_{fa\ rate} \)): Overall recognition memory rates were higher for emotional vs. neutral pictures (\( M_{emo} = .92, SE = .01 \ vs. \ M_{neut} = .89, SE = .02 \); main effect of emotion: \((F(1, 24) = 6.148, p = .021, \eta^2 = .204, 95\%\ CI [.01, .05])\). There was neither a main effect of condition for overall recognition memory rates \((F(1, 24) = .225, p = .639, \eta^2 = .009)\) nor an emotion by condition interaction \((F(1, 24) = 1.488, p = .234, \eta^2 = .058; \) Fig. 3C).

Subjective sense of recollection \((R_{hit\ rate} - R_{fa\ rate})\): Consistent with Experiments 1 and 2, subjective sense of recollection was higher for emotional vs. neutral pictures \((M_{emo} = .77, SE = .03 \ vs. \ M_{neut} = .71, SE = .04; \) main effect of emotion: \((F(1, 24) = 11.421, p = .002, \eta^2 = .322)\). There was neither a main effect of condition \((F(1, 24) = .225, p = .639, \eta^2 = .009)\) nor an emotion by condition interaction \((F(1, 24) = .071, p = .792, \eta^2 = .003; \) Fig. 3F; for separate \( R_{hit\ rate} \) and \( R_{fa\ rate} \) see Fig. 1C & 1I and Table 1 in Supplementary).

Familiarity \((K_{hit\ rate} - K_{fa\ rate})\): Familiarity was marginally higher in neutral vs. emotional scenes \((M_{emo} = .14, SE = .03 \ vs. \ M_{neut} = .17, SE = .03; \) main effect of emotion: \((F(1, 24) = 3.484, p = .074, \eta^2 = .127)\). There was neither a main effect of condition \((F(1, 24) = .071, p = .792, \eta^2 = .003)\).
.003) nor an emotion by condition interaction ($F(1, 24) = .737, p = .609, \eta^2 = .058$; Fig. 3I; for separate $K_{hit}$ rate and $K_{fa}$ rate see Fig. 1F & 1L and Table 1 in Supplementary).

Confidence about memory: Consistent with Experiments 1 and 2, hit rate with high confidence ($6 = I am sure I have seen this scene before$) was higher for emotional vs. neutral pictures ($M_{emo} = .87, SE = .02$ vs. $M_{neur} = .82, SE = .02$; main effect of emotion: $F(1, 24) = 10.628, p = .003, \eta^2 = .307$). There was neither main an effect of condition ($F(1, 24) = .318, p = .578, \eta^2 = .013$) nor an emotion by condition interaction ($F(1, 24) = .567, p = .459, \eta^2 = .023$) for high confidence hit rate (Fig. 4C).

Across conditions, on average there was only $1.07 (SE = .25)$ correctly recognized scene with medium confidence ($5 = I am not sure I have seen this scene before$) and less than one ($M = .61, SE = .21$) with low confidence ($4 = I guess I have seen this scene before$; for presentation and analyses on low and medium confidence hit rates see Fig. 2C & 2F and Tables 2 & 3 in Supplementary).

**Figure 4.** Emotion regulation effects on High Confidence Hit Rate.
In all three experiments, high confidence hit rate (hit rate with high confidence, $6 = I am sure I have seen this scene before$) was higher for emotional vs. neutral scenes (main effect of emotion). In Experiment 2, emotion suppression decreased high confidence hit rate (B; main effect of condition). There were no effects of condition on high confidence hit rates in Experiments 1 and 3 (A & C).
Error bars indicate SEM and * $p < .05$, ** $p < .01$, *** $p < .001$. 

"Looking at the image, the page discusses the effects of emotion regulation on subjective recollection. It mentions that there were no main or interaction effects of emotion by condition on high confidence hit rate (Fig. 3I), and that high confidence hit rate was higher for emotional vs. neutral pictures (main effect of emotion). The text also notes that there were no main or interaction effects of condition on high confidence hit rates. Additionally, it states that across conditions, on average there was only 1.07 correctly recognized scene with medium confidence and less than one with low confidence. Finally, the figure illustrates the effects of emotion regulation on high confidence hit rates in all three experiments, with error bars indicating SEM and significance levels."
Memory for the location of the scene: The proportion of $R_{\text{hits}}$ with correct memory for the location of the scene did not differ for emotional and neutral scenes (main effect of emotion: $F(1, 24) = 2.871, p = .103, \eta^2 = .107$). There was no main effect of condition ($F(1, 24) = 2.871, p = .103, \eta^2 = .107$) but an emotion by condition interaction ($F(1, 24) = 4.261, p = .050, \eta^2 = .151$). In particular, the proportion of $R_{\text{hits}}$ with correct memory for the location of the scene decreased in the Express vs. Look condition for emotional pictures ($M_{\text{Look}} = .51, SE = .05$ vs. $M_{\text{Express}} = .45, SE = .04$; $t(24) = 2.166, p = .040, r = .398, 95\% \text{ CI [.00, .13]}$) but not for neutral pictures ($M_{\text{Look}} = .57, SE = .1$ vs. $M_{\text{Express}} = .61, SE = .08$; $t(24) = -.780, p = .443, r = .154, 95\% \text{ CI [-.14, .06]}$; Fig. 5C).

Neither emotion nor condition had an effect on the proportion of high confidence rates associated with correct memory for original location of each scene (all $p > .129$).

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**Figure 5.** Emotion regulation effects on % Remember hit rate with correct memory for detail. In Experiment 1, the percentage of correct Remember responses associated with accurate memory for the color of the frame was higher for neutral scenes in comparison to emotional scenes (Panel A; main effect of emotion). In Experiment 2, the percentage of correct Remember responses associated with accurate memory for the location of the scene was marginally higher for neutral scenes in comparison to emotional scenes (Panel B). In Experiment 3, intensifying emotion decreased the proportion of accurate subjective sense of recollection linked with correct memory for the location of each scene for emotional pictures (Panel C; emotion by condition interaction). Error bars indicate SEM and * $p < .05$, ** $p < .01$, *** $p < .001$. 
Discussion

In Experiment 3, we observed that intensifying emotion expression did not affect subjective arousal ratings of emotional scenes, unlike in previous studies using similar procedures (Dillon et al., 2007; Kim & Hamann, 2007) and the observed emotion suppression effects on arousal in Experiment 1 and 2. Moreover, in contrast to previous findings (Bonanno et al., 2004; Demaree et al., 2006) and to emotion suppression effects in Experiments 1 and 2, intensifying emotion expression affected neither overall recognition memory scores nor confidence about memory.

Interestingly, intensifying emotion expression also did not alter the subjective sense of recollection ($R_{hit \, rate} - R_{fa \, rate}$) for emotional vs. neutral stimuli. In particular, there was a main effect of emotion, i.e. the characteristic enhancement in subjective sense of recollection for emotional vs. neutral scenes in both conditions, replicating the Look condition of Experiment 1 and 2, as well as previous findings (Ochsner, 2000; Sharot et al., 2004). In addition, there was no effect of the Express condition on familiarity judgments.

It is possible that there was no effect of intensifying emotion expression on overall recognition memory scores, confidence about memory and subjective sense of recollection, because there was no effect of this emotion regulation technique on arousal ratings. However, as the two null findings cannot be statistically compared, a direct link between the absence of these two effects cannot be proven.

In Experiment 3, there was no difference in the proportion of $R_{hits}$ associated with correct memory for the original location of each scene between emotional and neutral scenes, consistent with a previous study (Rimmele et al., 2012; but see Boywitt, 2015). In contrast to emotion
suppression in Experiments 1 and 2, we observed here that intensifying emotion expression decreased the recollection of the original location specifically for emotional scenes in comparison to the control condition.

**General Discussion**

To summarize, in Experiment 1 we demonstrated that emotion suppression decreases subjective arousal and lowers later overall recognition scores for emotional scenes and, more importantly, blunts the characteristic emotional enhancement in subjective sense of recollection. In Experiment 2, emotion suppression decreased subjective arousal and later overall recognition scores as well as subjective sense of recollection. Moreover, intensifying one’s emotion in Experiment 3 induced no change in subjective arousal and did not affect later memory and subjective sense of recollection. Interestingly, emotion suppression did not affect the actual recollection of an extrinsic contextual detail (Experiment 1) and an intrinsic item feature (Experiment 2), while intensifying vs. naturally experiencing emotion expression decreased the recollection of an intrinsic item feature for emotional scenes (Experiment 3).

This study extends previous work by showing that emotion suppression modulates subjective sense of recollection ($R_{hit} - R_{fa}$) but not familiarity (Experiments 1 & 2). In contrast, intensifying emotion expression does not affect any of the two memory measures (Experiment 3). Across the three experiments, in our Look condition we observed that emotional scenes were more often recalled with an enhanced subjective sense of recollection in comparison to neutral scenes, replicating a robust finding of previous studies (Ochsner, 2000; Kensinger & Corkin, 2003; Sharot et al., 2004; Sharot & Yonelinas, 2008; Rimmiele et al., 2011; Rimmiele et al., 2012; Boywitt, 2015). Crucially, we found no emotional enhancement for the subjective
sense of recollection in the Suppress condition in Experiment 1 and an overall decrease in the subjective sense of recollection in the Suppress condition in Experiment 2. In contrast, there was no effect of intensifying emotion expression on the subjective sense of recollection in Experiment 3. The dual task demands of emotion regulation per se thus did not affect subjective sense of recollection.

Consistent with previous findings (Dillon et al., 2007; Kim & Hamann, 2007; Binder et al., 2012), emotion suppression decreased subjective arousal in Experiments 1 and 2. In contrast, intensifying emotion expression in Experiment 3 did not affect subjective arousal. Because blocking arousal with the beta-adrenergic antagonist propranolol at encoding impairs the emotional memory enhancement (Cahill, Prins, Weber, & McGaugh, 1994; Strange, Hurlemann, & Dolan, 2003) and reduces the later subjective sense of recollection (Rimmeele, Lackovic, Tobe, Leventhal, & Phelps, 2016), we surmise that the decrease in subjective arousal at encoding in the Suppress condition may contribute to the later decrease in subjective sense of recollection in Experiments 1 and 2. This interpretation is consistent with a previously found linear relation between arousal and subjective sense of recollection (Ochsner, 2000; Kensinger & Corkin, 2003). Of note, when intensifying emotion expression in Experiment 3, we observed no change in both subjective arousal and later subjective sense of recollection.

Regarding context memory, we found no effect of emotion suppression on the actual recollection of an extrinsic contextual detail (color of the frame in Experiment 1) and an intrinsic item feature (the original location of each scene in Experiments 2). Interestingly, intensifying vs. naturally experiencing emotion expression in Experiment 3 specifically lowered recollection of an intrinsic item feature for emotional scenes. Consistent with previous findings (Rimmeele et al., 2011; Boywitt, 2015), in Experiment 1 we found increased recollection of an extrinsic contextual
detail for neutral vs. emotional scenes in respect to remember responses in both conditions, in agreement with the account that arousal does not benefit memory for extrinsic contextual details (Kensinger, 2009b). Replicating previous findings (Rimmele et al., 2012; but see: Boywitt, 2015), in Experiments 2 and 3 there was no main effect of emotion for the proportion of $R_{\text{hits}}$ with correct memory for the location of the scenes, but an emotion by condition interaction in Experiment 3. These findings suggest that different response-focused emotion regulation techniques modulate the subjective sense of recollection and its relation to actual recollection for contextual details in a different way. Given that suppression decreased arousal in Experiment 2 and intensifying emotion expression did not affect arousal in Experiment 3, it is less likely that the observed effects of intensifying emotion expression on the recollection of intrinsic details for emotional scenes are due to arousal modulation.

Consistent with previous studies (Richards & Gross, 1999, 2000; Binder et al., 2012), we found that emotion suppression decreases overall recognition scores for emotional scenes in Experiment 1 and overall recognition scores in Experiment 2. However, in contrast to previous findings (Dillon et al., 2007; Kim & Hamann, 2007), intensifying emotion did not affect overall recognition memory scores in Experiment 3. Response-focused emotion regulation techniques, such as suppressing and intensifying emotion expression, have been reported cost-intense even for irrelevant following cognitive tasks (Schmeichel, Vohs, & Baumeister, 2003; Schmeichel, Demaree, Robinson, & Pu, 2006; Gyrak, Goodkind, Kramer, Miller, & Levenson, 2012; Friese, Binder, Luechinger, Boesiger, & Rasch, 2013) and their memory effects are commonly explained by the assumed cognitive load of their late intervention to emotional processing (Richards & Gross, 1999, 2000; Binder et al., 2012). Nevertheless, cost intensity in terms of subjective effort ratings has been found to be only a partial component of the emotion regulation
effects on memory, as revealed by a mediation analysis (Robinson & Demaree, 2009). Indeed, cost-intensity might not be the crucial component modulating memory particularly for arousing stimuli: when cognitive load has been experimentally manipulated with a divided attention paradigm, memory for arousing stimuli was not or only minimally affected, in contrast to memory for neutral stimuli (Bush & Geer, 2001; Kern, Libkuman, Otani, & Holmes, 2005; Kensinger, 2009a). Our data suggest that another crucial component of emotion regulation effects on memory might be the modulation of arousal, as we have proposed in our hypothesis for the case of distinct memory effects for Suppress vs. Look and Express vs. Look conditions. Emotion suppression decreased arousal, overall recognition and subjective sense of recollection, while intensifying emotion had no effect on arousal, overall recognition and subjective sense of recollection. As such, the modulation of arousal may be the crucial component underlying the effects of emotion suppression on overall recognition rates and subjective sense of recollection.

Moreover, emotion suppression decreased high confidence hit rate in Experiment 2 but not in Experiment 1. There was no effect of intensifying emotion expression on high confidence hit rate in Experiment 3. In previous studies, emotion suppression consistently decreased confidence about memory, in accordance with the findings for high confidence hit rate in Experiment 2 (Richards & Gross, 1999, 2000). The small number of correctly recognized scenes with low and medium confidence judgments in all experiments restricted potential comparisons between confidence levels and therefore future studies are needed to address more precisely the effects of suppressing and intensifying emotion expression on different confidence levels.

A limitation of our study paradigm is that the influences of suppressing vs. intensifying emotion on memory were tested in different experiments, rather than in a within-study design. Given the different participant samples and the fact that there were procedural changes between
the Suppress and the Express experiments (photos were shown for 4 s vs. 2.5 s during encoding), the results cannot be directly compared across experiments. Moreover, it might also be that intensifying emotion expression is indeed something very different to emotion suppression and these response-focused emotion regulation techniques are not comparable to each other, because the underlying cognitive processes differ to such a degree that it should not be expected to have similar cost-intensity and effects on memory encoding. Interestingly, in an fMRI study comparing emotion suppression vs. imitating emotion expression in order to increase emotional response to dynamic emotional expressions, only emotion suppression was found to increase activity in brain regions associated with cognitive control, while imitation induced higher activity in regions related to emotion, somatosensory and (pre)motor processing as well as social cognition (Vrticka et al., 2013). Future studies need to test the impact of different emotion regulation strategies, such as suppressing and intensifying emotion, within the same experiment to allow direct comparison.

Further experiments will be needed to clarify the role of arousal modulation in emotion regulation effects on memory. In particular, the arousal modulation component could be further studied by including physiological measures as additional indicator of arousal. In previous studies, emotion suppression has been reported to decrease physiological arousal as indicated by overall somatic activity and heart rate (Gross & Levenson, 1993; Kunzmann, Kupperbusch, & Levenson, 2005) as well as startle magnitude and corrugator activity (Jackson, Malmstadt, Larson, & Davidson, 2000), but to increase overall sympathetic activity (Gross & Levenson, 1993, 1997; Kunzmann et al., 2005; Roberts, Levenson, & Gross, 2008). Further research is needed to clarify how suppressing or intensifying emotion expression affects different measures
of physiological arousal specifically in perspective to memory measures such as subjective sense of recollection and actual context recollection for different types of details.

Moreover, future neuroimaging studies need to address the underlying neural mechanism of emotion suppression effects on subjective sense of recollection. Emotion suppression has been associated with decreased activation of amygdala and hippocampus (Ohira et al., 2006; Hayes et al., 2010; Binder et al., 2012), impaired amygdala-hippocampus coupling (Hayes et al., 2010) as well as reduced functional connectivity between hippocampus and dorsolateral prefrontal cortex during emotional memory encoding (Binder et al., 2012). Activity in the same brain regions (amygdala and hippocampus) has been associated with the increased subjective sense of recollection for emotional vs. neutral stimuli (Cahill, Uncapher, Kilpatrick, Alkire, & Turner, 2004; Sharot et al., 2004; Dolcos, LaBar, & Cabeza, 2005). Possibly, emotion suppression during memory formation affects activity of the amygdala and hippocampus and their interaction, and thus lowers the subjective sense of recollection.

In summary, this study shows for the first time that emotion suppression affects the subjective sense of recollection, while intensifying emotion expression has no effect on the subjective sense of recollection. Moreover, emotion suppression did not affect the actual recollection of an extrinsic contextual detail and an intrinsic item feature, but intensifying emotion decreased actual recollection of intrinsic item features of emotional scenes. Emotional memories are commonly recalled as a very vivid part of our experience, with an enhanced subjective sense of recollection irrespective of actual context recollection (Phelps & Sharot, 2008). Our findings demonstrate that is possible to alter this later subjective sense of recollection with a short behavioural intervention during memory formation. In particular, a better understanding of emotion suppression and its effects on subjective sense of recollection and
actual recollection of different types of contextual details might crucially inform and contribute to the development of effective interventions for the case of traumatic emotional memories, commonly characterized by increased vividness but weak context associations (Maren, Phan, & Liberzon, 2013).
References


Supplementary Figure 1. Emotion suppression decreased Remember hit rate for emotional scenes in Experiment 2 (B; main effect of condition). Remember hit rates were higher for emotional vs. neutral scenes in all three experiments (Panels A, B & C; main effect of emotion). Know hit rate was higher for neutral vs. emotional scenes in Experiment 1 (D; main effect of emotion).
There were no effects of condition or emotion on remember and know false alarm rates (Panels G-L).
Error bars indicate SEM and * $p < .05$, ** $p < .01$, *** $p < .001$. 
Supplementary Figure 2. Across experiments, there were very few correctly recognized scenes given low (4 = I guess I have seen this scene before) or medium (5 = I am not sure I have seen this scene before) confidence judgments.

In Experiment 1, medium confidence hit rate was higher for emotional vs. neutral scenes (main effect of emotion).

In Experiment 3, there was an emotion by condition interaction in low confidence hit rate. Error bars indicate SEM and * p < .05, ** p < .01, *** p < .001.
Table 1. Main effects and interactions from a 2 (emotional /neutral) x 2 (Look/Regulate condition) mixed design analyses of variance (ANOVA) for Remember hit rates, Know hit rates, Remember false alarm rates and Know false alarm rates

<table>
<thead>
<tr>
<th></th>
<th>Experiment 1</th>
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<th></th>
<th>Experiment 3</th>
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<tbody>
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<td>df</td>
<td>F</td>
<td>p</td>
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<td>df</td>
<td>F</td>
<td>p</td>
<td>$\eta^2$</td>
<td>df</td>
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<tr>
<td><strong>R</strong>hit rate</td>
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<td>.842</td>
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<td>.224</td>
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<td>.090</td>
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<td>.060</td>
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<td>.622</td>
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<td>1, 17</td>
<td>.739</td>
<td>.331</td>
<td>.042</td>
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*Note: The significant effects are depicted in bold font.*

Table 2. Main effects and interactions from a 2 (emotional /neutral) x 2 (Look/Regulate condition) x 3 (levels of confidence) mixed design analyses of variance (ANOVA)

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<tr>
<td><strong>R</strong>hit rate</td>
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*Note: The significant effects are depicted in bold font.*
**Table 3.** Main effects and interactions from a 2 (emotional/neutral) x 2 (Look/Regulate condition) mixed design analyses of variance (ANOVA), run separately for medium and low confidence hit rates

<table>
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<td>η²</td>
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<td>.003</td>
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<td>1.000</td>
<td>.000</td>
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<td>.030</td>
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<td>.001</td>
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<td>.575</td>
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<td>.877</td>
<td>.001</td>
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<td>.100</td>
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*Note: The significant effects are depicted in bold font.*