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SHORT COMMUNICATION

Only "efficient" emotional stimuli affect the content of working memory during free-recollection from natural scenes

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Abstract
Emotional events are thought to have privileged access to attention and memory, consuming resources needed to encode competing emotionally neutral stimuli. However, it is not clear whether this detrimental effect is automatic or depends on the successful maintenance of the specific emotional object within working memory. Here, participants viewed everyday scenes including an emotional object among other neutral objects followed by a free-recollection task. Results showed that emotional objects—irrespective of their perceptual saliency—were recollected more often than neutral objects. The probability of being recollected increased as a function of the arousal of the emotional objects, specifically for negative objects. Successful recollection of emotional objects (positive or negative) from a scene reduced the overall number of recollected neutral objects from the same scene. This indicates that only emotional stimuli that are efficient in grabbing (and then consuming) available attentional resources play a crucial role during the encoding of competing information, with a subsequent bias in the recollection of neutral representations.

Keywords Emotion · Salience · Working memory · Capacity · Free recollection

Introduction

Previous research demonstrates that emotional events have privileged access to attention selection and memory representation (Buchanan and Adolphs 2002; Kensinger and Corkin 2003; Simione et al. 2014). Emotional stimuli tend to capture attention and processing resources in a bottom-up fashion (Vuilleumier 2005; Yiend 2010), which results in greater memory performance for emotional stimuli compared to neutral stimuli (Anderson and Phelps 2001;

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LaBar and Cabeza 2006; Pedale et al. 2017; Simione et al. 2014). The processing of emotional stimuli might consume resources needed to process simultaneously presented neutral stimuli, so that the emotional element tends to be better remembered, whereas other neutral aspects of the same event are more likely to be forgotten (reviewed in Buchanan and Adolphs 2002). Moreover, in working memory (WM) tasks, the presence of emotional stimuli tends to impair performance when the emotional saliency is not the main focus of the task (Sakaki et al. 2014). Mather et al. (2006) found worse spatial WM performance when participants had to retrieve locations for emotional compared to neutral pictures (but see also Bannerman et al. 2012, for a lack of facilitation for emotional stimuli in a similar task). Kensinger and Corkin (2003) found worse WM performance—measured by an N-back task—when the to-be-detected target was a fearful rather than a neutral face. These findings could be interpreted as evidence that the emotionally arousing stimuli consume attentional resources needed to accomplish the WM tasks, with the consequence of decreasing participants' performance under neutral conditions.

These studies provide intriguing evidence linking emotional processing to the modulation of WM. Nevertheless, the previous literature did not clarify whether the detrimental effect of emotional processing on memory for neutral stimuli depends merely on the presentation of an emotional object, or whether the emotional object must be successful encoded in memory to affect the probability of encoding other, neutral information. Similarly, the great majority of these previous studies did not control whether low-level sensory features (the so-called "perceptual saliency," based on local discontinuities in line orientation, intensity contrast, and color opponency; Itti et al. 1998) of emotional stimuli could influence memory performance. This is particularly important when the emotional stimulus is co-occurring along with a number of other potentially relevant objects, such as when the emotional stimulus is embedded within commonplace visual scenes. Several previous studies have demonstrated that highly salient perceptual stimuli—such as emotional stimuli—tend to grab bottom-up attention (see, for a review, Santangelo 2015). This attention-grabbing characteristic of emotional stimuli thus increases the probability that these stimuli will be selected and recollected, and suggests that the resources needed to process lower saliency, emotionally neutral, stimuli may be consumed leading to reduced processing of such lower saliency stimuli. This leaves open the question of whether processing of low-level sensory features might interact with processing of emotional features in affecting WM performance. To date, it is unclear whether emotional stimuli are attention grabbing due to emotional features per se (e.g., the level of emotional arousal; Kensinger and Corkin 2004; Steinmetz et al. 2010) or because they happen to be perceptually salient in the scene.

Here, we investigated these issues (i.e., the impact of successful encoding of emotional stimuli and the impact of low-level sensory features on the simultaneous processing of neutral stimuli) by presenting participants with commonplace scenes, which included a number of emotionally salient objects that result in a high level of stimulus competition to enter memory representation (e.g., Kim et al. 2013; Melcher 2010). Moreover, we measured the perceptual saliency of each emotional object using a computational model (Itti et al. 1998). For each scene, we asked participants to verbally report as many objects as possible (free-recollection task; Standing 1973; Pedale and Santangelo 2015). We computed three different indices related to the internal memory representation of the scene: the "recollection probability," i.e., the probability of successfully recollecting the emotional and the neutral objects; the "recollection position," i.e., the temporal position of a given object in the stream of recollected items, indicative of the accessibility of the memory representation; and the "amount of recollected objects," i.e., the number of objects recollected for a scene.

If the selection and temporary maintenance of the emotional object embedded in the visual scene is enhanced, we would expect higher recollection probability for emotional than neutral objects, and this might be further modulated by the arousal of the emotional object (Kensinger and Corkin 2004; Steinmetz et al. 2010). This would be consistent with a stronger memory representation for emotional as compared to neutral objects. This effect could be further evidenced by the recollection position (Katkov et al. 2015). After word-list presentation, participants typically start their recollection with the weaker encoded items of the last part of the list (coming from short term memory and so short-lived). Then they move on to the more strongly encoded items located in the first part of the list, which likely have been rehearsed over more time and are consequently more resistant to interference (Beaman and Morton 2000; Tan and Ward 2007). Accordingly, we would expect a similar retrieval outcome in the current task, with earlier retrieval of neutral (i.e., weakly represented) items, followed by the retrieval of the emotional (i.e., strongly encoded) items. More importantly, we investigate how the recollection of emotional objects modulates the content of WM. If the mere presence of the emotional object in the scene would reduce WM resources irrespective of whether the emotional object was successfully recollected or not, we would expect no difference in the number of neutral objects reported on the basis of emotional object recollection. By contrast, if the successful encoding and maintenance of the emotional object is necessary to affect WM resources, we would expect a decrease in the number of neutral objects recollected only when the emotional object was successfully recollected. This latter hypothesis would be in agreement with the notion that only objects that are "efficient" in grabbing attention (e.g., Nardo et al. 2011)—like the emotional objects here—are more likely to access internal memory representation, biasing the contents of WM toward the emotional, and away from the neutral stimuli (Kensinger and Corkin 2003; Mather et al. 2006). Finally, if low-level sensory features determine WM resources, we would expect an increased effect of emotional stimuli on WM performance as a function of the emotional object's perceptual saliency.

Methods and materials

Participants

Twenty healthy volunteers (8 males; mean age = 25.5 years, range: 21–35 years) with normal or corrected-to-normal vision participated in the study. Our sample size ($N = 20$) was estimated on the basis of a previous study (Pedale and Santangelo 2015), and taking into account: a large effect size (Cohen's $d = 0.8$), power (95%), and significance level (0.05, 2-sided). All participants gave written informed consent and were naïve to the main purpose of the study, which was conducted in accordance with the principles of the Declaration of Helsinki.

Stimuli: selection and validation

Eighty pictures depicting scenes of everyday life were collected from the World Wide Web; these pictures have been used in previous studies (Pedale and Santangelo 2015; Santangelo and Macaluso 2013). The pictures illustrated either internal (a kitchen, a bathroom, etc.) or external scenes (a garden, a street, etc.), but no single-object photos. No people were represented in any scene. In the current study, each picture was digitally modified using CorelDraw Graphics Suite v. 12 to include emotional objects that were also collected from the World Wide Web (see Fig. 1a). In 40 pictures, we included an emotionally positive object, based on categories derived from the International Affective Picture System (IAPS; Lang et al. 2005), such as puppies, sweets and pies, colorful candies, etc. The other 40 pictures included an emotionally negative object, again based on IAPS categories, such as dead animals, bloody knives, excrements, etc.

We checked that the inserted object did not appear "odd" in the scene (e.g., as a consequence of bad digital photo editing or context-incongruence) by asking 20 independent observers not taking part in the main experiment, to evaluate the general congruency of the objects present in each scene ("Are all the objects present in this scene congruent with the scene?" using a ten-point scale: 1 = totally incongruent, 10 = totally congruent). This procedure allowed us to select scenes for the current experiment that had an average congruency score of 7 or higher.

Finally, to ensure that the inclusion of the emotional object affected the emotional impact of the whole scenes, we asked another group of 50 independent observers not taking part in the main experiment (18 males; mean age = 30.0 years, range: 21–61 years) to rate the emotional valence (9-point scale: 1 = totally negative, 9 = totally positive) and the emotional arousal (9-point scale: 1 = totally calm, 9 = totally excited) of the scenes by means of an online survey. Observers in the online survey were randomly presented with two versions of each scene, either including the emotional object or not (i.e., 160 scenes overall). Crucially, the inclusion of the emotional object significantly influenced emotional valence (mean ± standard error for scenes with negative objects: 2.45 ± 0.10 vs. 5.28 ± 0.12, $t\,(78) = -17.7$, $p < .001$; for scenes with positive objects: 6.30 ± 0.13 vs. 5.71 ± 0.11; $t\,(78) = 3.5$, $p < .01$), and emotional arousal (for negative pictures: 6.21 ± 0.12 vs. 3.37 ± 0.08, $t\,(78) = 19.2$, $p < .001$; for positive pictures: 3.71 ± 0.07 vs. 3.14 ± 0.06; $t\,(78) = 6.1$, $p < .001$). Overall, these data indicate that the inclusion of the emotional object (either negative or positive) was clearly detected by the observers and changed the emotional impact of the whole scene, which was rated as neutral without the inclusion of the emotional object.

Task

The task consisted of an encoding phase (4 s, in which the visual scene, displayed at 18° × 12° of visual angle, was presented), a maintenance phase (8 s delay, where a blank screen appeared), and a recollection phase (unlimited time; Fig. 1b; cf. Pedale and Santangelo 2015) of the 80 scenes (40 positive and 40 negative) described above. At encoding, participants had to freely observe the scene and memorize as many details as possible for later recollection. After the maintenance phase, a "start recollecting" signal was displayed and participants had to verbally report as many objects as possible from the previous scene. Participants were instructed to be as accurate as possible, taking all the time they needed. When their recollection was completed, participants pressed the spacebar for the next trial. After 1 s, a new scene was presented. The 80 trials were randomly presented to all the participants in two sessions of 40 trials each. Participants' verbal responses were recorded with an external microphone and digitalized into .wav files for subsequent data management and analysis.

Data analysis

The experimental design consisted of two within-participants factors, namely the emotional valence of the scene, i.e., "scene valence," positive versus negative, and the emotional valence of the object recollected in the scene, i.e.,

Fig. 1 **a** Examples of visual scenes used in the experiment. They included either a positive (a puppy and a fruitcake in the left and right examples, respectively) or a negative (a dead dog or a pair of bloody scissors in the left and right examples, respectively) object. **b** Diagram showing the sequence of events during one trial. The trial began with the presentation of a scene for 4 s (encoding phase). Then, a blank display was shown for 8 s (delay phase). This was followed by a "start recollecting" signal. Participants had no time constraint to recollect as much objects/details as possible from the previous scene. When the recollection was completed, participants pressed the space bar to start the next trial

"object type," emotional versus neutral. Objects were coded as successfully recollected only when correctly named. When the scene included similar objects (e.g., several "cups" of different colors), an object was assigned as successfully recollected only when it was possible to unequivocally establish the object/name relation (e.g., the recollection of a "green" cup). The object was scored as successfully recollected when participants used more general labels that were unequivocally related to a specific object in the scene (e.g., "fruit" if the scene included one and only one fruit, e.g., an apple). For each scene, we therefore built a chronological list of objects that were successfully recollected by each participant. This allowed us to compute the "mean recollection probability" and the "mean recollection position" for the two object types presented within each scene (the emotional and the neutral object). These indices were used to assess whether the emotional objects were more likely to be remembered compared to neutral objects ("recollection probability") and whether emotional objects were accessed at a different point of retrieval of the scene compared to neutral objects ("recollection position"). It is important to note that each scene included a single emotional object, while there were many neutral objects that could be recollected. This is why the mean recollection probability and recollection position for neutral objects was averaged across all neutral objects reported by the participants for each scene, with the constraint that a given neutral object should have been recollected by at least two participants to be included in the average. For instance, if at least two participants reported a given neutral object in a scene, we computed the recollection probability (i.e., how many participants reported that object as a function of total participants) and the recollection position (i.e., the average position across the participants that reported the object) for that neutral object. The same procedure was repeated for each neutral object reported for that scene by at least two participants. Then, the final recollection probability and recollection position of neutral objects in that scene was obtained by averaging across the indices computed for each neutral object.

Note, however, that before the averaging procedure, the recollection position of both the emotional and neutral object in the stream of recollected items was scaled by the total number of objects recollected for that scene by that participant.[1] This weighting procedure allowed us to more accurately compare the meaning of the different temporal positions among them: a position of four when twelve objects were recollected has a different meaning compared to when only four objects were recollected (i.e., among the first positions or the last position, respectively). This index varied between 0 and 1: the closer it was to 0, the earlier the target-object was recollected; by contrast, the closer it was to 1, the later the target-object was recollected.

Next, we examined the impact of perceptual saliency on emotional memory. Each picture was analyzed with the Saliency Toolbox 2.2 (http://www.saliencytoolbox.net/), which computes saliency maps using local discontinuities in line orientation, intensity contrast, and color opponency using a winner-take-all mechanism (Itti et al. 1998). The saliency maps allowed us to measure the relative saliency of the emotional object as compared to the other objects/locations in the scene. The perceptual saliency of the emotional object was defined as the peak saliency value falling inside the object shape (cf. Santangelo and Macaluso 2013). Saliency values were entered into a correlational analysis in which we investigated whether the recollection probability and the recollection position of a given positive or negative emotional object (averaged across participants) co-varied along with the saliency value of that object. Using a similar correlational approach, we also investigated whether the recollection probability and the recollection position of emotional objects co-varied as a function of their emotional arousal, as assessed during the validation procedure (see above section "Stimuli: selection and validation").

Finally, we computed the number of neutral objects recollected for each scene by each participant according to whether the emotional object was successfully reported (Emo_R) or not (Emo_{nR}) by that participant. This index was used to assess whether the encoding/maintenance of the emotional object predicted the contents of WM, i.e., the overall number of neutral objects recollected for that scene. This number was scaled by the average number of recollected objects by all participants in that scene. Again, this weighting procedure allowed us to more accurately compare the meaning of each recollection total across each scene: e.g., recollection of six objects in a scene in which the group recollected an average of twelve objects reflects a poor performance, but recollecting six objects when the group recollected an average of five represents an excellent performance. The closer this index was to 1, the more the participant's performance was close to the group average; the more this index was distant from 1, the more the performance was distant to the group average (i.e., poorer performance < 1; better performance > 1). Averaging across participants and scenes, we obtained the final number of neutral objects that were recollected when the emotional object was also recollected or not.

Results

Overall, the participants successfully recollected an average (unscaled) number of 5.0 ± 0.7 (mean ± std) objects from each scene. The average of successfully recollected objects varied between a minimum of 3.2 and a maximum of 6.6 objects per scene across participants.

A 2 × 2 ANOVA including the within-participants factors of Object type (emotional vs. neutral) and Scene valence (positive vs. negative) was conducted on the recollection probability data. This revealed a main effect of object type [$F(1,39) = 229.1$, $p < .001$; $\eta^2 = .855$], indicating a greater probability of recollecting emotional (mean proportion = .72) rather than neutral (.44) objects from each scene, irrespective of their valence (Fig. 2a). This analysis did not reveal other significant effects (Fs < 1, n.s.).

An analogous 2 × 2 ANOVA on the recollection position data revealed a main effect of object type [$F(1,39) = 38.6$, $p < .001$; $\eta^2 = .497$], indicating that emotional objects (mean scaled position = .71) were reported later than neutral objects (.63) in the stream of recollected items. The analysis also revealed a main effect of scene valence [$F(1,39) = 11.2$, $p = .002$; $\eta^2 = .222$], with negative objects (.69) reported later than positive objects (.65), and a significant interaction between the two factors [$F(1,39) = 5.5$, $p = .024$; $\eta^2 = .123$]. Post hoc analysis (Scheffe test) revealed that in both positive and negative scenes, emotional objects were reported later than neutral objects ($p = .009$ and $p < .001$, respectively). However, the magnitude of the effect was larger for negative scenes, as evidenced by a two-tailed t test comparing the recollection position for "Emo minus Neu objects" in negative versus positive scenes [$t(39) = 2.3$, $p = .027$]. This indicates that the difference in the recollection position between

[1] It is worth noting here that assessing how many objects are included in a commonplace scene is not a trivial issue, since this depends on the definition of what constitutes an "object". For example, when a picture contains a car, should the car be considered as a single object or should all single components (wheels, license plate, mirror, etc.) be counted as distinct objects? Here we address this problem—at least to some extent—by relying on a subjective measure, that is, on the number of objects successfully reported by participants during the time-constrained scene exploration (4 s).

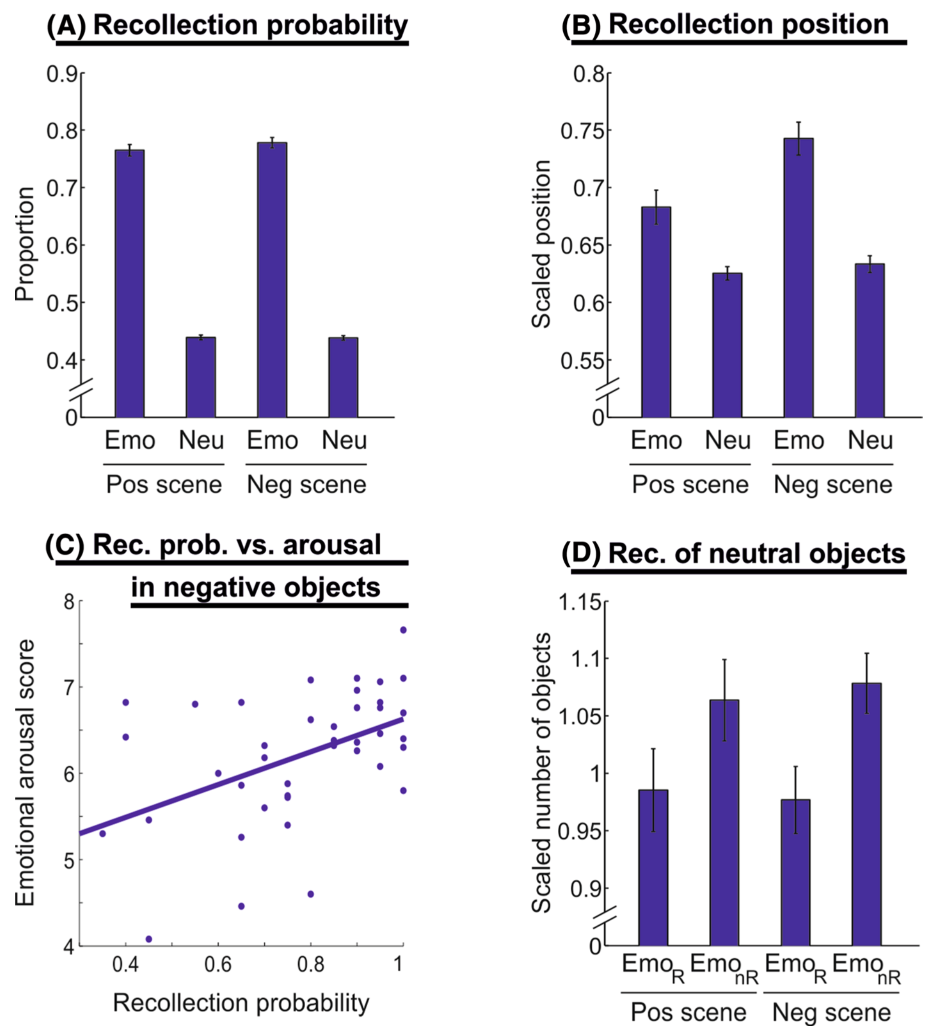

Fig. 2 **a**, **b** Mean recollection probability and mean of recollection position of either the emotional (Emo) or neutral (Neu) objects in both positive and negative scenes. Note that in B, higher scaled position indicates later recollection in the sequence. **c** Correlation between the recollection probability of emotionally negative objects and their emotional arousal score. **d** Number of recollected neutral objects in positive or negative scenes depending on whether the emotional object was reported (Emo_R) or not (Emo_{nR}). In all graphs, the error bars represent the standard error of the mean

emotional and neutral targets mainly arose in negative scenes (compare bar 3 minus 4 vs. bar 1 minus 2 in Fig. 2b).

Next, we carried out correlational analyses to investigate the possible role of perceptual saliency on emotional memory. These analyses failed to show significant results, indicating that neither the recollection probability nor the recollection position co-varied with the mean saliency of negative ($r = -.167$, $p = .303$ and $r = -.060$, $p = .713$) or positive objects ($r = -.029$, $p = .858$ and $r = .054$, $p = .743$). We also carried a correlational analysis to investigate the role of negative and positive arousal on emotional memory. Our results revealed that the recollection probability increased as a function of emotional arousal of negative objects ($r = .466$, $p = .003$; see Fig. 2c), but not for positive objects ($r = .074$, $p = .648$). The recollection position did not change as a function of either negative or positive object arousal ($r = -.280$, $p = .080$ and $r = .006$, $p = .969$).

Finally, we examined whether the successful recollection of emotional objects affected the number of neutral objects recollected by participants. Overall, participants recollected a similar percentage of emotional objects across positive (77%) and negative (78%) scenes, as evidenced by a two-tailed t-test [$t(38) = 0.3$, $p = .771$]. We then conducted a 2 × 2 repeated-measures ANOVA on the number of neutral objects successfully recollected with the factor of Recollected emotional object (recollected vs. not recollected) and Scene valence (positive vs. negative). This revealed a main effect of recollected emotional object [$F(1,39) = 33.5$, $p < .001$; $\eta^2 = .638$], indicating that fewer neutral objects were successfully recollected when the emotional object was recollected (.98) compared to when the emotional object was not recollected (1.07; Fig. 2d). No other effects were significant (Fs < 1, n.s.).

Discussion

This study aimed to investigate whether and under which conditions the encoding of emotional objects modulated WM content and access to competing emotionally neutral objects. We found that the probability and timing of recollecting objects varied according to their emotional salience, with emotional objects—either positive or negative—reported far more often and later in the stream of recollected items compared to neutral objects. These effects were independent of the perceptual saliency of the emotional object. Moreover, we found a significant reduction in the number of neutral recollected objects when the emotional object was successfully retrieved from WM.

The increased recollection performance in our task might derive from attention priorities (Desimone and Duncan 1995) assigned to emotional stimuli in a bottom-up fashion during scene-viewing (Santangelo 2015), because of their importance for survival (Bradley 2009). The immediate consequence might be a deeper processing of emotional objects, resulting in stronger encoding and more likely retrieval. This is in line with previous literature demonstrating an automatic capture of attention by emotional stimuli (Pourtois et al. 2013; Yiend 2010), and with the emotional enhancement of memory (Buchanan and Adolphs 2002; LaBar and Cabeza 2006; Pedale et al. 2017), even under highly demanding conditions (Simione et al. 2014). The previous literature typically employed very simple and repetitive stimuli (Dolcos and McCarthy 2006; Kensinger and Corkin 2003; Mather et al. 2006; Perlstein et al. 2002). Here, we extended the emotional effect on memory using everyday scenes involving a high level of stimulus competition.

We also found that the emotional objects were reported later than neutral objects in the stream of recollected items. This finding might be interpreted in light of the classical free-recall word-list experiment. Here, participants typically begin their recall with items belonging to the final part of the list, the weaker encoded items (recency effect), then move on to recall the stronger encoded items occurring in an earlier position of the list (primacy effect; Beaman and Morton 2000; Tan and Ward 2007). Note, however, that because all objects were viewed simultaneously, we cannot infer a true serial position effect. The later recollection of emotional objects could be due to the same mechanism observed by Brainerd et al. (1990) at retrieval: participants started recollecting neutral objects, which may have had a weaker memory representation, to avoid forgetting them. Then, they moved on to recollection of the emotional objects that may have had a stronger memory representation. The higher recollection probability for emotional than neutral objects demonstrated that their memory representation was strongly resistant to output interference (Hurlstone et al. 2014). In fact, recollection of neutral items did not interfere and reduce the accessibility of emotional objects that were yet to be recalled.

Interestingly, the impact of emotional stimuli on WM performance was not affected by low-level sensory features, here modeled in terms of perceptual saliency (Itti et al. 1998). Perceptual saliency has proven to be effective at predicting WM performance in previous research (see, for a review, Santangelo 2015). For instance, Pedale and Santangelo (2015) using a similar design based on free-recollection of objects from emotionally neutral scenes showed that objects high in perceptually saliency have more chance to be recollected than low perceptually salient objects. Here, we found that "emotionally salient" versus "emotionally neutral" stimuli improved WM performance, an effect that is unrelated to low-level perceptual features. The presence of an emotional object in a complex visual scene therefore appears to grab attention irrespective of its perceptual features, which does not further influence memory performance.

Recollection probability instead increased as a function of emotional arousal, but only for negative objects. This result is in line with previous research showing increased attentional capture by negative stimuli as a function of arousal (Kensinger and Corkin 2004). Here, we confirm in complex scenes that highly arousal negative objects have a greater chance of successful encoding and retrieval (Steinmetz et al. 2010).

Finally, we found a decrease in the number of neutral objects recollected when the emotional object was successfully recollected, indicating that encoding of emotional objects plays a crucial role in the capacity to encode and recollect competing neutral objects. This is consistent with the notion that emotional information can disrupt memory processes for neutral information (Kensinger and Corkin 2003; Mather et al. 2006). Here, we further extend this notion, showing for the first time that emotional stimuli not only tend to capture attention in a bottom-up way and are preferentially stored in WM during a highly demanding task (Simione et al. 2014), but they also exhaust WM capacity when correctly encoded. This means that the impaired encoding and retrieval of neutral objects in a complex scene might not be merely a consequence of the presence of the emotional object. In fact, the reduction in the amount of neutral information reported occurred most strongly when the emotional object was effectively recollected. This indicates that the more efficient the emotional object was in capturing attention resources at encoding (Nardo et al. 2011), the less attention resources were available to encode end retrieve other neutral objects in the scene. By contrast, the encoding/recollection of neutral objects from the scene suffers from less limitation when the emotional object was not efficient enough to consume attentional resources.

To conclude, the current study provides evidence that the processing of emotionally salient objects in everyday scenes—irrespective of their perceptual saliency—is prioritized during formation of object/scene memory traces, affecting the subsequent retrieval strategy during access of the stored representation. The successful encoding and recollection of the emotional object was accompanied by a reduction in the number of neutral stimuli reported. This is interpreted as evidence that emotional stimuli might not have an automatic effect on the modulation of WM content per se, but the effect of emotional stimuli would instead be subordinate to the efficiency of the specific stimulus to grab attention resources. When stimuli are efficient in capturing attention, emotional objects not only have a greater chance of being successfully encoded, but are also more likely to exhaust resources, thus impairing global memory performance.

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