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Evidence for the Differential Salience of Disgust and Fear in Episodic Memory

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Studies of emotional memory typically focus on the memory-enhancing effects of emotional dimensions such as arousal and valence. However, it is unclear to what extent different emotional categories could have distinct effects on memory over and above these dimensional influences. We tested this possibility by investigating the impact of two negative, highly arousing, and withdrawal-related emotions—disgust and fear—on attention and subsequent memory. To index differential attention during encoding, participants performed a speeded line discrimination task (LDT) while viewing disgusting and fearful photographs of similar valence and arousal, which were assessed for later memory. LDT performance was slower, and subsequent recall and recognition were greater, for disgusting compared to both fearful and neutral images. Disgust enhancement of memory remained significant even when controlling for attention at encoding and for arousal, visual salience, and conceptual distinctiveness. Receiver-operating curve analyses indicated that disgust enhancement of memory was due to increased sensitivity, rather than response bias. Thus, disgust appears to have a special salience in memory relative to certain other emotions, suggesting that a purely dimensional model of emotional influences on cognition is inadequate to account for their effects. We speculate that disgust enhancement of memory could arise from an origin in conditioned taste aversion, a highly enduring form of implicit memory.

Keywords: emotion, memory, disgust

Two competing models of emotion currently dominate the study of human affective psychology and neuroscience. On the one hand, basic emotions models claim that all humans possess a limited number of distinct emotions, typically including anger, fear, surprise, sadness, disgust and happiness (e.g., Ekman, 1992). On the other hand, dimensional models maintain that seemingly distinct emotions are actually combinations of simpler dimensions, such as valence and arousal (e.g., Russell, 1980) or approach and withdrawal (e.g., Davidson, Jackson, & Kalin, 2000).

Dimensional and basic emotions models make different predictions about emotional influences on memory but have not yet been

tested against one another in this context. Dimensional models have been highly influential in the emotional memory literature and focus on the importance of an emotion's dimensionality—especially its valence and arousal—in determining its mnemonic effects. Indeed, a considerable body of evidence has demonstrated that emotionally arousing stimuli are better remembered than neutral stimuli, especially with increasing delay between study and test (Bradley, Greenwald, Petry, & Lang, 1992; Sharot & Phelps, 2004). At longer delays, arousal enhancement of memory appears to be driven primarily by amygdala modulation of consolidation processes (Hamann, 2001; LaBar & Cabeza, 2006). Emotional valence can also enhance memory (Kensinger, 2004), with positive and negative valence potentially having distinct influences (Talmi, Schimmack, Paterson, & Moscovitch, 2007).

While emotional dimensions have been shown to have an important influence on memory, a basic emotions perspective suggests that arousal and valence may not be sufficient to fully account for all of emotion's cognitive effects. Different basic emotions are associated with characteristic patterns of cognitive appraisal (Scherer, 1987), action readiness (Frijda, 1987), judgment (Lerner & Keltner, 2000), and problem solving (Bodenhause, Sheppard, & Kramer, 1994) and may depend on at least partially distinct neural substrates (Calder, Lawrence, & Young, 2001). Accordingly, differences on these variables could influence how stimuli from various emotion categories are encoded, with their distinct forms of processing influencing how accurately they are later remembered (Levine & Pizarro, 2004). Thus, according to

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a basic emotions model, there could be important differences in how well different kinds of emotional stimuli are remembered, even if they have similar dimensionality.

Our aim in the current research was to compare the dimensional and basic emotions perspectives by examining memory for stimuli that belong to different emotion categories, while holding constant dimensions that are thought to be important for emotional influences on memory, i.e., valence and arousal (Bradley et al., 1992; Cahill & McGaugh, 1998; LaBar & Phelps, 1998). More specifically, we compared episodic memory for disgusting and fearful photographs. Disgust and fear are ideal emotions to compare, since both are negative, highly arousing, and avoidance-related—that is, they have similar dimensionality. Accordingly, by matching our disgusting and fearful stimuli on these dimensions, we may isolate the effects of specific emotions on memory. The comparison stimuli in the current study—fearful images—should present a particularly strong test of any special salience of disgust. Although the amygdala is not tuned specifically to fear (Anderson, Christoff, Stappen, et al., 2003; Cunningham, Van Bavel, & Johnsen, 2008; Sergerie, Chochol, & Armony, 2008), fearful stimuli, including faces and emotional scenes, are strong activators of the amygdala (Morris et al., 1996; Phillips et al., 1997; Whalen et al., 2001), which, in turn, is strongly tied to emotional enhancement of memory (Hamann, 2001; LaBar & Cabeza, 2006; Phelps, 2006).

Based on the evidence described above for neuroanatomical and cognitive differences between basic emotions, we anticipated that memory might differ for the disgusting and fearful stimuli. Specifically, we predicted that memory for the disgusting stimuli would be enhanced relative to the fearful stimuli. This prediction was based on the unique contaminating property of disgusting stimuli. In particular, a disgusting object can render a previously neutral object disgusting, simply by contacting it. Contamination is a potent psychological force: Minute or even imperceptible amounts of disgusting material can contaminate, and contamination spreads easily and invisibly between objects (Rozin & Fallon, 1987). The contaminating nature of disgusting objects may present a particularly strong challenge to memory, in that disgusting and contaminated objects must be remembered so as to avoid contamination of the self. Moreover, contamination is highly resistant to decay (Rachman, 2004), so contaminated objects may retain their salience over time. As such, like contamination itself, memory for disgusting stimuli may also be resistant to decay.

Consistent with the notion that disgust memory may be especially accurate and enduring, there is a strong conceptual similarity between disgust and conditioned taste aversion (CTA), a particularly powerful form of memory (Welzl, D'Adamo, & Lipp, 2001). CTAs result from the pairing of a neutral gustatory stimulus with a sickness-inducing treatment. Subsequent exposures to the previously neutral stimulus result in avoidance of the conditioned gustatory stimulus, accompanied in humans by intense feelings of disgust and nausea (Garb & Stunkard, 1974). CTAs can be extraordinarily persistent: aversions acquired in childhood have been reported to persist 50 years later (Garb & Stunkard, 1974). Disgusting and contaminated objects, many of which are potential sources of sickness and disease (Curtis, Aunger, & Rabie, 2004), could potentially draw upon part of the neural circuitry of CTA to strongly enhance episodic memory.

Although a special role for disgust in enhancing memory makes sense, evidence pertaining to this issue is sparse. Patients with

contamination-focused obsessive-compulsive disorder can have remarkably long-lasting memories of contaminated objects (Rachman & Rachman, 1999), although this could reflect fear as much as disgust. There have been few attempts to examine disgust memory in healthy individuals (Charash & McKay, 2002; Croucher, Calder, Ramponi, Barnard, & Murphy, 2011). One study found an advantage for disgusting words relative to fearful words in free recall, but the disgusting and fearful stimuli were not matched on valence and arousal (Charash & McKay, 2002). More recent work has also found enhanced recognition for disgusting relative to fearful photographs (Croucher et al., 2011). However, this study did not examine possible confounds (e.g., attention, visual complexity, differences in response bias across emotion types; Dougal & Rotello, 2007) that could account for any categorical differences in memory.

It is especially important to consider whether fear and disgust may differ in their ability to capture and hold attention (Buodo, Sarlo, & Palomba, 2002; Sawchuk, Lohr, Lee, & Tolin, 1999). Because allocation of attention at encoding can influence subsequent memory performance (Craig, Govoni, Naveh-Benjamin, & Anderson, 1996), differences in the attentional resources devoted to processing disgusting and fearful stimuli could have important consequences for how well these stimuli are remembered. If one emotion receives more attention than the other during encoding, then it may be remembered better, irrespective of influences on memory consolidation or retrieval (Cahill & McGaugh, 1998; Hamann, 2001; LaBar & Cabeza, 2006). We therefore assessed differences in the ability of disgusting and fearful stimuli to capture and hold on to attention (Öhman, Flykt, & Esteves, 2001; Schimmack & Derryberry, 2005; Williams, Mathews, & MacLeod, 1996). Only a few studies have examined attentional differences between fear and disgust (e.g., Buodo et al., 2002; Charash & McKay, 2002; Cisler, Olatunji, Lohr, & Williams, 2009), with mixed results, and no study has controlled for their underlying emotional dimensions.

We conducted three experiments to examine attention and memory for fearful and disgusting stimuli. In each, participants first performed an incidental encoding task in which they viewed disgusting, fearful, and neutral photographs while concurrently performing a speeded line location discrimination task (LDT). Following the logic of emotional Stroop tasks (McKenna & Sharma, 1995; Watts, McKenna, Sharrock, & Trezise, 1986; Williams et al., 1996), reaction times on the LDT served as an indicator of the ability of items to capture attention: Slowed reaction times for emotional images relative to neutral would suggest that the emotional images were more attentionally salient (Talmi et al., 2007). This measure allowed us to control for variation in attentional salience at encoding on later memory. Memory for the stimuli presented during the LDT was tested after varying delays and using both free recall and recognition memory tests.

Experiment 1

Method

Participants. Participants were 51 University of Toronto students (36 female, M age = 18.4 years), who received course credit as compensation.

Stimuli. To match the fearful and disgusting photographs on valence and arousal, a pilot study ($N = 20$) was conducted to obtain subjective ratings of fear, disgust, valence, and arousal for 192 photographs taken from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005) and other sources. Using these ratings, 16 disgust-themed and 16 fear-themed photographs were chosen such that the disgusting photographs were rated as high in disgust and low in fear, while the fearful photographs were rated as high in fear and low in disgust. Disgusting and fearful photographs were matched on mean valence, $t(19) = 1.61, p = .124$. However, fearful photographs were significantly more arousing than disgusting photographs ($x_{\text{disgusting}} = 5.44, x_{\text{fearful}} = 6.91$), $t(19) = 3.92, p = .001$. We note that this difference should work against enhanced memory for disgusting stimuli, since higher arousal is usually associated with better recall. We also selected 16 neutral photographs rated as low in disgust, fear, and arousal and intermediate (neutral) in valence. Pilot ratings for the selected photographs are shown in Figures 1A and 1B. All photographs had unique content to avoid confusion at the recall stage (e.g., we presented only one

picture of a shark). Disgusting images included insects such as lice and cockroaches (threatening insects such as spiders or scorpions were not included), body products such as feces and vomit, and disease and deformity. Fearful images included human or animal threat, disasters, and social unrest (e.g., riots). Neutral images consisted primarily of household objects (e.g., coffee maker, coat hanger, book).

Procedure. Participants first completed a computerized line location discrimination task (LDT), designed to assess the attentional salience of the images and fear while allowing for incidental encoding of the images. On each trial, a randomly selected fearful, disgusting, or neutral photograph (24.5×22.5 cm) appeared centrally (subtending approximately 34×31 degrees of visual angle), with a 9.5×0.3 cm horizontal white line randomly positioned 1 cm above or 1 cm below the image. Images were displayed for 2 s, followed by 500 ms of central fixation. Participants were instructed to indicate with a key press, as quickly and accurately as possible, whether the line appeared above or below the picture. Secondly, participants were told to look at the pictures throughout the time they were presented.

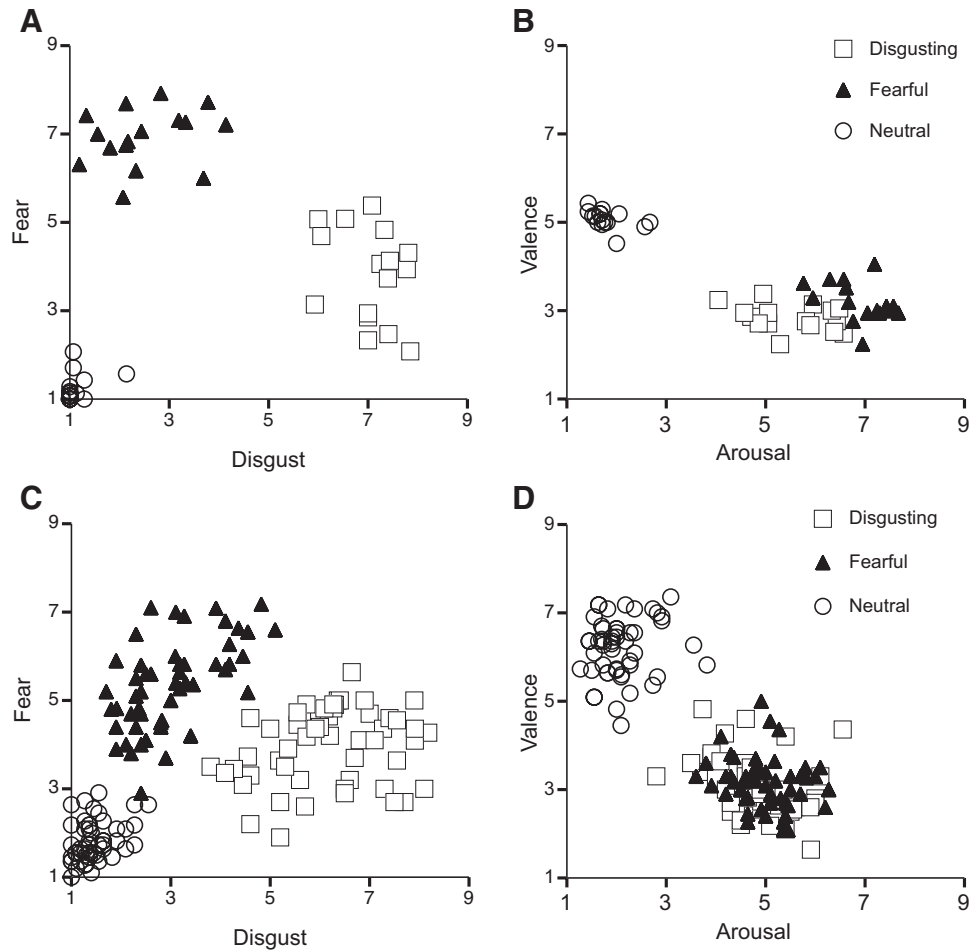


Figure 1. Pilot ratings of the photographs used as stimuli in Experiments 1 and 2 (A and B) and Experiment 3 (C and D). Points represent the mean rating for each photograph across subjects. Disgust, fear, and arousal were rated on 1–9 scales ranging from 1 (*not at all*) to 9 (*very*); valence was rated on a bipolar 1–9 scale with anchors of 1 (*very negative*), 5 (*neutral*), and 9 (*very positive*).

Following the LDT, there was a 10-min or 45-min delay, manipulated as a between-subjects variable (10 min, $n = 28$, 18 female, M age = 18.0 years; 45 min, $n = 23$, 17 female, M age = 18.7). During the delay, participants completed unrelated filler tasks. For both groups, one filler was an equation-search task in which participants searched for true equations in a matrix of random numbers and function signs. To maintain participant engagement during the longer study-test interval, participants in the 45-min delay group also completed an additional, more varied filler task in which they made speeded responses to target and nontarget stimuli of various colors.

After the delay, there was a surprise free recall test for the photographs. Participants were instructed to record on paper the pictures they could remember, in any order, by describing the picture in a few words. Finally, participants viewed all of the photographs again and rated them on disgust, fear, valence and arousal using 1–9 scales.

Data analysis. Data from the LDT consisted of latencies to indicate the location of the line, contingent on correct localization. Latency data were sorted by participant and condition, and extreme outliers (values more than three interquartile ranges distant from the quartiles) were removed. Mean latencies were then calculated for each participant in each condition. Recall data were coded as matches or nonmatches to study photographs, and the proportion of correctly recalled photographs within each emotion condition was calculated. To check the reliability of the coding and protect against experimenter bias, a second rater, who was blind to the study aims and hypotheses, also coded the data. Agreement computed across all subjects and images was 97%.

Results and Discussion

Recall. Recall data were analyzed using an analysis of variance (ANOVA) with factors of Emotion Category (disgusting, fearful or neutral) and Delay Interval (10- or 45-min delay). This analysis revealed significant main effects for both Emotion Category, $F(2, 94) = 67.9$, $p < .001$, and Delay Interval, $F(1, 47) = 9.08$, $p < .01$, as well as an Emotion \times Delay interaction, $F(2, 94) = 4.58$, $p < .05$. As shown in Figure 2A, for the 45-min delay, recall

of disgusting pictures was significantly higher than fearful pictures, $t(22) = 3.67$, $p < .01$, and fearful was higher than neutral, $t(22) = 5.89$, $p < .001$. For the 10-min delay, disgust was nonsignificantly greater relative to fear, $t(25) = 1.59$, $p = .125$, while fear memory remained higher than neutral, $t(25) = 5.26$, $p < .001$. Thus, enhanced memory for disgust relative to fear was most pronounced after longer delays. A caveat is that subjects in the 45-min delay condition performed an additional filler task to occupy the extra time. This task was unrelated to memory or emotion and seems unlikely to influence the results, particularly given that memory for the neutral stimuli was not affected by this difference.

Figure 2A also shows a tendency toward enhanced memory for emotional items at the 45-min delay relative to the 10-min delay. In particular, significantly more disgusting items, $t(47) = 3.35$, $p < .01$, and marginally more fearful items, $t(47) = 1.92$, $p = .061$, were recalled after a 45-min delay than after a 10-min delay. Increased memory with increasing delay is not unheard of in the emotional memory literature (Kleinsmith & Kaplan, 1963; LaBar & Phelps, 1998; Sharot & Phelps, 2004; Sharot & Yonelinas, 2008), although this finding is somewhat inconsistent (Hamann, Ely, Grafton, & Kilts, 1999; Mather, Gorlick, & Nesmith, 2009; Mather & Knight, 2005; Payne et al., 2006).

Arousal is known to be a key factor in the emotional enhancement of memory (Hamann, 2001; LaBar & Phelps, 1998). Since our disgusting images were actually less arousing than the fearful images, it is unlikely that differences in arousal can account for the superiority of disgust memory over fear. Nevertheless, given the significant arousal differences across categories, we performed an item analysis on the data from the 45-min delay group. We computed mean ratings of disgust, fear, and arousal for each image, as well as the proportion of times the image was recalled across the group (relative to the maximum number of times it could have been recalled). We then calculated partial correlations between disgust ratings and recall and between fear ratings and recall, controlling for arousal in each. Disgust ratings were significantly correlated with recall, even when arousal was controlled ($r = .450$, $p = .002$; see Figure 2B). In other words, images that

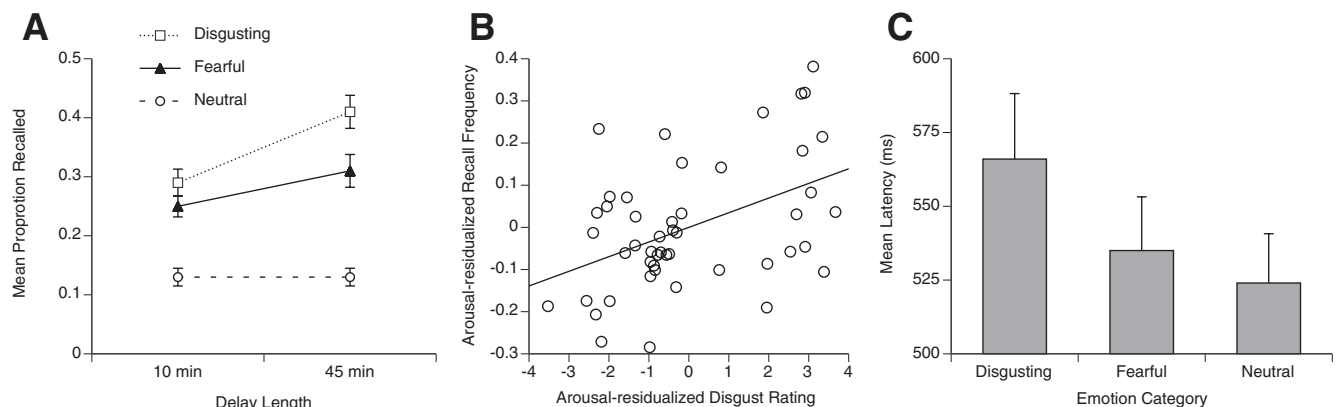


Figure 2. A. Mean proportion of pictures recalled correctly in Experiment 1. B. Relationship between disgust ratings and frequency of recall in the 45-min delay group, controlling for arousal. Points represent the mean values for each photograph across subjects. Linear fit is shown. C. Mean latencies on the line discrimination task for Experiment 1. Error bars in A and C give 1 SEM.

were perceived as more disgusting were recalled more frequently, over and above any effect of arousal. By contrast, fear ratings were not significantly associated with recall after controlling for arousal ($r = .092, p = .536$).

Line-discrimination task. Latencies were analyzed with a repeated-measures ANOVA with one factor of Emotion Category (disgusting, fearful, or neutral). As shown in Figure 2C, latencies differed significantly according to Emotion Category, $F(2, 100) = 10.7, p < .001$. Latencies were slower for disgusting photographs than for fearful photographs, $t(50) = 3.13, p < .005$, and there was a nonsignificant trend toward slower latencies for fear photographs relative to neutral photographs, $t(50) = 1.73, p = .09$. These results suggest that disgusting images may capture attention to a greater extent than fearful images, thus interfering with performance of the primary line discrimination task.

For emotionally neutral information, enhanced attention at encoding results in better memory at test (Craig et al., 1996). In the current study, disgusting photographs received more attention than fearful or neutral photographs. We therefore wondered whether the enhanced memory for disgusting photographs relative to fearful photographs after a 45-min delay might be due to the increased attentional salience of these images. To test for this possibility, we performed another item analysis, this time to control for LDT latency, our index of attention toward the photographs. Disgust ratings were correlated with both recall frequency ($r = .61, p < .001$) and LDT latencies ($r = .47, p = .001$). However, the correlation between disgust ratings and recall remained significant even after partialling out the effect of LDT latencies ($r = .53, p < .001$). Statistically controlling for the effects of attention during encoding on later memory thus did not eliminate superior recall for disgust relative to fear after a 45-min delay.

Experiment 2

Experiment 1 found disgust enhancement of memory that was not accounted for by enhanced attentional salience of disgusting images, as measured by reaction times on the LDT. However, a limitation of the LDT measure of attention is that the line-discrimination portion of the task was completed early in each trial. Mean LDT reaction times were around 550 ms; however, the picture was displayed for a full 2 s. Using LDT reaction times as a measure of attention thus leaves nearly 1,500 ms of “uncontrolled” attention that could potentially drive memory effects. If disgusting photographs hold attention over a prolonged period, this later attentional effect could be responsible for enhanced recall of the images.

To test this possibility, we moved the LDT from the beginning of each trial to near the end, thereby obtaining an index of later or continued attention toward the photographs. If enhanced recall for disgusting images is driven by continued attention, then statistically controlling for it should eliminate the disgust memory advantage. On the other hand, if disgust enhancement of memory is independent of continued as well as initial attention, then disgust should still have a significant impact on recall, even after controlling for continued attention.

In addition to further exploring the role of attention in disgust enhancement of memory, a secondary aim of this experiment was to examine two other potential confounds, namely, objective visual salience and subjective distinctiveness. To assess whether the

disgusting images might be more distinctive and eye-catching than the fearful images, we computed multiple metrics of objective visual distinctiveness and also collected ratings of subjective distinctiveness for the disgusting, fearful and neutral images after subjects completed the recall test.

Method

Participants. Twenty-three University of Toronto students (13 female; M age = 22.8 years) participated in the experiment in return for pay.

Procedure. The study was conducted largely as in the 45-min delay condition in Experiment 1. The line-discrimination task was modified so that the line appeared 1,300 ms after the onset of the photograph; the photograph and line then persisted for a further 700 ms, for a total trial length of 2 s. The 1,300-ms latency to line onset was selected so that in most cases, participants would be able to make their response before the end of the trial. Indeed, participants missed only an average of 2.7 trials out of a possible 48 (range = 1–7).

After completing the recall test, participants viewed all of the photographs again and rated them on disgust, fear, valence, and arousal using 1–9 scales. Participants also rated the subjective distinctiveness of each image, described in the instructions as how “eye-catching or unusual” each image was felt to be. A 1–9 scale with anchors of “not at all distinctive” to “very distinctive” was used.

Data analysis. LDT data were included for trials in which localization was correct and the response was made before the end of the trial (i.e., reaction time less than 700 ms). The 700-ms cutoff did not produce excessive trimming of the reaction-time distribution, as indicated by examination of the histograms.

Recall data were coded by an experimenter as in Experiment 1, and the data were also coded by a blind second rater. Agreement between coders was 96%.

Results and Discussion

Recall. Recall data replicated the results of Experiment 1 (see Figure 3A). There was a significant effect of Emotion Category on recall accuracy, $F(2, 44) = 34.6, p < .001$. Disgusting photographs were recalled more accurately than fearful photographs, $t(22) = 2.93, p = .008$, which, in turn, were recalled more accurately than neutral photographs, $t(22) = 6.09, p < .001$. As in Experiment 1, we conducted an item analysis to examine the influence of the significant difference in arousal across disgust and fear. The effect of disgust on recall remained significant even when controlling for arousal (partial $r = .406, p = .005$; see Figure 3B). By contrast, fear was no longer a significant predictor of recall when arousal was controlled (partial $r = -.069, p = .643$).

Subjective and objective distinctiveness. We next examined whether subjective and objective distinctiveness differed between disgusting and fearful images. Analysis of the subjective distinctiveness ratings revealed a significant effect of Emotion Category, $F(2, 44) = 66.0, p < .001$. Both disgusting ($x = 5.9$) and fearful ($x = 5.5$) images were judged to be more distinctive than neutral images ($x = 2.5$); disgust versus neutral $t(22) = 8.72, p < .001$; fearful versus neutral, $t(22) = 9.47, p < .001$. However, the

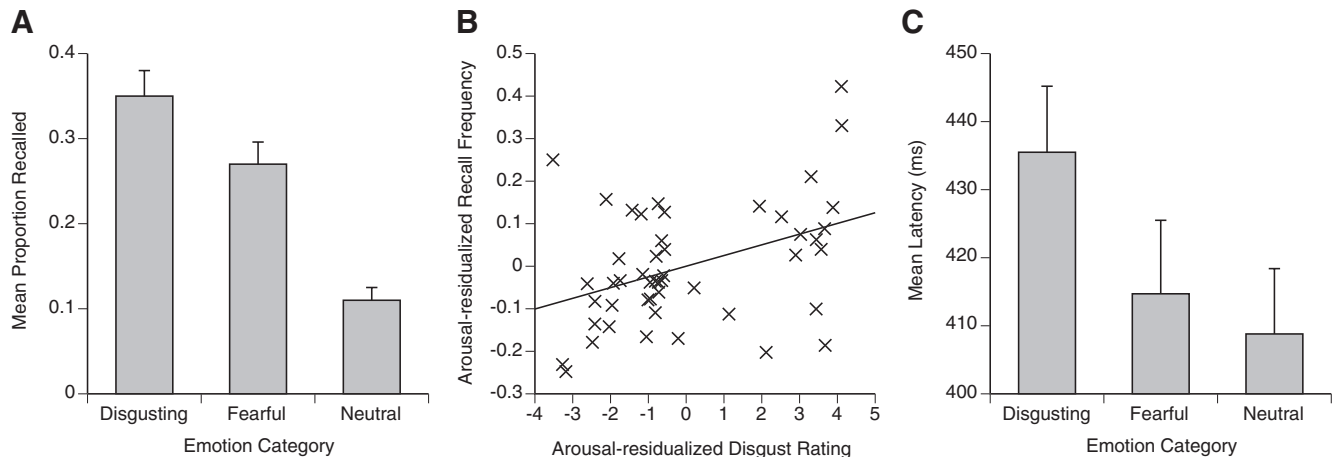


Figure 3. A. Mean proportion of pictures recalled correctly in Experiment 2. B. Relationship between disgust ratings and frequency of recall, controlling for arousal. Points represent the mean values for each photograph across subjects. Linear fit is shown. C. Mean latencies on the line discrimination task for Experiment 2. Error bars in A and C give 1 *SEM*.

disgusting and fearful photographs did not differ significantly in distinctiveness, $t(22) = 1.7, p = .106$. This similarity was not a reflection of a ceiling effect, as the rating scale extended to 9. Thus, while subjective distinctiveness may contribute to the enhancement of disgust and fear memory relative to neutral, it is unlikely that this factor can account for the enhancement of disgust relative to fear.

We also examined a number of incidental visual factors that could potentially differ across image categories, resulting in differential salience and distinctiveness. Using the Image Processing Toolbox from Matlab 7.0, we computed several objective measures of image salience—the luminance, contrast, hue and saturation of each image—as well as an objective measure of visual complexity—the edge density of each image (Mack & Oliva, 2004; Rosenholtz, Li, & Nakano, 2007). A repeated-measures ANOVA indicated significant differences in these measures across emotion categories (Emotion Category \times Measure interaction), $F(8, 180) = 4.17, p < .001$. To control for these differences, we calculated a partial correlation between disgust ratings and recall, controlling for the visual parameters. The correlation between disgust and recall remained significant even when the luminance, contrast, hue, saturation, and edge density of each image were partialled out (partial $r = .571, p < .001$). Thus, disgust enhancement of memory was not driven by any of these visual salience or complexity variables that contribute to visual distinctiveness.

Line-discrimination task. Replicating Experiment 1, there was a significant effect of Emotion Category on LDT latency (see Figure 3C), $F(2, 44) = 7.90, p = .001$. Latencies for disgusting images were higher than for fearful images, $t(22) = 2.75, p = .012$, suggesting that the extra attention salience associated with disgusting images continues later into the trial. Latencies for fearful images did not differ significantly from neutral, $t(22) = 1.03, p = .313$, consistent with prior research showing that attentional bias for threatening stimuli is found consistently only in high-anxiety populations (Bishop, 2008).

We again conducted an item analysis to examine whether enhanced memory for disgusting images could be explained by their heightened attentional salience later in each trial. As in Experiment 1, we computed mean disgust ratings and LDT latencies for each image, as well as the proportion of times each image was recalled across subjects. Consistent with the ANOVA results, higher disgust ratings were associated with both longer LDT latencies ($r = .33, p = .02$) and higher recall frequency ($r = .54, p < .001$). However, the correlation between disgust ratings on recall frequency remained strong and significant even after controlling for LDT latencies ($r = .45, p = .002$). Thus, enhanced recall related to the disgusting quality of the images is not accounted for by the increased attentional salience of these images, specifically their ability to hold attention even later into the trial.

Experiment 3

Experiment 1 suggested that with increasing delay between study and test, recall of disgusting photographs might gain an increasing advantage over recall of fearful photographs. In Experiment 3, we pursued this effect further by increasing the study–test delay to 1 week. To examine whether the apparent memory advantage for disgust in Experiments 1 and 2 could be an artifact of performing the LDT concurrently with encoding, half of the participants in Experiment 3 studied the images while performing the LDT (as in Experiments 1 and 2), and the other half studied them without performing a concurrent task. Experiment 3 also employed a recognition paradigm, which served both to ensure adequate memory after the longer delay and to control for any organizational influences during recall (Tulving, 1962), which is one potential account of the difference between disgust and fear memory. Recognition tests are relatively immune to organizational influences. Lastly, a recognition methodology allowed us to examine potential differences in sensitivity versus response bias across emotion categories, using a receiver-operating characteristic (ROC) approach (Dougal & Rotello, 2007).

Method

Participants. Participants were 50 University of Toronto students (30 female, M age = 21.2), who received course credit or monetary compensation.

Stimuli. Recognition paradigms require lures in addition to targets, which increases the number of stimuli required. Additional images were therefore collected via an internet-based image search, and a pilot study similar to the one described for Experiment 1 was conducted. Pilot ratings were used to select 52 disgust-themed and 52-fear themed images, while 52 neutral images were selected from the IAPS according to the same criteria as Experiment 1. Content of the images was similar to Experiment 1, with the addition of some depictions of injuries and other body envelope violations for disgust and indoor and outdoor scenes for neutral. Pilot ratings for selected images are given in Figures 1C and 1D. The disgusting and fearful images did not differ significantly on valence ($x_{\text{disgusting}} = 3.01$; $x_{\text{fearful}} = 3.15$), $t(52) = 1.11$, $p = .27$, or arousal ($x_{\text{disgusting}} = 4.84$; $x_{\text{fearful}} = 4.99$), $t(52) = 1.13$, $p = .26$). Disgusting images received significantly higher disgust ratings than fearful images ($x_{\text{disgusting}} = 6.17$; $x_{\text{fearful}} = 3.04$), $t(52) = 15.5$, $p < .001$, but significantly lower fear ratings than fearful images ($x_{\text{disgusting}} = 3.96$; $x_{\text{fearful}} = 5.38$), $t(52) = 7.72$, $p < .001$. Neutral images received low ratings of arousal ($x = 2.08$), fear ($x = 1.81$) and disgust ($x = 1.46$), as well as intermediate valence ratings (indicating neutral valence; $x = 6.21$).

The 156 images were divided into two lists of targets (35 images per emotion category) and lures (17 images per emotion category). Targets and lures were switched between the two lists, such that each list contained a distinct group of lures that did not overlap with the other list. Participants were randomly assigned to receive one of the two lists.

Procedure. The experiment involved two sessions, an initial encoding session and a recognition session that took place 6–8 days later.¹ At the beginning of the encoding session, participants were randomly assigned to study the target photographs either while performing the LDT (concurrent task condition) or not (nonconcurrent condition). For participants in the concurrent group, the LDT was identical to Experiment 1. For participants in the nonconcurrent group, photographs and lines were not presented simultaneously. Rather, on each trial, a photograph was presented for 2 s, followed by 1 s of fixation, and then the line appeared for 1 s. Participants were instructed to look at the photographs as they appeared, and to indicate the location of the line when it appeared, as in Experiment 1.

In the recognition session, participants first reported their subjective memory experience for each target and lure image by endorsing it as vividly remembered, associated with a more vague feeling of “knowing,” or new (Gardiner & Java, 1993; Tulving, 1985). They also rated memory confidence for each item on a 1–6 scale, using labels of “sure new,” “unsure new,” “guessing new,” “guessing old,” “unsure old,” and “sure old.” Finally, participants viewed all of the photographs a final time and rated them on arousal, valence, disgust, and fear using 1–9 scales.

Data analysis. Technical errors occurred during the recognition session for six participants, and 10 more did not return for the recognition test session, for a final sample size of 34 in the recognition analyses, divided evenly between the nonconcurrent and concurrent task groups.

Recognition accuracy was first examined separately for remember, know, and new responses, which were coded into hits, misses, false alarms (FA) and correct rejections (CR). The proportion of remember hits and FA was used to calculate remember d' as an index of recollection. However, the proportion of know responses cannot be used directly to examine familiarity, since participants are instructed to respond “know” when an item is familiar but not recollected. Thus, if familiarity and recollection are independent rather than exclusive processes, the number of know responses will tend to underestimate the probability that an item is familiar (Yonelinas, 2002). We therefore used the “independence remember/know” method to calculate the proportion of know responses relative to the number of possible know responses as an index of familiarity: $F = K/(1 - R)$ (Yonelinas, 2002). Because of concerns that d' for know responses does not reflect a true estimate of sensitivity (Macmillan, Rotello, & Verde, 2005), we examined familiarity using corrected recognition (hits minus false alarms). This measure in turn is open to the criticism that is confounded with response bias (Rotello, Masson, & Verde, 2008), and we therefore present it primarily for descriptive purposes. As is discussed shortly, memory sensitivity was examined with receiver-operating characteristic (ROC) statistics.

We also conducted an analysis focusing on memory confidence ratings, in which recognition was examined by dividing participants' continuous ratings into hits (all “old” responses to target items) and false alarms (all “old” responses to lure items). The frequencies of hits and false alarms were computed relative to the total possible number of such responses (i.e., 35 for hits and 17 for false alarms). Confidence-based hit and false alarm rates were used to compute criterion ($c = 0.5[z_{\text{FA}} + z_{\text{HITS}}$]), as an index of response bias.

Drawing upon participant confidence responses (sure, unsure, or guess), we next computed receiver-operating characteristic (ROC) curves as an index of memory sensitivity. ROC curves were created for each participant and condition by plotting hit rates against false alarm rates at each of the six levels of confidence (sure old, unsure old, guess old, guess new, unsure new, and sure new), collapsing across remember and know responses. We computed area under the ROC curve (AUROC) for each participant and condition as a measure of memory sensitivity.

LDT latencies from participants in the concurrent task group were of primary interest, and these were analyzed as in Experiment 1. Subjects who did not complete the recognition task were included in the analysis of LDT data. Of this group, one participant was excluded from further analyses because they did not follow the task instructions, and a further three achieved less than 75% accuracy on the LDT task, for a final sample size of 21 in the LDT analyses.

Results and Discussion

Recognition data. Figure 4 gives the hit and false alarm rates for the different stimulus types, computed independently of confidence data. We first analyzed the d' results for remem-

¹ One participant completed the second session 12 days after the first, due to scheduling difficulties. Excluding this participant from analyses did not influence the pattern or significance of the results.

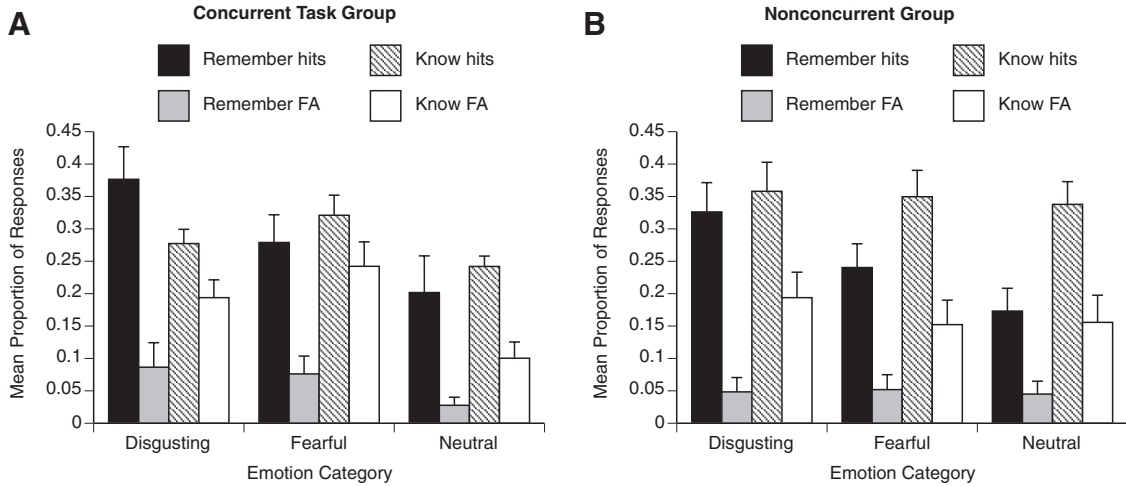


Figure 4. Hit and false alarm rates for the concurrent (A) and nonconcurrent (B) groups in Experiment 3. Error bars give 1 SEM.

ber responses. We conducted a repeated-measures ANOVA with factors of Emotion Category and Group (concurrent vs. nonconcurrent). As shown in Figure 5A, there was a significant main effect of Emotion Category, $F(2, 64) = 16.3, p < .001$. There was no significant main effect or interaction related to Group ($F < 1$), indicating that participants' recognition responses were not affected by performance of the LDT task. To follow up on the significant effect of Emotion Category, we collapsed the two groups together. d' was higher for disgusting compared to fearful stimuli, $t(33) = 4.25, p < .001$, and higher for fearful stimuli compared to neutral stimuli, $t(33) = 2.41, p = .022$.

To investigate the know responses, we conducted a similar repeated-measures ANOVA on the corrected recognition data (see Figure 5B). In contrast to the remember responses, there was no effect of Emotion Category on familiarity, $F(2, 64) = 1.84, p = .167$ (see Figure 5B). There was also no effect of Group, $F(1, 32) = 1.74, p = .197$, and no interaction ($F < 1$). Taken together, these results suggest that episodic recollec-

tion—but not familiarity—was superior for disgust photographs compared to fear photographs after a 1-week delay, similar to the free-recall results after a 45-min delay.

Although it is common to examine recognition data using d' , Dougal and Rotello (2007) have reported that this measure does not provide a consistent estimate of memory sensitivity when there are differences in response bias across conditions, and these authors have presented evidence that emotional materials in particular often introduce response bias. Consistent with these concerns, we observed a significant difference in criterion values according to Emotion Category, $F(2, 72) = 36.1, p < .001$, collapsing across the concurrent and nonconcurrent groups. Disgusting photographs ($x = 0.12$) were associated with a more liberal response bias than fearful photographs ($x = 0.28$), $t(36) = 2.61, p = .01$, which, in turn, had a more liberal bias than neutral photographs ($x = 0.62$), $t(36) = 5.63, p < .001$. Thus, there is reason to believe that higher d' for remember responses to disgusting stimuli could reflect bias rather than sensitivity.

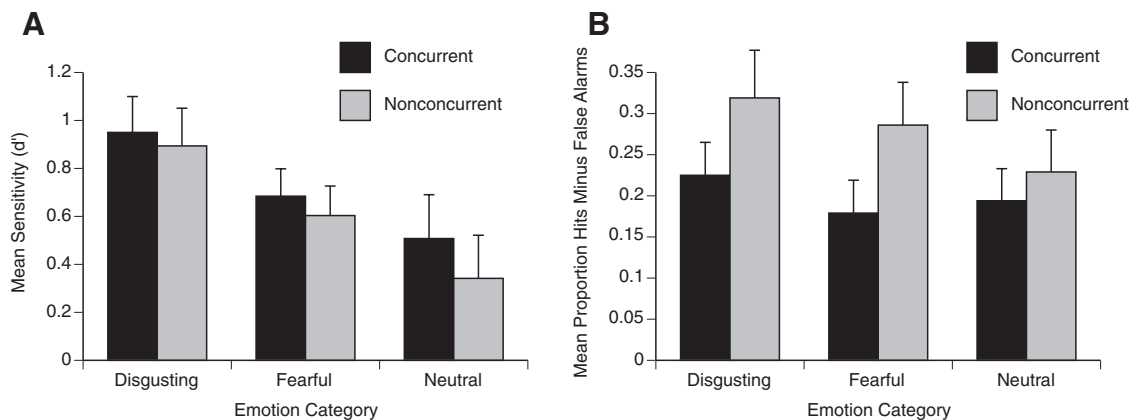


Figure 5. Recognition data from Experiment 3. A. Remember d' for the concurrent and nonconcurrent groups. B. Corrected recognition (hits minus false alarms) for the familiarity index in the concurrent and nonconcurrent groups. Error bars give 1 SEM.

Accordingly, we turned to AUROC, an ROC-based measure of memory sensitivity that does not require an assumption of equivalent criterion levels across conditions (Dougal & Rotello, 2007). Examining the effects of Emotion Category and Group on AUROC values, we found a main effect of Emotion Category, $F(2, 70) = 4.82, p = .011$, but no effect of Group and no interaction. AUROC was higher for the disgusting photographs compared to the fearful photographs, $t(36) = 2.56, p = .015$ (see Figure 6 for group ROC curves for the three types of photographs). Thus, although the disgusting photographs were associated with a more liberal response bias than the fearful photographs, they were also associated with increased memory sensitivity, and this effect did not depend on the concurrent LDT task manipulation.

In contrast to the enhanced memory sensitivity associated with the disgusting photographs, the fearful photographs did not differ from neutral ($t < 1$). This finding suggests that the apparent enhancement of fear recollection that we observed in the d' data could be due to response bias (Dougal & Rotello, 2007; Grider & Malmberg, 2008). The dissociation between disgust and fear sensitivity effects is consistent with the idea that these two emotions may have qualitatively different influences on memory. Moreover, the divergent effects of disgust versus fear could help to explain previous inconsistencies in the literature on emotion and recognition memory. While some studies have found that negative stimuli are recognized better than neutral stimuli (Grider & Malmberg, 2008; Kensinger & Corkin, 2003), others have found no difference (Doerksen & Shimamura, 2001; Ochsner, 2000) or even decreased accuracy (Dougal & Rotello, 2007). Past work has generally not distinguished between disgusting and fearful stimuli, lumping the two stimulus types together into a “negative” category. Differences among studies in the blend of negative stimuli—i.e., more or less disgust—could account for whether the negative stimuli were associated with enhanced recognition accuracy. That said, another noteworthy difference between the present research and much past work is that we examined memory for emotional photographs rather than words. The two types of stimuli do not always have equivalent effects on memory (e.g., Talmi & Moscovitch, 2004; Talmi et al., 2007). The effect of disgusting words on memory remains a topic for future research.

As in Experiments 1 and 2, we were interested in controlling for the effects of potential confounds on disgust memory. Because the

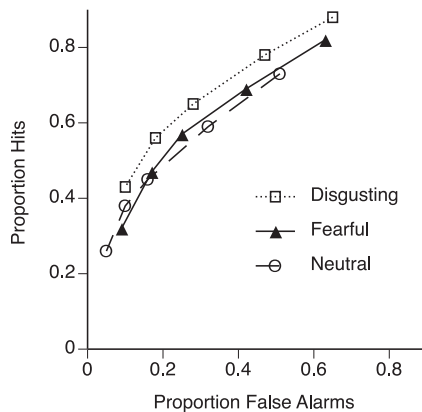


Figure 6. Group receiver-operating characteristic curves from Experiment 3.

disgusting and fearful photographs used in Experiment 3 did not differ significantly in arousal, we did not pursue this variable further. However, a repeated-measures ANOVA indicated significant differences in objective visual saliency measures across emotion categories (Emotion Category \times Measure interaction), $F(8, 604) = 5.67, p < .001$. Controlling for these parameters is complicated by our use of a recognition procedure in Experiment 3. Since we used two partially overlapping lists of targets and lures, some photographs were seen only as targets or lures, while some were seen as both. Therefore, it is not possible to compute a d' or ROC score for each photograph, since not all images have both hits and false alarms. As an alternative, we conducted the control analyses using remember hit rates, computed as a proportion of the total number of times each image was seen as a target across lists and participants in both delay groups. A partial correlation indicated that disgust remained a significant predictor of remember hits even when controlling for visual saliency parameters (partial $r = .413, p < .001$). A limitation of this analysis is that hit rates do not take into account differences in response bias.

Line-discrimination task. LDT latencies were primarily of interest in the concurrent task group, where the photographs were competing with the LDT for attention. Even though we used an expanded stimulus set, we replicated a significant difference in latencies according to Emotion Category, $F(2, 40) = 3.74, p = .032$. As in Experiment 1, latencies were slower for disgusting photographs than for fearful photographs ($x_{\text{disgusting}} = 526$ ms; $x_{\text{fearful}} = 501$ ms), $t(20) = 3.16, p < .01$. Latencies for fearful photographs did not differ from neutral ($x_{\text{neutral}} = 511$ ms), $t(20) = 1.30, p = .207$.

As in the earlier experiments, it could be that increased attentional salience for the disgusting relative to the fearful images is responsible for disgust enhancement of memory. Similar to Experiments 1 and 2, we addressed this possibility using an item analysis with photographs as the units of analysis. Since it was not possible to compute d' or ROC measures for individual photographs, recognition was indexed using remember hit rates as above. A partial correlation showed that remember responses were significantly predicted by disgust ratings even after controlling for LDT performance ($r = .380, p < .001$). These results suggest that the enhanced attentional salience of the disgusting images is not responsible for their enhanced memory after a 1-week delay. However, as described previously, since hit rates do not take potential differences in bias into account, this conclusion should be treated with caution.

For exploratory purposes, we examined LDT latencies in the nonconcurrent group, where the photographs and lines did not compete for attention. In this group, there was no effect of Emotion Category on latencies ($F < 1$). This null LDT effect suggests that enhanced attentional and/or cognitive engagement with the disgusting photographs did not persist after their offset. Thus, enhanced memory for disgusting stimuli is likely independent of postencoding attentional or cognitive processes, at least in the period immediately following stimulus offset.

General Discussion

The aim of the current research was to determine which of two competing models best describes the emotional enhancement of memory. For disgusting and fearful stimuli that are of similar

valence and arousal, dimensional models predict that memory should be similar for both types of stimuli, while basic emotions models suggest that they might differ. We found that with a short (10-min) delay between encoding and test, there was a trend-level memory enhancement for disgusting relative to fearful photographs; at longer delays (45 min and 1 week) this differential memory increased, with disgust gaining a significant memory advantage over fear. Our results are thus consistent with a basic emotions perspective on emotional memory.

To our knowledge, only two previous studies have found enhanced memory for disgusting relative to fearful stimuli (Charash & McKay, 2002; Croucher et al., 2011). Our data replicate these results but also extend them by ruling out many of the typical psychological mechanisms that enhance memory for neutral stimuli. For example, heightened memory for disgusting stimuli persisted when attentional differences between fear and disgust were statistically controlled, both early and late during image viewing. Similarly, responses to attentional probes presented after image offset did not differ across emotion categories, arguing against differences in postencoding attention. Heightened memory for disgust was also independent of whether the items were encoded while performing a concurrent task or not. Disgusting images retained their memory advantage even when controlling for both low-level visual and high-level cognitive distinctiveness. Finally, our use of receiver-operating curve (ROC) methodology in Experiment 3 allowed us to rule out differences in response bias as an explanation for disgust enhancement of memory.

Although the current research cannot test all of the mechanisms that enhance memory for neutral stimuli, we would not be surprised if these mechanisms ultimately fail to explain disgust enhancement of memory. In particular, others have argued that emotional enhancement of memory may depend on specialized neural mechanisms that cannot be easily understood in terms of general memory principles (Hamann, 2001; LaBar & Cabeza, 2006). However, this latter approach to emotional memory is largely predicated on a dimensional model of emotions, with a focus on arousal-mediated amygdala enhancement of consolidation (Anderson, Wais, & Gabrieli, 2006; Hamann et al., 1999; LaBar & Phelps, 1998). Our results present a challenge to this dominant understanding of emotional memory, since they demonstrate a difference in memory for disgust and fear that cannot be explained by arousal or valence.

A competing explanation for emotional enhancement of memory is that it depends on a quality known as “impact” (Ewbank, Barnard, Croucher, Ramponi, & Calder, 2009; Murphy, Hill, Ramponi, Calder, & Barnard, 2010). Impact is a term derived from photojournalism, where it refers to powerful or striking images that are relevant to the self. On this view, emotional images are especially impactful stimuli, and thus they are remembered especially well. Recent work has shown that disgusting images may be more impactful than fearful images, even when the two types of images are matched on arousal and valence (Croucher et al., 2011). Heightened impact for disgusting stimuli could thus account for enhanced memory relative to fearful stimuli. However, this hypothesis has not yet been directly tested. Moreover, we imagine that impact should align with the attentional salience of disgusting events, which reflects the capacity to demand attention in the face of a concurrent task. We show here that the disgust memory advantage remains even when controlling for these effects. Finally,

even if heightened impact does explain disgust enhancement of memory, it begs the question of why disgusting images are so impactful, and how they get their impact. In other words, heightened impact could be a mechanism for disgust enhancement of memory, rather than a confound.

Along these lines, one possible explanation for disgust enhancement of memory is that disgust may draw upon distinctive neural mechanisms that improve memory over and above the boost provided by general emotional arousal. Speculatively, the insula is a good candidate for such an effect, given its strong association with disgust (Chapman & Anderson, 2012; Fusar-Poli et al., 2009; Phillips et al., 1997; Vytal & Hamann, 2010). Indeed, the insula is known to play an important role in conditioned taste aversion (CTA), a form of implicit memory that results from pairing a previously neutral gustatory stimulus (CS) with a sickness-inducing treatment (UCS). CTA manifests in two ways: avoidance of the CS and aversion or disgust toward the CS (Berridge, Grill, & Norgren, 1981; Parker, 1982; Parker & Limebeer, 2006). The latter is inferred from vomiting in emetic species and facial movements such as gaping and tongue protrusion in nonemetic species, which are believed to indicate nausea or malaise (Parker & Limebeer, 2006). While conditioned avoidance depends on integrity of the amygdala (Rana & Parker, 2008), conditioned aversion requires the gustatory insula (Kiefer & Orr, 1992).

Although CTA is a form of implicit memory, there are also direct connections between the insula, the hippocampus, and other medial temporal lobe structures that could support the effects of disgust on episodic memory (Augustine, 1996). Alternatively, the insula could interact with amygdala-based systems for emotional enhancement of memory (Hamann, 2001; LaBar & Cabeza, 2006; LaBar & Phelps, 1998) to increase memory for disgusting stimuli. Our own results may lean more toward a direct influence of the insula on episodic memory systems, given that disgust enhancement of memory persisted even when arousal effects were partialled out. Since the amygdala is most strongly tied to arousal (Anderson, Christoff, Stappen, et al., 2003; Small et al., 2003), some other neural mechanism may account for the substantial residual enhancement of memory due to disgust.

In addition to mnemonic differences between fear and disgust, we also found that disgusting photographs were more attentionally salient than fearful photographs, as indicated by slowed reaction times on the LDT both early (Experiment 1) and late (Experiment 2) in the picture presentation period. Two previous studies have found similar effects using divided attention tasks (Buodo et al., 2002; Sawchuk et al., 1999), although others have found either no difference between disgust and fear (e.g., Armstrong, Olatunji, Sarawgi, & Simmons, 2010; Charash & McKay, 2002) or greater attention for fear than disgust (Vermeulen, Godefroid, & Mermillod, 2009). Past studies have not controlled for valence and arousal, however.

One possible explanation for heightened attention toward disgust stems from research demonstrating that decoding of fearful facial expressions requires less attention than disgusting facial expressions (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003). More attention may be needed to recognize disgusting stimuli, perhaps related to the more ambiguous threat posed by disgusting compared to fearful stimuli (Rozin, Haidt, & McCauley, 2000). Alternatively, disgust could act to reduce perception of peripheral environmental stimuli such as the lines in our LDT,

consistent with its role in closing off the sensory organs to protect them from harm (Sussskind et al., 2008). This may act to slow responses to peripheral stimuli. Regardless of the mechanism, it is important to note that the greater attention paid to disgust stimuli did not account for their greater recall or recognition. This is consistent with evidence that the interaction between emotion and attention during encoding is partly dissociable from the influence of emotion on later memory (Kensinger & Corkin, 2004; Riggs, McQuiggan, Farb, Anderson, & Ryan, 2011; Talmi et al., 2007).

Across our studies, we controlled for a number of spurious factors that could have explained heightened memory and attention toward disgusting stimuli, including subjective arousal and valence, attention during and after encoding, objective perceptual salience and complexity of the stimuli, and subjective cognitive distinctiveness. We found that these factors are unlikely to account for enhanced memory for the disgusting images. Nevertheless, we cannot rule out the possibility that some other difference between stimulus categories, beyond their capacity to evoke distinct basic emotions, is responsible for the effects that we observed. For example, disgust stimuli could be more related to one another than fearful stimuli, or disgust states may enhance interitem associations, which could act to enhance memory (Talmi et al., 2007). While further work is needed to examine the underlying mechanisms of disgust enhancement of memory, we have shown that some of the most well-known and powerful dimensional influences on emotional memory are not responsible for the superiority of disgust memory over fear.

An interesting future direction will be to search for other categories of emotional stimuli with particularly strong—or weak—effects on cognition (Levine & Pizarro, 2004). For example, recent work has found that biological stimuli related to survival or reproduction (e.g., erotic images, threatening animals) are remembered better than social stimuli (e.g., smiling people, money; Sakaki, Niki, & Mather, 2012). Similarly, words encoded in a survival context are more likely to be remembered than words that receive other forms of deep processing (Nairne, Thompson, & Pandeirada, 2007). A related possibility is that there may be subcategories of disgusting stimuli that could have different cognitive effects. In particular, recent work has shown that disgust related to foods and disgust related to injuries have partially distinct physiological and neural correlates (Harrison, Gray, Gianaros, & Critchley, 2010). These subcategories could also have distinct effects on cognition–emotion interactions. Last, it has been shown that urban legends that evoke disgust are especially likely to be passed on to others (Heath, Bell, & Sternberg, 2001). It would be interesting to examine whether this cultural persistence is associated with the highly memorable nature of disgusting stimuli.

In summary, our results are consistent with the idea that disgust may be an especially potent modulator of cognition and behavior, which, in turn, has considerable theoretical significance for models of emotion–cognition interactions. Many studies that examine the effects of emotion on cognition use a heterogeneous assortment of negative stimuli, including both disgusting and fearful images. At the very least, our research suggests that these two subcategories of negative stimuli, and perhaps others (Levine & Pizarro, 2004), could have markedly different cognitive effects. Appreciating differences between emotion categories could thus greatly improve our present understanding of emotion–cognition interactions.

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