

Emotion and Working Memory: Evidence for Domain-Specific Processes for Affective Maintenance

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Working memory is comprised of separable subsystems for visual and verbal information, but what if the information is affective? Does the maintenance of affective information rely on the same processes that maintain nonaffective information? The authors address this question using a novel delayed-response task developed to investigate the short-term maintenance of affective memoranda. Using selective interference methods the authors find that a secondary emotion-regulation task impaired affect intensity maintenance, whereas secondary cognitive tasks disrupted brightness intensity maintenance, but facilitated affect maintenance. Additionally, performance on the affect maintenance task depends on the valence of the maintained feeling, further supporting the domain-specific nature of the task. The importance of affect *maintenance* per se is further supported by demonstrating that the observed valence effects depend on a memory delay and are not evident with simultaneous presentation of stimuli. These findings suggest that the working memory system may include domain-specific components that are specialized for the maintenance of affective memoranda.

Keywords: affect, working memory, emotion, cognition

Working memory mediates the short-term maintenance and manipulation of information used to guide goal-directed behavior (Goldman-Rakic, 1987). Behavioral, neuropsychological, and neuroimaging research established that separable working memory subsystems are involved in the maintenance of verbal, spatial, and visual information (Smith & Jonides, 1999). Separable processes for maintaining object representations (Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998; Smith et al., 1995) and semantic information (Potter, 1993; Shivde & Thompson-Schill, 2004) have also been indicated. Here, we investigate the possibility that working memory for affective information may also be mediated by separable processes (Davidson & Irwin, 1999; Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005). Our approach is twofold. After developing parallel tasks to assess the maintenance of information about the subjective intensity of emotional versus nonemotional (i.e., brightness) stimulus attributes, we use selective interference methodology to determine whether affect maintenance is specifically and uniquely disrupted by emotion processing. We

then test whether performance on the affect maintenance task is affected by the valence of the emotional information being held in memory. The findings are consistent with the proposal that working memory may include domain-specific components for the active maintenance of affective memoranda.

Selective interference methodology has been a cornerstone for establishing the separability of different working memory subsystems (see, e.g., Baddeley, 1998). For example, in landmark work by Brooks (1967, 1968) comparing verbal and visuospatial working memory, spatial responses (pointing) relative to verbal responses resulted in inferior performance on an image maintenance task, whereas verbal responses relative to pointing resulted in inferior performance on a sentence maintenance task. Evidence from patient studies and neuroimaging provides converging support for these behavioral dissociations (for reviews see Jonides et al., 1996; Reuter-Lorenz et al., 2000; Smith & Jonides, 1999).

The question of separable working memory processes for emotional memoranda has received comparatively little attention. One prior report used emotional facial expressions in a delayed-match-to-sample task (Gooding & Tallent, 2003). The authors acknowledged however that their measurement of “affective” working memory was inconclusive because alternative visual or verbal memory strategies could not be ruled out. Similar concerns apply to other reports (e.g., Luciana, Burgund, Berman, & Hanson, 2001), including those that focus on the incidental and modulatory effect of valenced stimuli by comparing working memory for affective and nonaffective stimuli (Kensinger & Corkin, 2003; Perlstein, Elbert, & Stenger, 2002). The results of these studies did not dissociate working memory for affective versus nonaffective information, suggesting that both classes of information rely on the same working memory processes.

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Of importance, these studies did not specifically require the maintenance of *subjective* affective information, such as memory for an emotional experience. Only one study to date required that participants actively maintain an affective experience over a delay (Schaefer et al., 2002). When compared with experiencing an emotion and passively letting it go naturally, affect maintenance was associated with greater activation in the amygdala and self-reports of greater negative affect. These results suggest there may be distinct neural mechanisms for affect maintenance. Note however, that the self-report data used in this study lack objective verification and are subject to demand characteristics, thereby limiting the utility of the task studied by Schaefer et al. (2002).

The current report presents a novel task that targets subjective affect as the memoranda while using a quantifiable and normative performance measure that permits examination of the psychological characteristics of affect maintenance. In a delayed-response task, pictures were used to evoke affect, and the “experienced” affect intensity was the memorandum. Experiment 1 establishes that people can maintain and compare information about emotion intensity. Moreover this task is shown to be comparable to an analogous nonaffective task using neutral images from the same picture set to evoke a brightness percept, and the “experienced” brightness intensity as the memorandum. In Experiment 2 selective interference methodology was used to investigate whether maintaining affect intensity versus brightness intensity relies on separable working memory processes. In Experiment 3, we varied the valence of the evoked emotion to further investigate the psychological nature of affect maintenance. We reasoned that if the affect maintenance task utilized working memory components that were specialized for the affective domain, then the negativity bias that pervades other psychological phenomena (see, e.g., Rozin & Royzman, 2001) should also be evident on our task. Experiment 4 employed simultaneous presentation of stimuli and demonstrated that the valence effects we observe in Experiment 3 depend on *maintenance* requirements of the task—rather than other processes, such as encoding or comparison.

Experiment 1: Model Task Development

Our first goal was to determine whether or not people could maintain a feeling and subsequently compare it to another feeling. Thus, we constructed two new delayed response tasks (e.g., D’Esposito et al., 1998; Goldman-Rakic, 1987): an affect maintenance task and a brightness maintenance task. The affect maintenance task required participants to maintain over a delay period the feeling elicited from a static image and then compare the intensity of that reaction to a second feeling evoked by a second image. To parallel the affect maintenance task, we designed a “cognitive” analog task in which subjective brightness also derived from a static image was held in memory and later compared to the brightness of a second image. With these two tasks we could compare affect maintenance and brightness maintenance. The intensity “distance” between pairs of stimuli was varied, as was the order of the higher/lower member of the pair. Also, retention interval was varied to examine the time course of these two forms of maintenance.

These new delayed response tasks required maintenance and comparative judgments of affect intensity and brightness intensity. The dimension of affect intensity was chosen because it is less amenable to verbal coding than valence or category; it represents the amount of affect felt *psychologically* rather than *physiologi-*

cally and it is continuous, encompassing both valence and arousal (Feldman Barrett & Russell, 1999; Frijda, Ortony, Sonnemans, & Clore, 1992; Reisenzein, 1994). In the affect maintenance task, participants viewed a static image (International Affective Picture System (IAPS), Lang, Bradley, & Cuthbert, 1999) and were instructed to maintain the intensity of the feeling evoked by that image over a brief delay period. Then they were required to compare the intensity of the maintained feeling to the intensity of a feeling evoked by a second image. In the nonaffective analog task, subjective brightness information also derived from a static IAPS image was held in memory and subsequently compared to the brightness of a second image. The IAPS images have been shown to elicit multiple components of an emotional reaction, including an autonomic reaction, facial expressions, and self-reported subjective feelings (for reviews see Bradley & Lang, 2000; Lang, Bradley, & Cuthbert, 1998). Not only are these images adequate elicitors of affect, but valence, arousal, dominance, and categorical normative data have been collected on the stimuli (Lang et al., 1999; Mikels, Fredrickson, et al., 2005). Constructing the stimulus pairs for our tasks and assessing the “accuracy” of participants’ judgments required normative ratings of subjective affect intensity and brightness intensity, neither of which exists for the IAPS images. Because ratings of subjective intensity do not exist for the IAPS images, we conducted a series of preliminary pilot norming studies as well. For our “cognitive” analog task, we chose the variable of brightness intensity because we wanted to construct a comparable nonaffective task that required a subjective assessment of the IAPS images. Subjective brightness data do not exist for the IAPS either, so we also collected normative brightness data on the IAPS.

Normative Intensity Pilot Studies

As described above, we were interested in using affective and brightness intensity in our maintenance tasks. Thus, we collected affective and brightness intensity data on subsets of the IAPS images. A total of 120 participants were tested in three normative studies: 40 in Pilot Study A (mean age = 18.6; 50% female), 40 in Pilot Study B (mean age = 18.8; 55% female), and 40 in Pilot Study C (mean age = 20.19; 48% female).

In Pilot Study A, 203 images were selected as negatively valenced IAPS images (mean pleasure rating = 3.05, $SD = 0.84$; mean arousal rating = 5.56, $SD = 0.92$)¹. In Pilot Study B, 187 images were selected as positively valenced IAPS images (mean pleasure rating = 7.05, $SD = 0.63$; mean arousal rating = 4.87, $SD = 0.98$). To supplement this sample of positive images, we included 51 commercially produced images. In Pilot Study C, 199 images were selected as neutral IAPS images (mean pleasure rating = 5.32, $SD = 0.79$; mean arousal rating = 3.61, $SD = 1.01$). In each study, the images were divided into two randomly ordered subsets. The order of the subsets was counterbalanced across participants. In Studies A and B, participants rated the intensity of their feelings from the images. In Pilot Study C, they rated their subjective impressions of brightness inten-

¹ Mean ratings calculated from the data of Lang et al. (1999). Pleasure ratings are based on a 9-point scale, with 5 constituting neutral and 1 the extreme negative; arousal ratings are also based on a 9-point scale ranging from low (1) to high (9) arousal.

sity. In all studies, intensity was rated on a 7-point scale, with 1 signifying “low intensity” and 7 indicating “high intensity.” In a given trial, a picture appeared for 5 s, during which time participants allowed their feelings to occur naturally in Studies A and B or assessed their perception of brightness in Study C. The picture then disappeared and participants responded using the 7-point scale, after which a 2-s intertrial interval occurred before the next picture. Because our ultimate objective was to have participants maintain the experienced intensity of their affective response to each picture individually, norming was obtained for each picture in isolation, rather than requiring comparative intensity judgments.

Method: Maintenance Tasks

Participants

Sixty-four participants (mean age = 19.95, 53% female) were recruited from the university community, and randomly assigned to the affect maintenance or brightness maintenance conditions. Participants received course credit for their participation.

Apparatus

Macintosh iMac computers with PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) were used for stimulus presentation and data acquisition.

Materials

Negatively valenced images ($n = 192$) and neutral images ($n = 192$) were selected from the IAPS set for which normative intensity data had been collected in the pilot studies. The 192 negative images used in the current study ranged in intensity from 1.8 to 6.13 ($M = 4.00$, $SD = 1.01$) as determined from the intensity data collected in Pilot Study A. From the intensity data in Pilot Study C, the neutral subset varied in their brightness intensity from 1.68 to 6.28 ($M = 4.28$, $SD = 0.87$).

Design and Procedure

Two tasks were created, an affect maintenance task and a brightness maintenance task, in each of which 192 images were used. From the 192 images selected per task, 96 pairs were created: 48 for each of two retention intervals (3 s and 10 s). In Experiment 1, a between-subjects design was employed to circumvent fatigue effects given the large number of trials. In subsequent experiments with fewer trials, within-subject designs were employed for stronger comparisons between the tasks. For the affective task, within the categories described above, the pairs varied in the distance of their affective intensities from 0.025 to 3.3 ($M = 1.44$, $SD = 0.89$). For the brightness task, the pairs differed in their subjective luminance from 0.1 to 3.0 ($M = 1.39$, $SD = 0.85$). For each task, the pairs were divided into two groups differing in their affective distance: near (intensity difference of 1.43 or less for the affective task and of 1.15 or less for the brightness task) and far (intensity difference of 1.5 or more for the affective task and of 1.18 or more for the brightness task), thus resulting in 48 near pairs and 48 far pairs for each task. Within this affective distance division, the pairs were further divided into two groups: 24 pairs in which the second picture was higher in intensity than the first, and 24 pairs in which

the second picture was lower. Thus, there are four factors: task domain (affect or brightness), retention interval (3 s or 10 s), intensity distance (near or far), and intensity order (2nd picture higher or lower). Task was a between-subjects factor, whereas the other three factors were within-subject factors. For each task, the 96 pairs were divided into two blocks with equal numbers of trials for each of the three conditions. The ordering of the two blocks within each task was counterbalanced across participants, and all conditions were counterbalanced across all picture pairs.

Only for the affective task, in order to ensure that they were comfortable with the experiment, upon arrival at the laboratory each participant was shown a sample set of pictures similar in intensity to those in the actual experiment. As a result of this prescreening, three participants decided not to complete the experiment. At the beginning of the study, participants filled out consent and demographic forms and were then escorted to individual testing rooms, where they were presented with instructions for the task both visually on the computer screen and orally by the experimenter.

The task parameters were identical for both tasks: a picture was presented for 5 s (target), immediately followed by an unpredictable variable retention interval (3 or 10 s), a second picture for 5 s (probe), and a green cross. For a schematic of a representative trial, see Figure 1. For the affect maintenance task, it was explained that in each trial the participant would view an emotion-eliciting image and that they should let their feelings occur naturally. Following the picture presentation, they were instructed to sustain the feeling at the same intensity that they felt while viewing the picture. During this delay, they were also instructed to maintain central fixation on a cross. After the delay, they were to view and experience the feelings caused by the second picture after which time a green cross would appear signaling for them to decide if their feeling from the second picture had higher or lower intensity compared to their feeling from the first picture in the pair. They made their response via a key press with their right hand. For the brightness maintenance task, the instructions were similar, however participants were instructed to assess, hold in mind, and compare the brightness they perceived in the two pictures.

Results and Discussion

The following analyses were conducted on the dependent performance measure that we refer to as “concordance.” Objective accuracy per se cannot be scored in this task, because participants are comparing their subjective experiences of two consecutive images. However, as the image pairs were constructed using normative intensity data from the pilot studies, concordance with this normative data can be scored. Thus, concordance is a measure of a participant’s agreement with the relative intensity assignments (i.e., the high vs. low member of a pair) derived from the normative ratings.² Concordance scores were analyzed using a repeated measures ANOVA with the one between-subjects factor of task domain (affect, brightness) and the three within-subject factors of delay length (3 s, 10 s), distance (near, far), and intensity order (2nd picture lower, 2nd picture higher). Analyses for sex of participant did not reveal additional significant effects.

² Note that Mikels, Larkin, et al. (2005) also collected intensity ratings from each individual participant, and that the patterns of performance did not vary as a function of scoring concordance with normative or self-generated ratings.

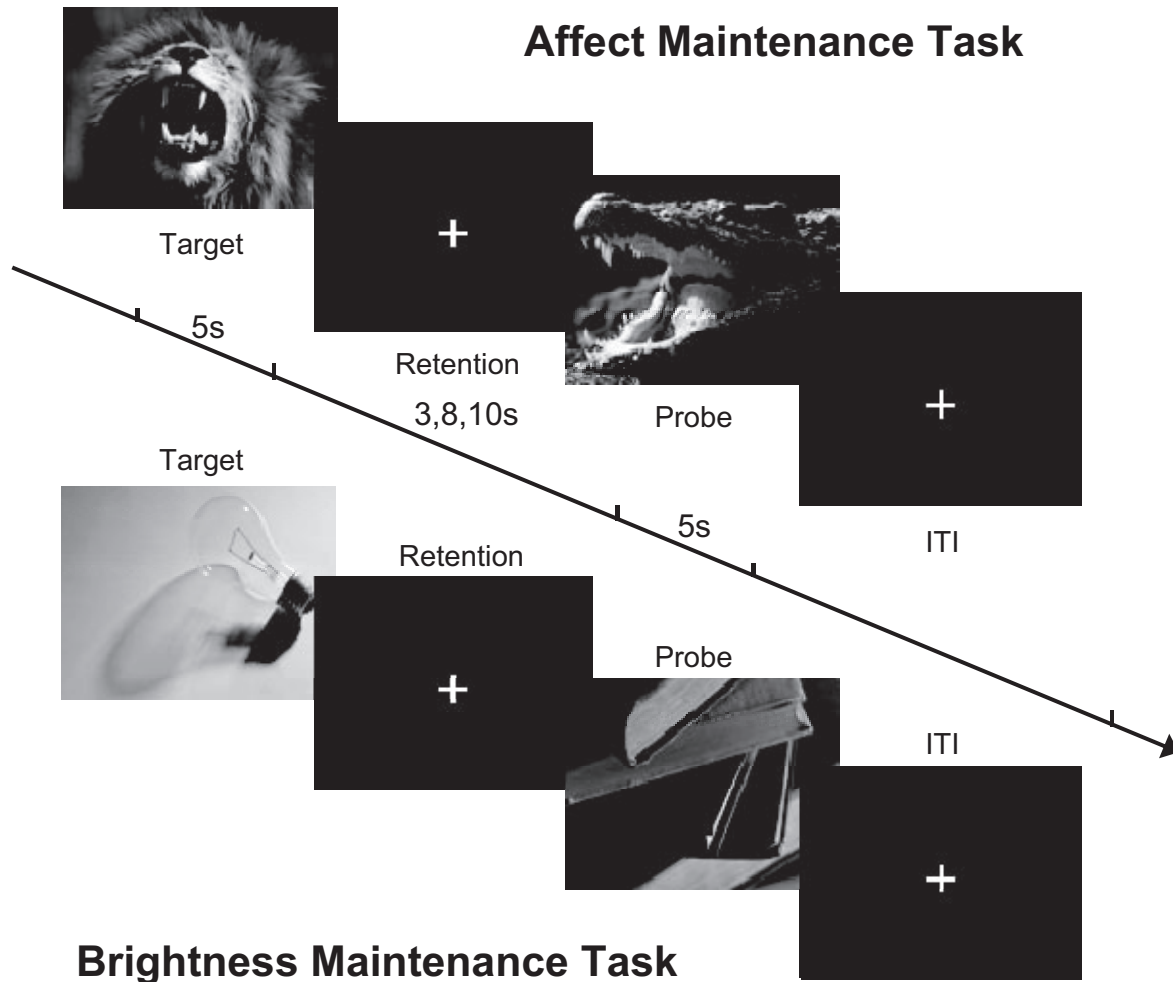


Figure 1. Schematic for the two tasks used in the experiments. In a given trial, a target image was presented, followed by a retention interval of 3, 8, or 10 s, depending on the study, and then a probe image. The probe image was followed by a fixation cross during which participants responded whether the intensity of their affective reaction (Affect Maintenance Task) or perception of brightness (Brightness Maintenance Task) to the probe was higher or lower than that to the target. The images are example images that were not actually used in the study (to protect IAPS copyright).

This analysis first revealed a main effect for task domain in concordance, $F(1, 62) = 9.69, p < .005$. This finding indicates that overall the brightness maintenance task (80.5%) was significantly easier than the affect maintenance task (74.9%). Our manipulation of intensity distance was effective in that performance was superior for pictures pairs far in intensity (88.3%) compared to those near in intensity (67%), $F(1, 62) = 536.08, p < .01$.

Intensity order produced several effects on the concordance data. First, performance was superior when the second picture had higher intensity than the first picture (82.7%), rather than when the second picture had lower intensity than the first picture (72.6%), $F(1, 62) = 54.13, p < .001$, indicating an overall bias to judge the second picture as higher. An interesting order-by-task domain interaction emerged also in concordance, indicating that this bias was significantly stronger in the affect maintenance task (see Table 1 for means and standard deviations), $F(1, 62) = 9.34, p < .005$.

Finally, the order effects are further evident in the interaction of intensity order with intensity distance, $F(1, 62) = 16.48, p < .001$. The bias to judge the second picture as higher was especially salient when participants compared similar intensities than when

Table 1
Experiment 1: Concordance Means and Standard Deviations Broken Down by Intensity Order and Task Domain

	Second higher		Second lower		Overall <i>M (%)</i>
	<i>M (%)</i>	<i>(SD)</i>	<i>M (%)</i>	<i>(SD)</i>	
Brightness	83.4	(14.5)	77.5	(18.0)	80.5
Affect	82.0	(15.6)	67.8	(20.1)	74.9
Overall	82.7		72.6		

comparing disparate intensities. See Table 2 for the means and standard deviations broken down by intensity order and intensity distance. There were no other significant effects.

These results establish the ability to maintain a veridical representation of an intensity state over a delay and the ability to use that representation comparatively. We suspect that the slightly lower concordance in the affective task, relative to the brightness task, reflects the greater subjectivity of affective evaluations. The intensity order effect indicates a bias to judge the present subjective state as more intense, which could be interpreted as an “immediacy bias” that was especially strong for affective comparisons.

The present results demonstrate successful performance on these novel delayed response tasks. The next step was to test whether the affective and nonaffective tasks rely on dissociable underlying mechanisms. Common working memory processes could conceivably underlie performance on both tasks. For example, both could rely on the maintenance of a visual image and thus visual working memory. Another possibility is that intensity is verbally recoded into a numeric code, for example, that is maintained and compared with a corresponding code for the second image.

Alternatively, the maintenance processes could be separable. Brightness maintenance could rely on visual and/or verbal mechanisms, whereas affect maintenance could rely on affective mechanisms. To investigate this possibility, selective interference methodology (e.g., Barnes, Nelson, & Reuter-Lorenz, 2001; Logie, Gilhooly, & Wynn, 1994) was applied to these two model tasks in Experiment 2.

Experiment 2: Selective Interference

This experiment used a secondary emotion task in an effort to disrupt affect maintenance but not brightness maintenance, and secondary cognitive tasks to produce the opposite effects on the maintenance tasks. The secondary cognitive tasks were chosen to maximize demand on visual *and* verbal processing in an effort to disrupt visual working memory and verbal recoding strategies. Our visual secondary task was a feature conjunction search, which unlike pre-attentive feature searches, requires longer search times and focal attention (Treisman & Gelade, 1980). Our secondary verbal task used articulatory suppression to thwart verbal recoding (Richardson & Baddeley, 1975) by requiring repetitive utterances, such as “one-two-three-four. . .one-two-three-four. . .” (Baddeley, Lewis, & Vallar, 1984).

We used an affect regulation task (modeled after Gross, 1998a; Ochsner, Bunge, Gross, & Gabrieli, 2002) to selectively disrupt

affect maintenance. Participants viewed an additional affective image during the retention interval and were instructed to think about it in a way that would make them feel less negative (down-regulate) and then to rate the intensity of their feeling. If the affect maintenance task requires the *active* maintenance of a feeling, then actively regulating another feeling should disrupt processes at work in the affect maintenance task. This self-regulation task was chosen based on pilot work indicating that the passive viewing of emotional images during retention did not affect either maintenance task.

Method

Participants

Sixty-four participants (mean age = 19.47, 49% female) recruited from the university community were assigned to the cognitive or affective interference conditions and received course credit. Three participants were replaced, due to an inability to follow the instructions.

Apparatus

Same as Experiment 1.

Materials

Images. Ninety-six image pairs were selected based on mean concordance from Experiment 1 to equate performance on the two maintenance tasks (concordance for affect pairs: $M = 81.81\%$; concordance for brightness pairs: $M = 80.79\%$). Overall affect intensity varied from 2.2 to 6.1 ($M = 4.07$, $SD = 1.01$). Overall brightness intensity varied from 1.675 to 5.85 ($M = 4.28$, $SD = 0.82$). An additional 48 negative images were included in the study for the affect regulation task. These images ranged in intensity from 4.1 to 6.125 ($M = 4.85$, $SD = 0.65$).

Visual displays. Modeled after Triesman & Gelade (1980, Experiment 2), letter arrays were constructed using 36 green and blue T's and F's in equal numbers (less the target), positioned randomly in a 6×6 matrix (16 cm \times 16 cm).

Design and Procedure

This study included five tasks: counting, visual search, affect regulation, affect maintenance, and brightness maintenance. Interference type (cognitive or affective) was a between-participants factor, however all participants performed *both* maintenance tasks under single task and dual task conditions. In the cognitive interference condition, participants first completed the counting and visual search tasks, followed by single and dual maintenance task conditions. In the dual task condition, each maintenance task was performed concurrently with the counting and visual search tasks. In the affective interference condition, participants first completed the affect regulation practice task, followed by each maintenance task under single and dual task conditions. In the dual task condition, each maintenance task was performed concurrently with the affect regulation task. Participants completed two practice trials of each task immediately prior to completing a given experimental block. The order of single and dual tasks was counterbalanced across participants.

Table 2
Experiment 1: Concordance Means and Standard Deviations Broken Down by Intensity Order and Intensity Distance

	Second higher		Second lower		Overall <i>M (%)</i>
	<i>M (%)</i>	<i>(SD)</i>	<i>M (%)</i>	<i>(SD)</i>	
Far	91.5	(8.5)	85.1	(11.7)	88.3
Near	73.9	(10.6)	60.2	(12.5)	67.0
Overall	82.7		72.6		

Counting practice task. Subjects practiced synchronized counting (“one-two-three-four,” repeatedly) with a tone that sounded once a second for 8 s (the counting duration in the dual tasks). Then they practiced counting without the synchronizing tone as required in the dual tasks. Practice continued until consistency was reached (approximately 8 trials). Performance was not measured further except to verify counting during the designated dual-task intervals.

Visual search practice task. Visual search practice consisted of 24 trials, half with a target (T_{green}), and half without. Distractors were always F_{green} and T_{blue} . Targets appeared randomly and with equal probability in any of the 36 positions. Each display appeared for 6 s, following a 2-s fixation cross. Participants made a “yes” or “no” key press response with their right hand. Both speed and accuracy were emphasized.

Affect regulation practice task. Participants practiced down-regulating their affective experience using a reappraisal procedure based on Gross (1998a) and Ochsner et al. (2002). Participants were shown a series of images, and for each they were to make themselves feel less negative by reinterpreting the image (e.g., for a mutilation image, to think that it is not real but from a movie). After 6 s, they rated the intensity of their feeling on a scale of 1 (“low intensity”) to 7 (“high intensity”). Participants were asked to describe their reinterpretations to ensure their use of effective reappraisals and if necessary, the practice was repeated.

General design for maintenance tasks. (Only the differences from Experiment 1 are noted). Single and dual affect and brightness maintenance blocks (24 trials each) used an 8-s retention interval and left-handed key press.

In separate affect and brightness dual-task blocks, participants completed 24 trials including either the cognitive secondary tasks (counting and visual search) or the affect regulation task. In the cognitive dual-task condition, each trial began with a tone and fixation cross, which signaled participants to start counting “one-two-three-four” once per second. Counting continued for 2 s, during the first IAPS image, and for 1 s that followed. Participants were instructed to stop counting when the search display appeared and to indicate via a right-hand key press whether or not the target was present. The second picture then appeared, and they made their maintenance task response. Counting was always monitored by the experimenter.

In the affective dual-task condition, affect and brightness maintenance trials began with an image followed by a delay, during which a second image appeared and participants performed the affect regulation task, and then the third image appeared and they made their maintenance task response.

Results and Discussion

Visual search. The accuracy and speed of visual search did not differ between the two maintenance tasks (brightness: $M = 94.5\%$, $M = 3,239$ ms; affect: $M = 92.9\%$, $M = 3,263$ ms), $t(31) = 1.66$, $p > .1$, and $t(31) = 0.38$, $p > .7$.

Affect Regulation. Overall, participants rated their feelings during the distractor image ($M = 2.56$, $SD = 0.59$) as significantly lower than ratings obtained on the same images in the normative study described above ($M = 4.80$, $SD = 0.65$), $t(31) = 21.37$, $p < .001$. This result indicates successful down-regulation of affect in accordance with task instructions. Ratings were lower in the

brightness maintenance task ($M = 2.07$, $SD = 0.35$) than in the affect maintenance task ($M = 2.88$, $SD = 0.71$), $t(31) = 7.61$, $p < .001$, suggesting more successful down-regulation during the brightness task. Nevertheless, significant down-regulation was achieved regardless of the memory domain.

Maintenance tasks. The concordance scores were analyzed with a repeated-measures ANOVA with interference type (affective, cognitive) as a between-subjects factor and the four within-subject factors of maintenance task domain (affect, brightness), condition (single, dual), intensity distance (near, far), and intensity order (2nd picture lower, 2nd picture higher).

Three effects replicated Experiment 1. First, there was a main effect of intensity distance: concordance was higher for far pairs (89.8%) compared to near pairs (76.6%), $F(1, 62) = 168.24$, $p < .001$. There was main effect for order, with an overall bias to judge the second image as higher in intensity (87.5%) relative to judging it lower in intensity (78.9%), $F(1, 62) = 89.24$, $p < .001$. Also, order interacted with distance, $F(1, 62) = 6.70$, $p < .05$. The bias to judge the second picture as higher was larger for pairs near versus far in intensity (see Table 3). Note, however, that the main effect for task domain was not significant, $F(1, 62) = .57$, $p > .45$, indicating that the maintenance tasks were equated successfully.

The critical observation was an interaction of interference type (affective/cognitive) by task domain (affect/brightness) by condition (single/dual), $F(1, 62) = 7.60$, $p < .01$. The means that contribute to this interaction are displayed in Table 4, which indicates that the secondary affective task interfered with the affect maintenance task and not the brightness maintenance task. Furthermore, the secondary cognitive tasks had opposing effects on the two memory tasks, disrupting brightness maintenance but facilitating affect maintenance. To simplify this interaction, selective interference scores were derived for each participant by subtracting mean concordance on the dual task from mean concordance on the single task for each domain. The effects of the cognitive secondary tasks were significantly different for the brightness maintenance and affect maintenance tasks, $t(31) = 3.38$, $p < .005$. Although the interference effect for the brightness maintenance task differed only marginally from zero, $t(31) = 2.25$, $p = .072$, one-tailed, these cognitive tasks had the opposite effect on affect maintenance which differed significantly from zero, $t(31) = 10.41$, $SE = 5.38$, $p < .005$. Further, as predicted, affective interference exerted a significant and selective effect on affect maintenance relative to brightness maintenance, $t(31) = 1.72$, $p < .05$ (one-tailed). Critically, while the interference effect for the affect maintenance task was significantly greater than zero, $t(31) = 2.02$, $p < .05$, the effect for the brightness maintenance task was not, $t(31) = 0.11$, $p > .9$. Note that emotional down-

Table 3
Experiment 2: Concordance Means and Standard Deviations
Broken Down by Intensity Order and Intensity Distance

	Second higher		Second lower		Overall <i>M (%)</i>
	<i>M (%)</i>	<i>(SD)</i>	<i>M (%)</i>	<i>(SD)</i>	
Far	92.8	(6.0)	86.8	(8.9)	89.8
Near	82.2	(8.7)	71.1	(9.5)	76.6
Overall	87.5		78.9		

Table 4
 Experiment 2: Concordance Means and Standard Deviations
 Broken Down by Interference Type, Task Domain, and Task
 Condition

	Alone		Dual	
	<i>M (%)</i>	<i>(SD)</i>	<i>M (%)</i>	<i>(SD)</i>
<i>Cognitive interference</i>				
Brightness	84.8	(7.4)	82.4	(8.7)
Affect	80.6	(8.9)	86.0	(7.9)
<i>Affective interference</i>				
Brightness	82.1	(7.9)	81.9	(9.2)
Affect	85.7	(6.9)	82.3	(8.2)

regulation was indeed more successful during brightness than affect maintenance, and that emotion regulation interfered more with affect maintenance (see Figure 2). Less successful emotion regulation while attempting to actively maintain different emotional feelings is consistent with the hypothesis that affect maintenance engages domain-specific working memory processes.

In sum, whereas a secondary affective task selectively interfered with performance of the affect maintenance task, secondary cognitive tasks influenced the maintenance tasks in opposite ways, interfering with brightness performance and improving affect maintenance. These selective effects suggest that the processes underlying the affect maintenance task may be indeed separable and affective in nature.

Experiment 3: Affective Valence Manipulation

In Experiment 3, we further explored the psychological nature of affect maintenance by including positive emotion images. Prominent valence differences have been identified in physiological reactivity, attentional focus, and long-term memory with negative emotions having a stronger impact than positive emotions (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Cacioppo, Gardner, & Bernston, 1999; Rozin & Royzman, 2001). The effects are so pervasive that this phenomenon has been termed the “negativity bias” (see, e.g., Rozin & Royzman, 2001). For instance, when thinking about interpersonal events, people spend more time thinking and reasoning about negative versus positive events (Abele, 1985). Furthermore, evidence suggests that people better remember negative relative to positive information due to greater cognitive processing of the negative during memory encoding (Ohira, Winton, & Oyama, 1998; Robinson-Riegler & Winton, 1996). Might this negativity bias also be reflected in our affect maintenance task? To the extent that affect maintenance relies on working memory processes that are specific to the affective domain, we would expect a negativity bias, such that concordance is higher when maintaining the intensity of a negative feeling than a positive feeling. Alternatively, as Kensinger and Corkin (2003) have reported, negatively valenced stimuli appear to have negligible effects on visual and verbal working memory performance (see, e.g., Kensinger & Corkin, 2003). Thus, if our affect maintenance task relies on working memory processes that support maintenance in these domains, we would not expect a negativity bias to emerge.

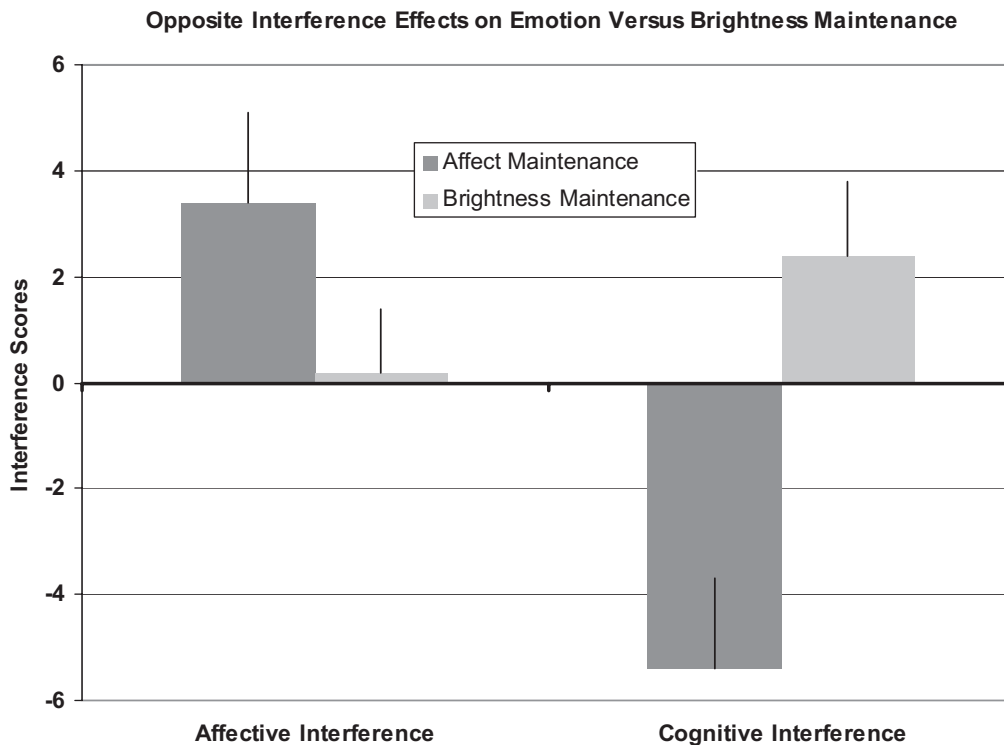


Figure 2. A graph depicting selective interference effects on affect and brightness maintenance performance in Experiment 2. Interference scores were calculated by subtracting dual task performance from single task performance (positive scores indicate interference).

Method

Participants

Forty-eight participants (age $M = 19.34$ years, 54% female) were recruited from the university community and were paid for participation.

Apparatus

Same as Experiment 1.

Materials

Images. Ninety-six negative and 96 positive images were chosen from the IAPS set, for which normative intensity data had been collected in Pilot Studies A and B. Forty-eight negative and 48 positive pairs were created. The negative images had an average intensity of 3.63 ($SD = 0.48$) and the average difference between images in a pair was 0.97 ($SD = 0.62$). The average intensity for the positive pairs was 3.67 ($SD = 0.48$) and the average difference between images in a pair was 0.97 ($SD = 0.69$). As in the previous studies, intensity distance was manipulated such that half of the trials had intensity differences that were “far,” while the other half had intensity differences that were “near.” For 24 pairs in each valence the second picture presented was higher in intensity than the first and for the remaining pairs, the second picture was lower. The intensity order of the images in a pair was counterbalanced across participants. The 96 pairs were divided into two blocks with equal numbers of trials for each valence. Pairs were presented randomly in one block followed by a short break before the second set was presented randomly. The ordering of these two blocks was counterbalanced across participants.

Design and Procedure

The parameters of the affect maintenance task were identical to that of Experiment 1, with the exception of a fixed delay of 3 s.

Results and Discussion

The concordance data were analyzed using a 3-way ANOVA. The three within-subject factors were affective valence (positive, negative), intensity order (2nd picture lower, 2nd picture higher), and intensity distance (near, far). Analyses of sex of participant did not reveal additional effects.

As in the previous experiments, we observed a main effect of intensity order in concordance, such that performance was superior when the second picture was more intense than the first (74.5%) relative to when the second picture was less intense than the first (63.4%), $F(1, 47) = 33.93, p < .001$. Also once again, concordance was higher for pictures far in intensity (75.3%) compared to those near in intensity (62.7%), $F(1, 47) = 93.71, p < .005$. The critical finding was superior affective working memory performance for the negative emotion trials (70.6%) as compared with the positive emotion trials (67.4%), $F(1, 47) = 5.19, p < .05$. This result is qualified by the interaction of affective valence and intensity distance, $F(1, 47) = 6.34, p < .05$ (see Table 5), which indicates a strong negative advantage for near pairs, $t(47) = 3.26, p < .005$, and equivalent concordance for far pairs. The valence main effect is further qualified by the interaction of affective

Table 5

Experiment 3: Concordance Means and Standard Deviations Broken Down by Valence and Distance

	Far		Near		Overall <i>M (%)</i>
	<i>M (%)</i>	<i>(SD)</i>	<i>M (%)</i>	<i>(SD)</i>	
Negative	75.5	(10.5)	65.6	(10.9)	70.6
Positive	75.2	(11.8)	59.8	(8.4)	67.4
Overall	75.3		62.7		

valence and intensity order, $F(1, 47) = 19.20, p < .001$ (see Table 6). This interaction indicates that the bias to judge the second image as higher in emotional intensity is more pronounced for negative feelings than for positive feelings. Thus, the affective valence of the feelings that were maintained clearly influences performance on this task which indicates a pronounced negativity bias.

Experiment 4: Simultaneous Presentation

In addition to active maintenance, our memory tasks also require perceptual encoding, appraisal, and comparison of feeling states. The negativity bias we observed in Experiment 3 may result from these other processes rather than from active maintenance per se. To isolate the source of this bias, we removed the maintenance component of the task and required only the immediate comparison of the intensities of the feelings produced by simultaneously presented images. If the negativity bias we observed depends on affect maintenance, then it should be reduced in this version of the task.

Method

Participants

Thirty-two participants (mean age = 18.9, 52% female) were recruited and received one course credit for their hour of participation.

Apparatus

Same as Experiment 1.

Materials

Same as Experiment 3.

Design

The design of Experiment 4 was very similar to the design of the other experiments. The same picture pairs used in Experiment 3 were employed in Experiment 4. The major difference in the design was the simultaneous presentation of the two pictures in each pair.

Procedure

The procedure was very similar to that of Experiment 3, except that the two emotion-eliciting images appeared simultaneously, and side-by-side on the screen for 5 s. Participants were told to

Table 6
*Experiment 3: Concordance Means and Standard Deviations
 Broken Down by Valence and Order*

	Second higher		Second lower		Overall M (%)
	M (%)	(SD)	M (%)	(SD)	
Negative	78.8	(11.0)	62.3	(11.4)	70.6
Positive	70.3	(10.4)	64.6	(13.3)	67.4
Overall	74.5		63.4		

allow their feelings to occur naturally to the two images. While the pictures were present, they were told to compare their feelings and judge whether the picture on the right side had higher or lower intensity than the picture on the left. This response was made with a key press.

Results and Discussion

The concordance data were analyzed using a 3-way ANOVA. The three within-subject factors were affective valence (positive, negative), intensity distance (near, far), and intensity order (second picture lower, second picture higher).

Unlike in Experiment 3, the data from Experiment 4 did not result in a main effect of valence on concordance, $F(1, 31) = 0.004, p > .90$; performance on the negative trials (70.8%) did not differ from performance on the positive trials (70.7%). This suggests that the difference in performance between positive and negative trials in Experiment 3 was due to differences in maintenance for positive versus negative feelings and not in other processes. Nevertheless, the manipulation of distance again emerged indicating better performance for pictures far in intensity (76.9%) than for pictures near in intensity (64.7%), $F(1, 31) = 61.62, p < .001$. A main effect of intensity order was also observed with superior performance on the picture pairs in which the higher picture was on the right side (72.6%) than for pairs with the lower picture on the right side (69%), $F(1, 31) = 5.30, p < .05$. Despite the simultaneous presentation of the images in Experiment 4, there was still a bias to judge the second image (the “probe”) as higher. The critical finding was the main effect for valence, that is, the negativity bias, and the valence interactions observed in Experiment 3 were no longer present in Experiment 4. These results indicate that the maintenance requirement of our task is critical for the emergence of valence modulated effects.

General Discussion

This project set out to determine whether the maintenance of affective information relies on domain-specific processes that are separable from those that maintain nonaffective information. Two new delayed-response tasks were developed and then selective interference methods were applied to assess the separability of associated maintenance processes. Moreover, valence was manipulated to examine affective influences on maintenance processes. The resulting effects provide new evidence suggesting separable mechanisms that are specialized for the online maintenance of information about affect intensity.

While we believe that the present results support domain-specific working memory components specialized for the maintenance of affective information, alternative interpretations should be considered. In particular, could performance of the affect maintenance task be mediated by episodic long-term memory processes? While this is plausible, we favor a working memory interpretation for several reasons. First, the 3-s retention interval used in several of the experiments is clearly within the temporal parameters of canonical short-term/working memory tasks. Second, and most important, interference tasks designed to disrupt active, online maintenance led to significant and selective performance decrements in the affect task. If performance on the affect maintenance task had been mediated by episodic memory, then disrupting active maintenance, the sine qua non of working memory, should have been inconsequential to task performance.

Another possibility that must be considered is that affect maintenance is mediated by an episodic buffer (Baddeley, 2000, 2003), a multimodal component of the working memory system that provides an interface between long-term memory and the current online contents of the mental work space. An episodic buffer of this kind could conceivably explain the current results. However, in order to account for the present results, this buffer would have properties such that its efficiency is modulated by the emotional valence of the representations being maintained, and it would be uniquely susceptible to interference from concurrent emotional regulation, and facilitation from concurrent cognitive tasks. These properties seem to characterize mechanisms that are domain-specific, and thereby inconsistent with the type of multimodal/domain general characterization of the episodic buffer to date. One possible reconciliation is to posit an episodic buffer in working memory that is specialized for emotion, a proposal that we see as entirely consistent with our results and compatible with our interpretation thus far.

Another important issue we must consider is how our affect maintenance task relates to other psychological processes and to real world behavior. The task goal—the maintenance of a feeling and its comparison with another one—is clearly relevant to human choice behavior where decisions may involve comparing one’s current feeling to other feelings experienced recently, or conjured up from the past (Damasio, 1994). Likewise, current theorizing ascribes a role for an “affect pool” in decision making (Slovic, Finucane, Peters, & MacGregor, 2004). The various feelings that contribute to decision making require online representation, and we propose that this is one function of affect maintenance. Further, the maintenance of affect constitutes a means for regulating emotion (Gross, 1998b; Thompson, 1994). Indeed, the interference demonstrated between emotion regulation and affect maintenance suggests shared underlying processes. Additionally, alterations of affective working memory could underlie clinically relevant psychological phenomena. For example, dysfunctional affective maintenance may play a role in rumination which has been considered one predictor of depressive disorders (Nolen-Hoeksema, 2000). Inhibitory control processes that normally prevent intrusive affective thoughts may be disordered or insufficient in depression thereby permitting the entrance of affective memoranda into working memory. Thus, future research examining a larger array of working memory processes for affect is necessary, and how different working memory processes for affect relate to

various clinical phenomena would certainly be fruitful. Finally, the immediacy bias observed may be related to social psychology results indicating that a person's present affective state biases their judgment about future and past affective experiences (Fredrickson & Kahneman, 1993; Gilbert, Pinel, Wilson, Blumberg, & Wheatley, 1998; Gilbert & Wilson, 2000; Schkade & Kahneman, 1998). Our immediacy effect for brightness judgments suggests that this bias may also influence basic sensory processing.

The unexpected result in Experiment 2 of selective *facilitation* in the affect maintenance task not only provides further support for the dissociation of working memory processes for affective versus nonaffective memoranda, but also suggests interesting albeit speculative affect-cognition dynamics. Observing that secondary cognitive tasks have an opposite effect on the brightness versus affect maintenance task provides additional support for the notion that affective and nonaffective maintenance rely on separable processes. We expected the secondary cognitive tasks to have no effect on affect maintenance; however, this facilitation finding suggests not only separability but antagonism between cognitive and affective processes. For instance, focused attention in the cognitive dual task condition may have interfered with reappraisal processes that may otherwise modulate emotional feelings. Indeed, affective experience may frequently be overrun by regulatory cognitive processes, including reappraisal, that require attention (Gross, 1998b). Such reappraisal findings coupled with the facilitation in Experiment 2 suggest that cognitive processes naturally have a modulatory effect on affective reactions that may be mitigated when immediate attentional processes are engaged in other tasks. However, concentrating on difficult cognitive tasks can decrease mood intensity (Erber & Tesser, 1992). Thus, the antagonistic interplay of cognitive and affective processes remains a rich area for further investigations.

The present investigation introduces new model tasks that can help to elucidate the empirical and theoretical boundaries between affective and cognitive processes. It also provides evidence that is consistent with the view that the maintenance of affective intensity information may require domain-specific components that are specialized for emotion. This conclusion is supported by converging evidence that has emerged from our research program. First, with similar tasks we have found that relative to younger adults, older adults show declines on brightness maintenance, while demonstrating preserved performance on affect maintenance (Mikels, Larkin et al., 2005). Thus, normal aging has differential consequences on these forms of maintenance, consistent with the possibility of separable underlying mechanisms. Moreover, when participants perform these tasks in an fMRI scanner, we found that regions of activation in lateral orbitofrontal cortex are unique to affect maintenance (Mikels & Reuter-Lorenz, in press). Thus, the work we report here is in line with these converging indications of domain-specific working memory components for affect. Thus, the present results suggest that current working memory models may need to be reconfigured to include affect.

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