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Verbal Makes It Positive, Spatial Makes It Negative: Working Memory Biases Judgments, Attention, and Moods

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Prior research has suggested that emotion and working memory domains are integrated, such that positive affect enhances verbal working memory, whereas negative affect enhances spatial working memory (Gray, 2004; Storbeck, 2012). Simon (1967) postulated that one feature of emotion and cognition integration would be reciprocal connectedness (i.e., emotion influences cognition and cognition influences emotion). We explored whether affective judgments and attention to affective qualities are biased by the activation of verbal and spatial working memory mind-sets. For all experiments, participants completed a 2-back verbal or spatial working memory task followed by an endorsement task (Experiments 1 & 2), word-pair selection task (Exp. 3), or attentional dot-probe task (Exp. 4). Participants who had an activated verbal, compared with spatial, working memory mind-set were more likely to endorse pictures (Exp. 1) and words (Exp. 2) as being more positive and to select the more positive word pair out of a set of word pairs that went 'together best' (Exp. 3). Additionally, people who completed the verbal working memory task took longer to disengage from positive stimuli, whereas those who completed the spatial working memory task took longer to disengage from negative stimuli (Exp. 4). Interestingly, across the 4 experiments, we observed higher levels of self-reported negative affect for people who completed the spatial working memory task, which was consistent with their endorsement and attentional bias toward negative stimuli. Therefore, emotion and working memory may have a reciprocal connectedness allowing for bidirectional influence.

Keywords: attention, emotion, judgment, working memory

There is evidence to suggest that positive affect enhances and is integrated with verbal working memory, and that negative affect enhances and is integrated with spatial working memory (Gray, 2004; Gray, Braver, & Raichle, 2002). One feature of integration is a reciprocal relationship between two entities (Hebb, 1949; Simon, 1967), and we propose this reciprocal relationship exists between affect and working memory. Emotion influences working memory, but does activating a specific working memory domain bias processing toward a specific affective agenda? In other words, can simply completing a verbal working memory task lead a person to feel more positive, judge objects more positively, and attend longer to positive stimuli? Conversely, can completing a spatial working memory task lead a person to feel more negative, judge objects more negatively, and attend longer to negative stimuli?

Herbert Simon (1967) hypothesized that emotion interrupts the current cognitive agenda by reprioritizing a hierarchy of goals, resulting in a change in behavior. He postulated that specific emotions reprioritize the same hierarchy of goals and behavior results in the coupling (i.e., integration) of emotion and cognition. For instance, a dangerous environment may elicit fear and evoke freezing, which requires the cognitive process of inhibition. In a Hebbian fashion (Hebb, 1949), he suggested that fear would become coupled (integrated) with inhibition over time. However, an effective system for maintaining a behavioral goal would be an iterative, reciprocal system in which emotions (e.g., happiness) influence cognitions (e.g., working memory) and cognitions (e.g., working memory) influence emotions (e.g., happiness). It is the reciprocal nature of this theory that we seek to explore in the current study. Namely, if a specific emotional state motivates a specific cognitive process, can that cognitive process motivate that same emotional state?

The idea that cognition can directly modulate our emotional experience is well established. For instance, people often use cognitive control mechanisms, such as cognitive reappraisal, to regulate or change their emotional experiences (Gross, 2007; Hajcak, & Nieuwenhuis, 2006; Koole, 2009). Moreover, indirect effects of cognitive control on emotion have also been observed; engagement in a cognitive task or cognitively labeling affective feelings can result in reduced processing and experience of emotion (Erk, Kleczar, & Walter, 2007; Lieberman et al., 2007; Pessoa, Kastner, & Ungerleider, 2002; Pessoa, 2009; Van Dillen & Koole, 2009; Van Dillen, Heslenfeld, & Koole, 2009). For instance, engaging in a challenging attentional control task can reduce the emotional response to a fear face, but engaging in a nonchallenging attentional control task results in a strong emotional response to the same fear face.

Evidence from clinical psychology suggests that cognitive systems can be tuned to bias the processing of affective stimuli (Eysenck, Derakshan, Santos, & Calvo, 2007). For instance, indi-

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viduals high in trait anxiety may redirect cognitive processes toward stimulus-driven information, as opposed to goal-oriented (top-down) processing, emphasizing the processing of threat-related stimuli irrespective of task demands (Bradley, Mogg, Millar, & White, 1995; Fox, Russo, Bowles, & Dutton, 2001; Keogh & French, 2001; MacLeod & Rutherford, 1992). Other models, such as the general aggression model, posit that certain cognitive components, such as effortful control, attention, memory accessibility, and interpretation are associated with trait anger (Anderson & Bushman, 2002). Therefore, under ambiguous situations, these cognitive systems create attentional biases toward the processing of one kind of affective information (negative) over another (positive).

Certain cognitions have also been linked to experienced affect. The mere-exposure effect, famously observed by Zajonc (1980), found that simply being exposed to a stimulus one time was sufficient to produce mild feelings of positive affect upon seeing it again. Similarly, Winkielman and colleagues (Reber, Winkielman, & Schwarz, 1998; Winkielman & Cacioppo, 2001) found that fluent processing of stimuli during a cognitive task also led to an increase in positive affect.

Similar findings have been observed with broad semantic processing (defined as the activation of remotely related semantic concepts that allows for advancing from one context to another). Bar (2009) observed that individuals engaged in tasks that require broad semantic processing reported higher levels of positive affect. Interestingly, induced positive moods have long been known to increase the activation of remotely related semantic associations (e.g., Bolte, Goschke, & Kuhl, 2003; Corson, 2002; Fredrickson, 2001; Isen, 1999; Storbeck & Clore, 2007), suggesting a possible reciprocal connection (Bar, 2009). Mood dependent memory may be another example of a reciprocal relationship, which was tested using simulations. Rolls and Stringer (2001) tested two areas of the brain associated with affect (amygdala) and memory (inferior temporal cortex) based on their known structural and functional connections (Rolls, 1999). They observed reciprocal interactions, such that an affective mood biased the retrieval for affectively congruent memories, and retrieval of affective memories resulted in affect congruent changes in mood. They concluded that emotion can modulate the storage of memory (behavioral evidence exists supporting this, see Cahill, 2000; LaBar & Cabeza, 2006; McGaugh, 2004), and that the retrieval of memories also elicited mild changes in mood in a mood congruent manner (retrieving positive memories increased positive feelings). In sum, cognitive experiences of familiarity, fluency, activation of semantic associations, and memory retrieval can bring about changes in affective states, and cognitive systems can be tuned to bias processing of features correlated with affective factors.

The activation of mutual goals by emotional states and situational- or task-demands may be the basis for reciprocal connections between specific emotions (i.e., happiness) and specific cognitive processes (i.e., verbal working memory). We believe that a goal to interact socially may be the broadest goal that links positive affect and verbal working memory. Social interactions are inherently rewarding (Ashby & Isen, 1999; Beckes & Coan, 2011; Clore et al., 2001; Fredrickson, 2001), and to engage in such a goal requires specific cognitive processes (e.g., semantic memory, verbal working memory). Therefore, activating a goal to engage in social interactions should activate associated cognitive processes (e.g., semantic memory, verbal working memory) and associated affective feelings (i.e., positive affect) and motivations (i.e., approach). Over time, consistent coactivation of the subcomponents of the goal, like between positive affect and verbal working memory, may result in integration (Simon, 1967). Alternatively, we believe that a goal to identify threats and errors may be the broadest goal that links negative affect and spatial working memory. Identification of threats and errors produces anxiety and increases negative thoughts and feelings (Corr & McNaughton, 2012; Eysenck et al., 2007), and to engage in such a goal requires specific cognitive processes (e.g., spatial working memory, inhibition, attentional focus). Therefore, activating a goal to engage in threat and error detection should activate associated cognitive processes (e.g., spatial perception, spatial working memory, and inhibition) and associated negative thoughts, feelings, and motivations (i.e., withdraw). Again, over time, a functional, reciprocal relationship may develop between negative affect and spatial working memory.

Emotion and Working Memory Integration

Consistent with our theoretical belief that positive affect is linked with social interactions and negative affect with threat detection, there is behavioral evidence that links positive and negative affect with verbal and spatial domains of working memory, respectively (Gray, 2001; Gray et al., 2002; Storbeck, 2012). Gray observed that positive affect enhanced verbal working memory performance and impaired spatial working memory performance, and negative affect enhanced spatial working memory performance and impaired verbal working memory performance. Subsequent research has provided further evidence that emotion and working memory may be integrated (Gray, 2004; Pessoa, 2008; Storbeck, 2012). For instance, Gray et al., (2002) employed a similar task as Gray (2001) during a functional brain imaging study. Within the prefrontal cortex (PFC), they observed the same dissociative pattern for brain activation as Gray (2001) observed behaviorally. Specifically, the positive/verbal and negative/spatial conditions (alignment conditions) exhibited less activation compared with the positive/spatial and negative/verbal conditions (misalignment conditions) within the left and right PFC, respectively. They argued that the reduced activation during the alignment conditions was a result of reduced goal competition. Moreover, Storbeck (2012) examined whether the reduced cognitive demands during emotion and working memory alignment can facilitate self-control on a subsequent cognitive control task. Participants performed better on self-control tasks following a working memory task during alignment conditions compared with the misalignment conditions (Storbeck, 2012). Therefore, the combination of emotion and working memory alignment required fewer psychological resources than each independent process, a hallmark of integration.

Neuroscience evidence also suggests that integration of emotion and working memory may have a basis with respect to structural and functional associations within the prefrontal cortex (PFC). Positive emotions that foster appetitive tendencies are associated with relatively greater activity in left prefrontal cortical areas of the brain (Coan & Allen, 2004). In contrast, negative emotions that foster aversive or withdrawal tendencies are associated with relatively greater activity in right prefrontal cortical areas or reduced activity in the left PFC (Coan, Allen, & Harmon-Jones, 2001; Davidson, 1998; Gray et al., 2002). Interestingly, a large body of research points to a similar pattern of hemispheric specialization for cognitive control abilities (Cohen et al., 1997; D'Esposito et al., 1998). For example, verbal working memory is associated with relatively greater left dorsolateral (dl) PFC activity, whereas spatial working memory is associated with relatively greater right dlPFC activity (Cohen et al., 1997; D'Esposito et al., 1998; Fletcher & Hanson, 2001; Nystrom et al., 2000; Petrides, 1995). This structural overlap creates conditions through which the activation of emotion (i.e., positive affect) can concurrently activate processes associated with the cognitive system (i.e., verbal working memory), though it remains unclear whether a reciprocal relationship exists such that working memory domains activate affective feelings and thoughts. Therefore, we asked whether completing a verbal or spatial working memory task (activating verbal and spatial working memory processes, respectively) would influence affective states and produce affective biases in judgments and attention.

Judgments often involve evaluative information with respect to valence (Fishbein & Ajzen, 1975), and relying on feelings as a source of judgment is often efficient (Pham, 1998). Research has also observed that judgments reflect the moods that the judge happened to be in at the time (e.g., Bower, 1981; Clore & Huntsinger, 2007). For instance, when people make evaluative decisions, they often use the heuristic, "If it feels good, it is good" (Schwarz & Clore, 1988). In such situations, generally speaking, people have a more positive attitude toward objects when in a positive mood, and a more negative attitude toward objects when in a negative mood (Schwarz & Clore, 1983). For instance, the pleasantness of a sunny day or the victory of a sports team often leads to more positive judgments about one's quality of life (Schwarz & Clore, 1983; Schwarz, Strack, Kommer, & Wagner, 1987).

With respect to attention, mood-congruent processing frameworks suggest that focus of attention to emotional stimuli is often compatible with one's current feelings. For instance, Tamir and Robinson (2007) induced positive or negative mood states and then had participants complete an attentional dot probe task to rewarding stimuli. They found that people in positive moods showed a stronger bias toward processing rewarding items, whereas people in the negative mood avoided attending to rewarding items. Other research has observed that induced mood states can shift attention to stimuli that match in affective tone (Wadlinger & Isaacowitz, 2006). Similar findings have been observed for trait differences. Sutton and Davidson (2000) found that individuals with relatively greater left frontal activity, reflecting approach tendencies, were more likely to attend to, and consequently select, the more positive word pair from the presented pairs, which varied in valence (positive, neutral, and negative). On the other hand, dysphoric individuals had a more difficult time disengaging from negative material and selected more negative word pairs. In sum, affective cues can guide judgments and attention to affectively congruent stimuli, such that positive affective cues foster more positive judgments and attention to positive stimuli, whereas negative affective cues foster more negative judgments and attention to negative stimuli.

Design and Prediction

Given the claims that emotion and working memory are integrated, we wanted to examine whether completing a verbal or spatial working memory task would lead to changes in (a) affective states, (b) judgments, and (c) attentional biases. For all experiments, a mixed-subjects design was used: the working memory task (verbal vs. spatial) varied between participants and the stimuli used within each of the experiments varied with respect to emotional valence (positive, negative, neutral). To start, participants completed either the verbal or spatial working memory task. The working memory tasks served to activate verbal and spatial working memory processes or mind-sets, which rely on dissociated areas in the left and right prefrontal cortex, respectively (e.g., D'Esposito et al., 1998; Fletcher & Hanson, 2001). The working memory task was followed by an endorsement task (Exps. 1 and 2), a word-pair preference task (Exp. 3), or an attentional dot-probe task (Exp. 4; See Figure 1 for a graphical representation of the working memory task and the endorsement, word-pair preference, and dot-probe tasks). Finally, participants completed a variety of affective measures. The post-task mood check served to assess whether there were changes in mood resulting from the verbal and spatial working memory task. The affective tone question served to assess whether the verbal and spatial working memory task biased the global evaluative ratings of the affective stimuli presented during the evaluative/probe task. The task difficulty question assessed the difficulty experienced or effort required to complete the working memory task.

We predicted that the engagement in a verbal working memory task would bias judgments and attention to be more positive, whereas the engagement in a spatial working task would bias judgments and attention to be more negative.[1] Under this prediction, we expected that for the endorsement tasks (Exp. 1 & 2), the completion of the verbal, compared with the spatial, working memory task would result in (a) a bias toward endorsing pictures (Exp. 1) and words (Exp. 2) as being positive, (b) higher levels of self-reported positive affect (and/or lower levels of negative affect), and (c) rating the overall affective tone of the pictures and words as more positive. For Experiment 3, we predicted that people in the verbal, compared with the spatial, working memory condition would be more likely to select the more positive of two sets of word pairs as "going together best," and report higher levels of positive affect. Finally, in Experiment 4, we predicted that people in the verbal working memory condition would take longer to disengage from positive stimuli, whereas those in the spatial working memory condition would take longer to disengage from negative stimuli. Moreover, the people in the verbal condition would report higher levels of positive affect compared to the spatial working memory condition.

[1] It should be noted that for Experiments 1–3, there was no control condition; therefore, predictions are relative. We cannot be confident that verbal working memory increases the propensity of processing positive stimuli, that spatial working memory increases the propensity of processing negative stimuli, or a combination of the two. For Experiment 4, comparisons are made to neutral stimuli, which allows for absolute predictions and conclusions.

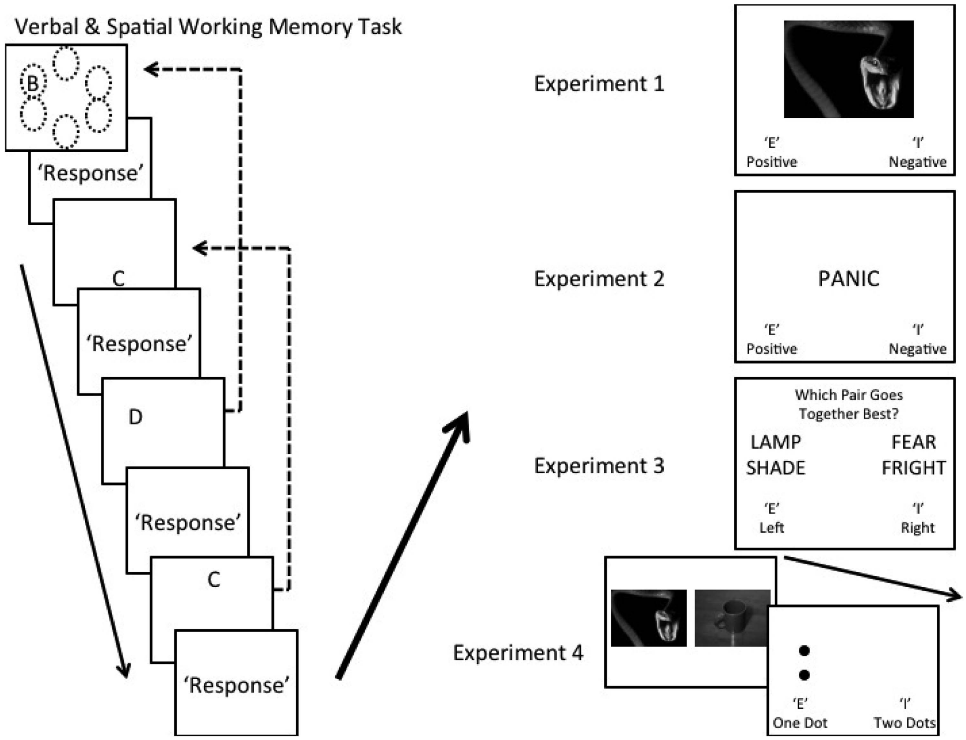

Figure 1. A schematic representation of the verbal and spatial working memory task and the endorsement (Exp. 1 & 2), word-pair selection (Exp. 3), and the dot-probe (Exp. 4) tasks. The first box of the working memory task reveals the six possible locations for the shown letter, identified by the dashed-circles. For the verbal (spatial) task participants responded by comparing the letter (location of the letter) presented on the current trial to the letter (location of the letter) presented 2 trials back (comparing Trial 3 to Trial 1 and Trial 4 to Trial 2—represented by the dashed arrows). The pictures were presented in color to the participants.

Experiment 1: Picture Endorsement Task

Method

Participants. Forty-four (33 female) individuals from Queens College participated for course credit (M_{age} = 23.64, SD = 8.76), and they all provided written, informed consent.

Working memory task. Following the procedures of Storbeck (2012), verbal and spatial 2-back tasks were used to activate verbal and spatial working memory processes, respectively (D'Esposito et al., 1998; Fletcher & Hanson, 2001; Nystrom et al., 2000). The stimuli consisted of letters of the alphabet. On each trial, a single letter was presented in one of six spatial locations around an *unseen* perimeter of a circle, with the top of the circle positioned 20% from the top of the monitor. The locations along the perimeter of the circle were at 30, 90, 120, 170, 230, and 290 degrees. Moreover, two predefined orders were created for both the verbal and spatial tasks in order to serve as a counterbalance manipulation. We selected to use a predefined list in order to maintain the same number of match versus nonmatch responses across the tasks.

Picture stimuli. Emotional pictures were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). Thirty negative, 30 positive, and 15 neutral pictures were selected based on the standardized ratings. A one-way ANOVA was conducted and the emotional picture sets differed in valence, $F(2, 72) = 262.25$, $p < .01$, $\eta^2 = 0.88$. Post hoc results revealed that the positive, negative, and neutral picture sets all differed from one another with respect to valence, all $ps < 0.01$. The emotional picture sets also varied with respect to arousal, $F(2, 72) = 20.67$, $p < .01$, $\eta^2 = 0.37$. The positive and negative sets had similar arousal ratings, $p = .98$; however, the neutral picture sets were less arousing than both the positive, $p < .01$, and the negative, $p < .01$, sets. See Table 1 for means, standard deviations, and the IAPS picture numbers.

Picture endorsement task. Participants were asked to endorse pictures as being *positive* or *negative*. Stimuli were presented one at a time in the middle of the screen. The pictures were sized to 4″ × 5″. The response options were positive ('E' key) and negative ('I' key), and the response options were countered-balanced across participants.

Task difficulty question. Participants were asked to "describe, in general, how difficult was the working memory task" on a 6-point scale (6 = *very easy* to 1 = *very difficult*).

Affective tone for presented stimuli. Participants were asked to "describe your overall feelings of the pictures you viewed" using a 6-point scale (6 = *very positive* to 1 = *very negative*).

Post-task mood check. Mood was assessed using the Brief Mood Introspection Scale (BMIS; Mayer & Gaschke, 1988). Var-

Table 1
Mean Valence and Arousal Ratings for Pictures (Experiments 1 & 4) and Words (Experiment 2)

Conditions	Valence and arousal statistics	
	Valence	Arousal
Experiments 1 & 4		
Positive pictures	7.39 (0.66)	5.36 (1.07)
Negative pictures	3.10 (0.67)	5.40 (1.05)
Neutral pictures	5.88 (0.95)	3.47 (0.90)
Experiment 2		
Positive words	7.79 (0.52)	5.09 (1.81)
Negative words	2.67 (0.82)	5.10 (1.76)
Neutral words	4.99 (0.36)	4.27 (0.78)

Note. Standard deviations are in parentheses. Words used in Experiment 2: Positive words: joy, romantic, kiss, graduate, passion, cash, miracle, rollercoaster, fun, surprised, secure, wise, warmth, cozy, gentle, politeness, butterfly, relaxed, carefree, bath, dove, angel, sunset, bunny, kindness, snuggle, rainbow, paradise, comfort, pillow. Negative words: murderer, betray, nightmare, enraged, panic, terrorist, fire, rage, cancer, roach, gloom, mucus, pity, grime, weary, rusty, meek, slow, bored, messy, fatigued, unhappy, sad, sick, rotten, maggot, slum, trash, morbid, handicap. Neutral words: bench, icebox, knot, privacy, rattle, shadow, violin, journal, curtains, noisy, context, aloof, phase, subdued, stiff. Picture numbers used in Experiments 1 & 4: Positive pictures: 1440, 1460, 1600, 1610, 1750, 1810, 2040, 2070, 2165, 2352, 2395, 2550, 4601, 4608, 4626, 4641, 4660, 5480, 5829, 7325, 8080, 8160, 8180, 8185, 8260, 8300, 8370, 8380, 8470, 8490. Negative pictures: 1050, 1120, 1201, 1220, 1270, 1300, 1301, 1931, 2110, 2120, 2301, 2312, 2520, 2753, 2800, 2900, 3350, 6242, 6260, 6510, 6570, 9600, 9622, 9001, 9010, 9280, 9415, 9421, 9469, 9561. Neutral pictures: 2309, 2383, 5000, 5220, 5300, 5500, 5600, 5720, 7010, 7061, 7095, 7100, 7130, 7238, 7490. Control pictures for Dot Probe Experiment: 2880, 5130, 5202, 5215, 5225, 5390, 5471, 5520, 5530, 5551, 5611, 5631, 5665, 5725, 5731, 5740, 5760, 5870, 6150, 7000, 7001, 7003, 7004, 7009, 7018, 7020, 7021, 7023, 7025, 7026, 7034, 7039, 7041, 7045, 7052, 7055, 7057, 7058, 7062, 7081, 7175, 7235, 7240, 7500, 7505.

ious affective adjectives were presented, and participants rated "how well does each adjective or phrase describe your present mood?" using a 6-point scale (6 = *Strongly feel* to 1 = *Strongly do not feel*). Grouping together similar adjectives created four factors. The factors were Positive Activation (lively, peppy, active), Positive Low Activation (happy, caring, content, calm), Negative Activation (jittery, nervous, fed up), and Negative Low Activation (sad, tired, gloomy, drowsy).

Procedure. Participants were provided instructions for the working memory task, and then were given 20 practice trials. One hundred sixty experimental trials were then completed. Each trial began with a single letter shown for 1 s, followed by a blank screen. Responses were made once the letter was removed, and the next trial started after the response was made. For the verbal (spatial) task, participants were instructed to determine whether the letter (location of the letter) presented was the same (by pressing the 'A' key) or different (by pressing the 'L' key) from the letter (location of the letter) presented two trials back. Then, all participants were provided instructions for the picture endorsement task. Participants completed two blocks with each block consisting of 75 trials (150 total trials). Stimuli were randomly presented, and every stimulus was presented once within each block. A trial started with a fixation cross in the center of the screen for 500 ms, followed by a blank screen for 200 ms. After the blank screen, the picture was presented and remained on the screen until a response was made. Lastly, participants completed the affective tone question, the task difficulty question, the post-task mood check, and then provided demographic information.

Results

Working memory accuracy. An independent measures *t* test revealed a nonsignificant effect of Working Memory Condition (verbal, spatial) on accuracy, $t(42) = 0.37$, $p = .72$. See Table 2 for descriptive statistics for working memory performance for each Experiment.[2]

Task difficulty–working memory task. An independent measures *t* test revealed a nonsignificant effect of Working Memory Condition (verbal, spatial) for self-reported task difficulty, $t(42) = 0.90$, $p = .38$. See Table 2 for descriptive statistics for task difficulty for each Experiment.

Affective tone. An independent measures *t* test revealed a significant effect for the overall affective tone of the pictures, $t(42) = 2.69$, $p = .01$. Participants in the verbal working memory condition rated the overall affective tone of the pictures as being more positive than those participants in the spatial working memory condition. See Table 2 for descriptive statistics for Affective Tone for each Experiment.

Post-task mood check. Four separate ANCOVAs were run assessing the effect of working memory task demands (verbal, spatial) on each Mood Factor (Positive Activation, Positive Low Activation, Negative Activation, and Negative Low Activation), and the covariates were task difficulty and working memory accuracy. We selected the covariates to adjust for changes in mood attributable to frustration (task difficulty) or performance (working memory task accuracy). The people in the spatial condition reported a higher level of Negative Activation, $F(1, 40) = 5.65$, $p = .02$, $\eta^2 = 0.12$, and a marginally higher level of Negative Low Activation, $F(1, 40) = 3.81$, $p = .06$, $\eta^2 = 0.09$, compared with the people in the verbal condition. No differences in mood were observed for Positive Activation, $F(1, 40) = 1.82$, $p = .19$, $\eta^2 = 0.04$, and Positive Low Activation, $F < 1$. The covariates for both working memory accuracy and task difficulty were all nonsignificant, *F*s < 1. See Table 2 for descriptive statistics for the Mood Check for each Experiment.

Picture endorsement task. A repeated-measures ANOVA was run to assess whether endorsement ratings were biased as a function of emotion picture sets (within factor; positive, negative, neutral) and working memory task (between factor). The within subjects effect (valence of stimuli) and interaction were both nonsignificant, *F*s < 1. However, as predicted, there was a main effect for working memory condition, $F(1, 42) = 10.03$, $p < .01$, $\eta^2 = 0.19$, such that those in the verbal working memory condition had a higher average endorsement of pictures as positive, regardless of the pictures initial affective value, compared with people in the spatial working memory condition. See Figure 2 for endorsement ratings of pictures.

[2] For each experiment, we counterbalanced two predefined lists (List Order [A, B]) for both the verbal and spatial working memory task. As such, we included List Order as a factor within the analysis. However, across each study, List Order never achieved a level of significance, nor did it interact with any other variable (all *p*s < .30). Therefore, we have removed this factor from the analyses reported.

Table 2
Mood Manipulation Check Results

Dependent variables	Working memory condition	
	Verbal	Spatial
Experiment 1 (Picture evaluation task)		
Working memory accuracy	0.82 (0.15)	0.81 (0.16)
Task difficulty rating	4.09 (1.19)	3.73 (1.49)
Affective tone	3.91 (0.81)	3.22 (0.87)
Positive activation	3.71 (0.99)	3.33 (0.87)
Positive low activation	4.59 (0.93)	4.23 (0.92)
Negative activation	2.32 (0.93)	2.95 (0.71)
Negative low activation	3.11 (1.09)	3.67 (0.67)
Experiment 2 (Word evaluation task)		
Working memory accuracy	0.86 (0.14)	0.82 (0.15)
Task difficulty rating	4.11 (1.05)	3.65 (0.98)
Affective tone	4.00 (0.78)	3.46 (0.71)
Positive activation	3.25 (1.25)	3.31 (1.02)
Positive low activation	4.25 (0.66)	4.19 (0.58)
Negative activation	2.65 (0.68)	3.03 (0.92)
Negative low activation	3.15 (0.77)	3.68 (0.67)
Experiment 3 (Word pair task)		
Working memory accuracy	0.95 (0.07)	0.94 (0.08)
Task difficulty rating	3.37 (1.31)	3.15 (1.35)
Overall mood check score	4.40 (0.98)	3.94 (0.83)
Experiment 4 (Dot probe attention task)		
Working memory accuracy	0.89 (0.11)	0.81 (0.22)
Task difficulty rating	2.62 (1.43)	2.72 (1.49)
Positive activation	2.81 (0.89)	3.08 (1.08)
Positive low activation	4.10 (0.78)	3.98 (0.94)
Negative activation	2.63 (0.79)	3.03 (0.99)
Negative low activation	3.42 (0.82)	3.99 (0.65)

Note. Standard deviations are in parentheses.

Regression for endorsement task. We sought to identify the strongest predictor for the endorsement of positive images using Working Memory Condition, accuracy on the working memory task, self-reported difficulty of the working memory task, and Post-Task Mood Check as the predictors. The regression was found to be marginally significant, $F(4, 43) = 2.44$, $p = .06$, and the only significant predictor was Working Memory Condition, $p < .01$. See Table 3 for regression statistics for each Experiment.

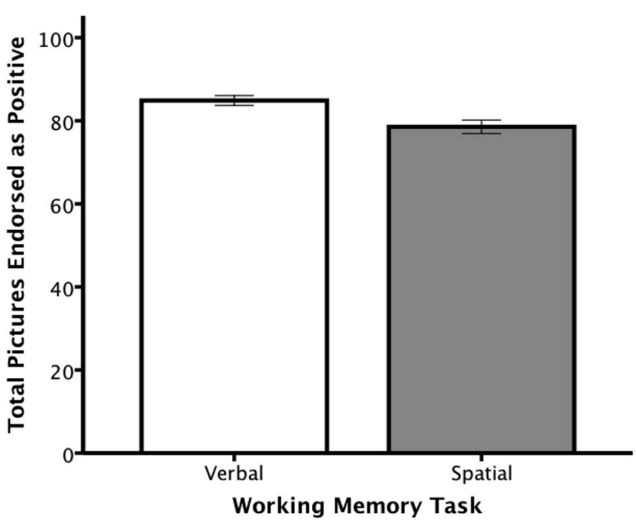

Figure 2. Total number of emotional and neutral pictures endorsed as being Positive in Experiment 1. Error bars represent one standard error of the mean.

Experiment 2: Word Endorsement Task

In the previous experiment, the participants in the verbal working memory condition were more likely to endorse and rate the overall affective tone of the images as more positive than the participants in the spatial working memory condition. Moreover, those in the spatial condition rated themselves as experiencing more negative affect than those in the verbal condition. However, the changes in mood failed to predict the endorsement of affective pictures.

One concern regarding the pictures used in Experiment 1 was that their inherent spatial properties may have been confounded with the spatial working memory task. The goal of Experiment 2 was to examine whether the effect generalized to a nonspatial domain. Positive, negative, and neutral words were used as stimuli within the same endorsement task as in the previous experiment. Again, we predicted that the individuals who completed the verbal working memory task would endorse and rate the overall affective tone of the words as more positive than those who completed the spatial working memory task. Moreover, we expected individuals in the verbal condition to feel more positive or less negative than those in the spatial condition.

Table 3
Regression Analyses

Condition	Affective adjective ratings			
	B	*SE*	β	*p*
Experiment 1				
Condition	–6.73	2.19	−0.47	<.01*
Accuracy	−0.07	6.91	<−0.01	.99
Difficulty	−0.10	0.80	−0.02	.90
Negative low act	0.68	1.18	0.06	.57
Experiment 2 (Reg)				
Condition	−4.42	1.58	−0.36	<.01*
Accuracy	0.46	5.13	0.01	.93
Difficulty	2.54	0.74	0.42	<.01*
Negative low act	0.57	0.99	0.07	.57
Experiment 2 (Mod)				
Condition	−4.12	1.40	−0.34	<.01*
Difficulty	2.34	0.69	0.39	<.01*
ZTask × ZDifficulty	−1.64	0.72	−0.26	.03*
Experiment 3				
Condition	−2.56	0.93	−.38	<.01*
Accuracy	0.26	6.27	<0.01	.97
Difficulty	0.15	0.34	0.06	.67
Positive mood score	0.23	0.50	0.06	.64

Note. Reg = Regression; Mod = Moderation. The predicted variable was Positivity Endorsement with the independent variables being Condition (Verbal vs. Spatial), Accuracy (working memory performance), Difficulty (self-reported working memory task difficulty), and Mood (Negative low activation score or the combined mood score -Exp3-). For Experiment 2 moderation, ZTask × ZDifficulty represents the moderator variable created for the moderation analysis.
* $p < .05$.

Method

Participants. Fifty-three (32 female) individuals from Queens College participated for course credit (M_{age} = 20.32, *SD* = 2.75), and they all provided written, informed consent.

Word stimuli. Words were selected from the Affective Norms for English Words (ANEW; Bradley & Lang, 1999). Thirty negative, 30 positive, and 15 neutral words were selected using the standardized ratings. A one-way ANOVA was conducted to examine whether the valence differed across the word types, and the effect was significant, $F(2, 72) = 490.33$, $p < .01$, $\eta^2 = 0.93$, and the direction of the effect was as expected, all *p*s < 0.01. The words did not vary with respect to arousal, $F(2, 72) = 1.51$, $p = .23$, $\eta^2 = 0.04$. See Table 1 for means, standard deviations, and the words used.

Procedure. The procedure was the same as in Experiment 1, except emotional words were evaluated rather than emotional pictures.

Results

Working memory accuracy. There were no differences in working memory accuracy between the verbal and spatial conditions, $t(51) = 0.90$, $p = .37$. See Table 2 for all descriptive statistics for this experiment.

Task difficulty–working memory task. Participants had similar ratings of task difficulty across the verbal and spatial working memory conditions, $t(51) = 1.64$, $p = .11$.

Affective tone. Participants completing the verbal working memory condition found the words to be more positive compared with the spatial working memory condition, $t(51) = 2.62$, $p = .01$.

Mood check. The same set of ANCOVAs as in Experiment 1 was run to assess changes in mood attributable to working memory conditions (covariates: task difficulty & working memory accuracy). The people in the spatial condition reported higher levels of Negative Low Activation, $F(1, 49) = 5.50$, $p = .02$, $\eta^2 = 0.10$, compared with the people in the verbal condition. No differences in mood were observed for Negative Activation, $F(1, 49) = 2.26$, $p = .14$, $\eta^2 = 0.04$, Positive Activation, $F < 1$, and Positive Low Activation, $F < 1$. All the covariates were also nonsignificant, *F*s < 1, (Positive Low Activation for working memory, $F(1, 49) = 2.13$, $p = .15$, $\eta^2 = 0.04$). See Table 2 for descriptive statistics for the Mood Check for each Experiment.

Word endorsement task. A repeated-measures ANOVA was run to assess whether positive endorsement ratings varied as a function of emotion word set (positive, negative, neutral) and working memory condition (verbal, spatial). The emotion word set and interaction were both nonsignificant, *F*s < 1. However, as predicted, there was a main effect for the working memory condition, $F(1, 51) = 10.88$, $p < .01$, $\eta^2 = 0.18$. People in the verbal working memory condition endorsed more words as positive, regardless of their initial affective value, compared to those in the spatial working memory condition. See Figure 3 for positive endorsement ratings of pictures.

Regression for endorsement task. The same regression to predict endorsement of words was performed as in Experiment 1. The effect was significant, $F(4, 48) = 6.13$, $p < .01$. There were two significant predictors, Working Memory Condition, $p = .02$, which was predicted, and Task Difficulty, $p < .01$. See Table 3 for regression statistics.

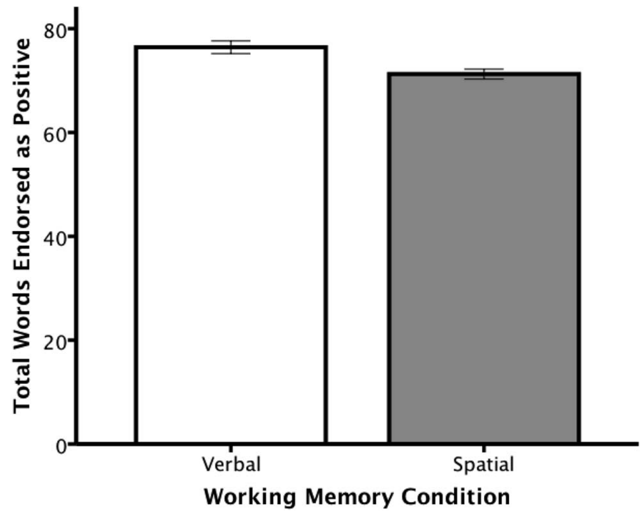

Figure 3. Total number of emotional and neutral words endorsed as being Positive in Experiment 2. Error bars represent one standard error of the mean.

We next examined whether working memory condition moderates the effect of task difficulty in predicting endorsement of words as being positive. We sought to address whether individuals in the verbal condition endorsed more items as positive because they experienced less frustration. For the moderation analysis, we centered the means with *z* scores for the two factors of Condition and Task Difficulty, and then the *z* scores were multiplied together creating the moderation variable. The two main effects of Task, $p < .01$, and Difficulty, $p < .01$, were significant, and critically, the moderator was also significant, $p = .03$. The moderation analysis revealed that for those in the verbal working memory condition, as they experienced greater task difficulty, their endorsement of words as being positive increased, whereas no relationship between task difficulty and completion of the spatial working memory condition existed to predict positive endorsement of words. See Figure 4 for a scatterplot of the moderation effect.

Discussion

For both Experiments 1 and 2, we observed that participants who completed the verbal working memory tasks were more likely to endorse items as positive. This bias to endorse items as positive was true irrespective of the initial affective value (positive, negative, neutral) of the stimuli. Moreover, participants in the verbal condition were more likely to perceive the overall affective tone of the words as more positive than those in the spatial condition. In addition, the working memory conditions influenced affective experiences, such that individuals in the spatial conditions reported feeling more negative compared to those in the verbal conditions. Finally, working memory task performance failed to influence endorsement ratings; however, as the task became more difficult for people in the verbal working memory condition, they were more likely to endorse words as being more positive.

Experiment 3 – Word Pair Selection Task

In the first two experiments, participants were explicitly asked to evaluate emotional pictures and words, and the evaluations were

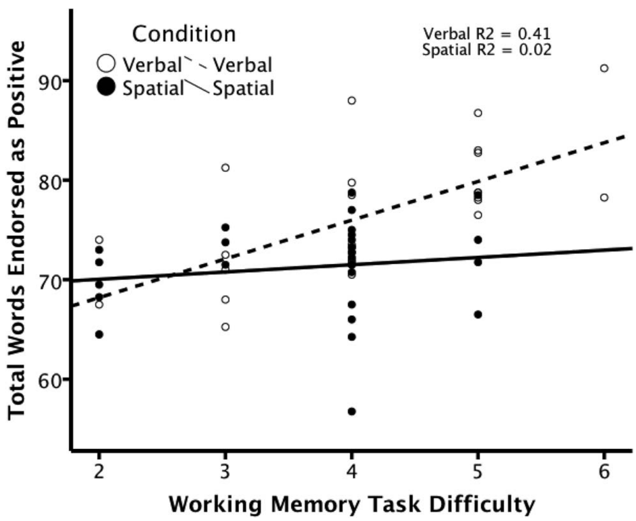

Figure 4. Moderation effect of Working Memory Condition and Task Difficulty from the Word Endorsement Task, Experiment 2.

influenced by the activation of a verbal or spatial working memory processes. The explicit task demand to evaluate the stimuli may have drawn attention to affective features. In the current study, we investigated whether similar effects could be observed without an explicit demand to evaluate stimuli. To examine the generality of this phenomena, the demand to evaluate was replaced with the instructions to select the word pair from two pairs of words that "went together best" (adopted from Rogers & Revelle, 1998). The selected word pairs were equated on associative strength, but varied with respect to affect. The word pairs were pleasant (e.g., candy/chocolate), neutral (e.g., lamp/shade), or unpleasant (e.g., fear/fright). Sutton and Davidson (2000) found that individuals high on appetitive motivation (i.e., relatively greater left frontal activity measured with EEG) selected the more positive word pair more often than individuals high on aversive motivation (i.e., relatively greater right frontal activity). We predicted that individuals completing the verbal, compared with the spatial, working memory task would exhibit a positivity bias (selecting the more positive word pair from the two words pairs presented). Moreover, we predicted that individuals in the verbal, compared with spatial, condition would have overall greater feelings of positive affect after completing the word selection task.

Method

Participants. Fifty-four (37 females) individuals from Queens College participated for course credit (M_{age} = 22.67, SD = 7.63), and they all provided written and informed consent.

Word pair selection task. The word pair selection task was adopted from Sutton and Davidson (2000; see Appendix A of Sutton and Davidson for the complete word pair lists). There were three categories: Pleasant, Neutral, and Unpleasant. Each category contained 48 word pairs. The two sets of word pairs presented on each trial were matched on associative strength (e.g., art/beauty was always presented with accordion/instrument; Rogers & Revelle, 1998). Six affective pairings (pleasant–unpleasant, pleasant–neutral, unpleasant–neutral, unpleasant–pleasant, neutral–pleasant, neutral–unpleasant) were created with the first category being presented on the left side of the monitor and the second category being presented on the right side of the monitor. Therefore, affective category pairings were equated in presentation location (i.e., left vs. right) to prevent hemisphere biases related to affective content.

Post-task mood check. The mood check consisted of a single question "Please describe how you felt after completing the working memory task," repeated three times with different sets of anchors. The three sets of anchors were (a) bad/good, (b) sad/happy, and (c) unpleasant/pleasant. The first item was associated with the value of 1 and the second item with a value of 6. The questions were averaged together to create an overall Mood score.

Task difficulty – Working memory task. The same scale was used as in Experiment 1.

Procedure. The procedures were similar to Experiment 1, with the following two exceptions. First, an affective tone measure, assessing the overall affective value of the stimuli, was not included in this experiment. Second, the endorsement task was replaced with the word pair selection task. Participants were asked to select the word pair that they "thought went best together." Participants pressed the 'Z' key to select the word pair presented on the left, and they pressed the '/' key to select the word pair presented on the right. The words were capitalized, and the first word of the pair was presented above the second word. The order of presentation for the two pairs of word pairs was randomly presented.

Results

Working memory accuracy. The verbal and spatial working memory tasks elicited similar levels of accuracy, $t(52) = 0.53$, $p = .60$.

Task difficulty – Working memory task. Participants in the verbal and spatial working memory conditions reported similar difficulty ratings on the working memory task, $t(52) = 0.62$, $p = .54$.

Post-task mood check. A univariate ANCOVA was run to assess changes in the Mood score by working memory conditions with task difficulty and working memory accuracy serving as the covariates. The effect was found to be marginally significant, $F(1, 50) = 3.52$, $p = .06$, $\eta^2 = 0.07$. Individuals in the verbal condition reported a more overall positive Mood score compared to the spatial condition. The effects for task difficulty and working memory accuracy were both nonsignificant, $F < 1$.

Word-pair selection task. In our analysis using the entire set of word pairs (Rogers & Revelle, 1998), we found a stronger positivity bias for participants in the verbal working memory condition when compared to those in the spatial condition, $t(52) = 3.11$, $p < .01$. Sutton and Davidson (2000) eliminated trials in which they observed no affective differences between the two pairs of word pairs. Following their procedure, we found the same positivity bias for participants in the verbal, compared with the spatial, working memory condition, $t(52) = 3.13$, $p < .01$. See Figure 5 for a graphical representation of the mean difference for the positivity bias.

Regression for selection task. We conducted a similar regression analysis as in Experiment 1, except that the predicted variable was Positivity Bias, and the postmood check was substituted for

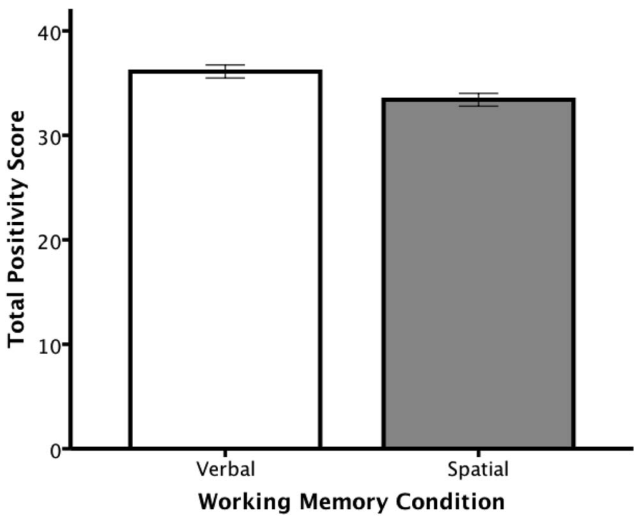

Figure 5. Total number of the more positive word pair selected in Experiment 3. Bars represent 1 *SE* of the mean.

the average Mood score. The regression analyses was found to be marginally significant, $F(4, 53) = 2.39$, $p = .06$. As predicted, the only significant predictor was Condition, $p < .01$, all other factors were not significant. See Table 3 for regression statistics.

Discussion

Working memory task type appeared to moderate the selection of word pairs, even when an explicit goal to evaluate the stimuli was not present. Participants in the verbal working memory condition were more drawn to the positive oriented word pair than those in the spatial condition. These findings suggest that affective biases persist on a nonevaluative task. As for the working memory task's influence on affective mood states, we observed tentative evidence that people in the verbal, compared to the spatial, condition rated themselves more positively following the word selection task.

Experiment 4 – Attentional Dot Probe Task

Thus far, we observed that working memory task demands influenced the endorsement and selection of affective stimuli in both evaluative and nonevaluative tasks. However, it remains unclear whether engaging in a verbal or a spatial working memory task creates a bias to attend to positive or negative stimuli, and whether that bias results in a more pronounced attentional engagement. In the following experiment, a dot-probe attentional task was used to examine whether verbal and spatial working memory processes influence attention to (orienting) affective stimuli and the attentional engagement of affective stimuli. Moreover, the dot-probe attentional task included neutral stimuli for us to assess attentional biases to positive and negative stimuli compared to a neutral baseline (Cooper & Langton, 2006; Lipp, 2006; Salemink, van den Hout, & Kindt, 2007). Thus, there were three trial types: (a) neutral–neutral, (b) congruent, and (c) incongruent. An orienting index was created by comparing RTs on congruent trials (the affective picture was in the same location as the dot(s)) to neutral-neutral trials. An engagement index was created by comparing reactions times on incongruent trials (the dot(s) was in the opposite location as the affective picture) to neutral-neutral trials.

We predicted that participants who completed the verbal working memory task would take longer to disengage from positive stimuli, whereas those participants who completed the spatial working memory task would take longer to disengage from negative stimuli. Moreover, we predicted that those in the verbal conditions would have higher levels of positive affect or lower levels of negative affect following the attentional task compared with participants in the spatial conditions. Contrary to our prior predictions, we predicted that there would be no differences in the affective tone of the presented pictures, simply because of the large number of neutral stimuli compared to positive and negative stimuli.

Method

Participants. Forty-three (25 female) individuals from Queens College participated for course credit ($M_{age} = 22.26$, $SD = 8.34$), and they all provided written and informed consent.

Materials. The working memory task, task difficulty question, affective tone question, and the mood check were the same as in Experiment 1.

Picture stimuli. The picture stimuli were the same as in Experiment 1; however, 45 additional neutral images were included bringing the total number of neutral images to 60. These images were included to prevent multiple repetitions of the neutral stimuli during the dot probe attentional task. The addition of the neutral pictures did not change the significance of the analyses reported in Experiment 1 for valence and arousal ratings.

Dot probe task. The main goal of the participant was to determine whether one or two dots were presented, and to do this as quickly as possible (Salemink et al., 2007). Each trial started with a fixation (+) presented for 500 ms followed by the simultaneous display of two pictures centered vertically, with one picture on the left, and the other picture on the right. Pictures remained on the screen for 500 ms. Pictures were removed, and either one dot or two dots appeared on either the left side or the right side of the screen in the same location as the left or right picture. The dot(s) remained on the screen until a response indicating the number of dots was recorded. There were three trial types: a positive picture with a neutral picture, a negative picture with a neutral picture, or two neutral pictures. Thus, in addition to the trials with two neutral pictures, this design created *congruent* trials, in which the dot(s) appear in the location of the affective picture (as opposed to the neutral picture), and *incongruent* trials, in which the dot(s) appear in the location of the neutral picture (as opposed to the affective picture). The location of the pictures (left or right), the number of dots (one or two), and the location of the dot(s) (left or right) were all randomized. Reaction time was the primary dependent measure.

Procedure. The procedure was the same as in Experiment 1, except that the dot probe task replaced the evaluation task. For the dot probe task, instructions were provided and then participants completed 10 practice trials followed by two experimental blocks. The 'E' key was pressed for one dot and the 'I' key was pressed for two dots. Responses were counterbalanced across participants. Each block consisted of 75 trials (150 total trials), 30 trials with positive/neutral pictures, 30 trials with negative/neutral pictures, and 15 trials with neutral/neutral pictures. Pictures were randomly presented, but for positive and negative pictures each picture was presented only once within a block. As for the neutral pictures, random selection without replacement (across the blocks) was used to minimize repetition of neutral pictures.

Results

Working memory accuracy. No difference in working memory performance was observed between participants in the verbal and spatial conditions, $t(41) = 1.43$, $p = .16$. See Table 2 for mean all the descriptive statistics for this experiment.

Task difficulty. There were no differences in self-reported task difficulty between the verbal and spatial working memory conditions, $t(41) = -0.24$, $p = .81$.

Affective tone. There were no differences in overall affective tone for the pictures between participants in the verbal and spatial working memory conditions, $t(41) = 0.45$, $p = .66$.

Post-task mood check. The same set of ANCOVAs (IV: verbal, spatial; Covariates: task difficulty and working memory performance) was run as in Experiment 1 to examine changes in mood due to the verbal and spatial working memory conditions. The only factor that reached a level of significance was Negative Low Activation, $F(1, 39) = 4.75$, $p = .03$, $\eta^2 = 0.11$, such that those in the spatial condition reported higher levels of negative low activation compared to participants in the verbal condition. The other mood check factors did not differ between the working memory conditions, Positive Activation, $F(1, 39) = 1.22$, $p = .28$, $\eta^2 = 0.03$, Positive Low Activation, $F < 1$, and Negative Activation, $F(1, 39) = 1.86$, $p = .18$, $\eta^2 = 0.05$. For the task difficulty covariate, all effects were nonsignificant, Fs < 1. As for the working memory performance covariate, there was a marginal effect for Positive Low Activation, $F(1, 39) = 3.46$, $p = .07$, $\eta^2 = 0.08$, all other effects were nonsignificant; Positive Activation, $F(1, 39) = 1.42$, $p = .28$, $\eta^2 = 0.04$; Negative Activation, $F < 1$; and Negative Low Activation, $F(1, 39) = 2.27$, $p = .14$, $\eta^2 = 0.06$.

Dot probe task reaction times. Before the analysis, we removed error trials and reaction time (RT) latencies over 2.5 SDs were replaced with the cutoff values (Robinson, Storbeck, Meier, & Kirkeby, 2004; Salemink et al., 2007). To examine whether the type of working memory task influenced RTs to emotional stimuli we conducted a 2 × 2 (Affect [positive, negative] × Congruency [congruent, incongruent]) repeated measures ANOVA with Task Type (verbal, spatial) as a fixed factor. The main effect for Affect, $F = 1$, and for Congruency, $F < 1$, were both nonsignificant, and the between subjects main effect of Task Type was nonsignificant, $F < 1$. The Affect by Task Type interaction and the Affect by Congruency were both nonsignificant, $F < 1$. The Congruency by Task Type interaction was significant, $F(1, 41) = 4.43$, $p = .04$, $\eta^2 = 0.10$, such that participants in the spatial condition had a faster RT on congruent trials than on incongruent trials, $t(22) = -1.76$, $p = .09$, whereas participants in the verbal task had similar RTs on both congruent and incongruent trials, $t(20) = 1.26$, $p = .22$.

Critically, the Affect by Congruency by Task Type interaction was also significant, $F(1, 41) = 12.25$, $p < .01$, $\eta^2 = 0.23$. The three-way interaction was broken down by Task, and separate 2 (Affect; positive, negative) × 2 (Congruency; congruent, incongruent) repeated measures ANOVAs were conducted for each working memory condition. For participants who completed the verbal working memory task, a significant Affect by Congruency interaction was observed, $F(1, 20) = 9.32$, $p < .01$, $\eta^2 = 0.32$, such that participants were faster responding on positive congruent trials (dot(s) appearing in the same location as a *positively* valenced picture) than on negative congruent trials, $t(20) = 2.06$, $p = .05$. They also responded faster on negative incongruent trials than on positive incongruent trials, $t(20) = -1.91$, $p = .07$. Both the Affect, $F < 1$, and the Congruency, $F(1, 20) = 1.58$, $p = .22$, $\eta^2 = 0.073$, main effects were nonsignificant. A significant Affect by Congruency interaction was also observed with participants completing the spatial working memory task, $F(1, 21) = 4.17$, $p = .05$, $\eta^2 = 0.17$. Participants responded faster on positive incongruent trials than on negative incongruent trials, $t(21) = 2.82$, $p = .01$. The main effect for Congruency showed a trending but nonsignificant effect, $F(1, 21) = 3.08$, $p = .09$, $\eta^2 = 0.13$. The main effect of Affect was nonsignificant, $F(1, 21) = 1.58$, $p = .22$, $\eta^2 = 0.07$. See Figure 6 for mean RTs by Affect for Congruent and Incongruent trials.

Following the procedures of Salemink et al. (2007), we created an attentional orienting index and an attentional disengagement index. The orienting index provides a measure of initial attentional direction by subtracting RTs on congruent trials from RTs on trials presenting two neutral pictures. Thus, a positive result on the orienting index indicates faster responding to dot(s) appearing at the same location of affective stimuli than to dot(s) appearing in the location of neutral stimuli. The disengaging index provides a measure of attentional engagement to affective stimuli and the quickness in which attention can be disengaged from the affective stimulus and redirected attention elsewhere. The disengaging index was computed by subtracting RTs on trials presenting two neutral pictures from the reactions times on incongruent trials (trials in which neutral and affective stimuli are presented and

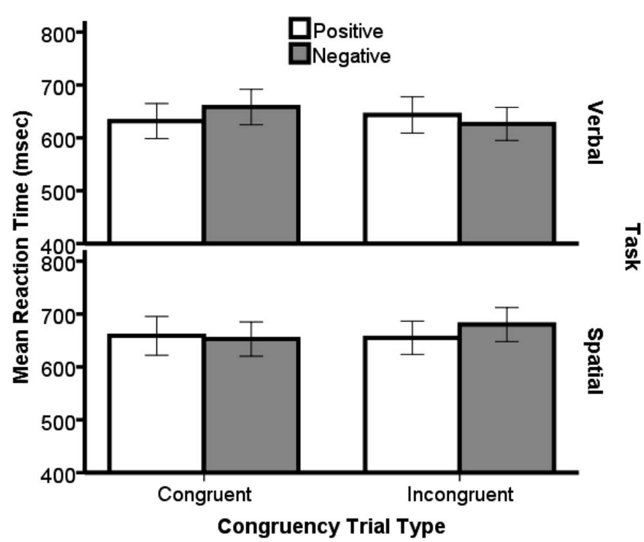

Figure 6. Mean RT (ms) for the Verbal (top panel) and Spatial (bottom panel) working memory tasks for Congruent and Incongruent trials as a function of the affect of the picture (Experiment 4).

dot(s) are in the location of the neutral stimulus). A positive score on the disengaging index results from slower responding to dot(s) appearing in the location of a neutral stimulus in the presence of an affective picture than to responding to a neutral stimulus, and suggests a process of initial attentional capture by the affective picture, disengagement, and reorientation of attention to the location of the target dot(s).

We calculated separate orienting and disengaging indices for negative picture trials and for positive picture trials, and examined whether the attentional indices were different from zero. As predicted, participants who completed the verbal working memory task took longer to disengage from positive pictures, $t(20) = 2.33$, $p = .03$. In addition, those participants also avoided orienting to negative pictures, $t(20) = -3.20$, $p < .01$. No effects were observed for disengaging from negative pictures, $t(20) = 0.37$, $p = .72$, or for orienting to positive pictures, $t(20) = -1.13$, $p = .27$. As for those completing the spatial working memory task, as predicted, participants took longer to disengage from the negative pictures, $t(21) = 3.31$, $p < .01$. No other index achieved a score significantly different from zero; orienting to negative, $t(21) = 0.77$, $p = .45$, orienting to positive, $t(21) = -0.35$, $p = .73$, and disengaging from positive stimuli, $t(21) = -0.17$, $p = .87$. See Figure 7 for a graphical representation of the orienting and disengagement indices.

Discussion

Verbal and spatial working memory tasks influenced responding to positive and negative stimuli in the dot probe task. Participants in the verbal condition responded faster on trials in which the dot(s) followed a positive image and slower on trials wherein the dot(s) followed a negative image. On the other hand, participants in the spatial condition responded faster on trials in which the dot(s) followed a negative image and slower on trials wherein the dot(s) followed a positive image. When these RT differences were used to create orienting and disengaging indices, we observed that those in the verbal condition took longer to disengage from positive pictures, whereas those in the spatial condition took longer to disengage from negative pictures. Moreover, the participants in the verbal condition had a greater tendency to avoid negative images. Given that the index used to create orienting and disengagement scores compared response times of positive and negative trials to neutral trials, we can confidently suggest that the participants in the verbal condition attended more to positive stimuli, whereas those in the spatial condition attended more to negative stimuli. Moreover, consistent with the previous experiments, the spatial condition participants reported higher levels of negative affect compared to the verbal condition participants. Finally, we failed to find differences between the working memory conditions for rating the overall affective tone of the stimuli, working memory accuracy, and task difficulty ratings.

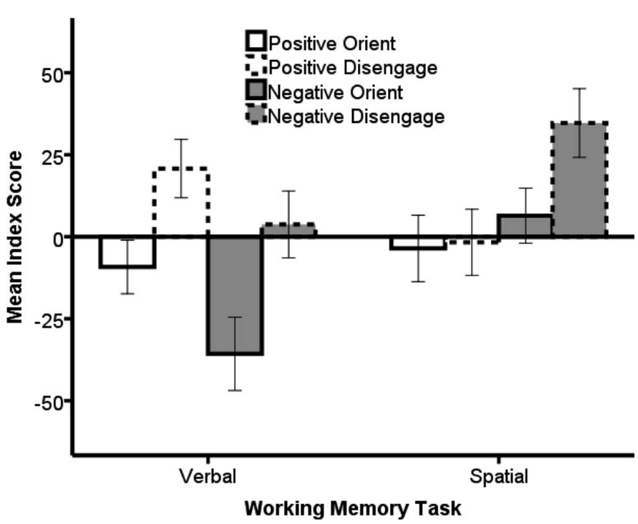

Figure 7. Mean scores for the Orienting and Disengaging indices resulting from the dot probe task in Experiment 4. Scores in the positive range signify stronger orientation to and slower disengagement from the affective stimuli. Error bars represent one standard error of the mean.

General Discussion

To review, we observed that completing a verbal working memory task led to more positive evaluations of stimuli, whereas completing a spatial working memory task led to more negative evaluations of stimuli. The same tendencies were observed when participants rated the overall affective tone of the stimuli in Experiments 1 and 2, where those in the verbal condition rated the overall tone as more positive than those in the spatial condition. In Experiment 3, which assessed nonevaluative, as opposed to evaluative, judgments, participants who completed the verbal working memory task selected more positive word-pairs than those who completed the spatial task. In addition, for the first three experiments, regression analyses provided evidence that the working memory task predicted the endorsement of items better than working memory performance or task difficulty, suggesting that our findings were not a result of changes in self-esteem or frustration.

The last study examined attentional biases to positive and negative stimuli, and we observed that the completion of a verbal task biased attention toward positive images, whereas the completion of a spatial task biased attention toward negative images. In addition, we observed a similar pattern of findings with respect to RTs. Engagement in the verbal condition elicited faster responding on trials in which the dot followed positive images and slower responding on trials in which the dot followed negative images. The spatial condition elicited faster responding on trials in which the dot followed negative images and slower responding on trials in which the dot followed positive images.

When we examined self-reported mood states across all experiments, there was consistent evidence that people who completed the verbal working memory task experienced less negative affect than those individuals who completed the spatial working memory task. Moreover, the mood scores were adjusted to account for self-reported task difficulty (frustration) and working memory performance. These findings suggest that mood may have changed as a result of the working memory task type. However, because of the lack of a control condition and a baseline measurement of mood, we cannot determine whether verbal working memory conditions reduced negative affect or whether spatial working memory conditions increased negative affect.

Overall, the activation of specific working memory domains (verbal and spatial) biased evaluations and attention and influenced participants' mood states. When combined with the findings from previous research that positive affect enhances verbal working memory and negative affect enhances spatial working memory (e.g., Gray, 2004; Storbeck, 2012), we suggest that there may be reciprocal associations between emotion and working memory domains. Specifically, positive affect and verbal working memory may reciprocally activate one another, whereas negative affect and spatial working memory may reciprocally activate one another. Prior research has suggested that such reciprocal relations between emotion and cognition may exist. For instance, Bar (2009) observed that engaging in broad semantic processing leads to increases in positive affect, whereas others have observed that positive affect broadens semantic processing (e.g., Fredrickson, 2001; Isen, 1999). These findings are also consistent with Simon's (1967) theory that the consistent activation of both an emotional state and a cognitive process can result in a coupling (integration) that is similar to Hebb's (1949) description of the formation of memory at the neuronal level: "neurons that fire together wire together."

Emotion and Cognitive Control Integration

This research raises several questions about how working memory can influence evaluations, attention, and mood. Several theories suggest that when cognitive control processes are invoked during the processing of emotional stimuli, one of two things occur: (a) competition or (b) a flattening of the affective response to emotional stimuli. For instance, Pessoa (2009) argued that stimuli with low affective salience do not interfere or compete for limited executive control resources. However, stimuli with high affective salience, particularly when negatively valenced, compete for limited executive control resources, which results in a reduction of behavioral control. Other research (e.g., Van Dillen & Koole, 2009) has shown that the level of engagement with task factors during a cognitive control task can attenuate responding to emotional stimuli. That is, when emotional stimuli are presented as nonrelevant task factors (e.g., distractors), affective responses occur under low load task conditions but are reduced under high load task conditions (Erthal et al., 2005; Öhman, Flykt, & Esteves, 2001; Pessoa et al., 2002; Van Dillen & Koole, 2009).

In the current study, however, we removed the simultaneous dual-processing of cognitive task factors and emotional factors. Rather, we explored whether the activation of a domain-specific working memory mind-set facilitates the processing of affective stimuli and changes in mood. We propose that the activation of specific working memory domains resulted in the priming/activation of other processes that are either functionally related or anatomically proximal. These two possibilities may be independent processes or interdependent. For functional connectedness, we propose that integration stems from reciprocal connections that develop through mutual activation as part of a larger behavioral goal. Another possibility is that integration stems from associations attributable to anatomical or structural closeness, which may imply a biological basis.

With respect to the first possibility, integration may stem from a functional relationship caused by a goal or goals that include subcomponents associated with affect, motivation, and cognitive processes. A goal related to social interaction would result in activation of cognitive processes (e.g., verbal working memory, semantic activation) necessary for behavior and a motivational component to approach others and a desire to feel positive as social interactions are inherently rewarding (Ashby & Isen, 1999; Beckes & Coan, 2011; Fredrickson, 2001). Moreover, we believe that positive affect would also reinforce the social interaction goal by further activating related cognitive subcomponents. For instance, positive affect increases semantic associations (e.g., Bolte et al., 2003; Storbeck & Clore, 2007), episodic retrieval (Ashby & Isen, 1999), verbal working memory (e.g., Gray, 2001; Gray et al., 2002), set-shifting (e.g., Dreisbach & Goschke, 2004), and cognitive flexibility (e.g., Isen, Daubman, & Nowicki, 1987; Isen, 1999). Over time, with similar affective and cognitive components being consistently activated by a goal related to social interaction may develop into a functional relationship between positive affect and verbal working memory (we note other associations may develop as well). Thus, a reciprocal, functional relationship between positive affect and verbal working memory would reduce goal competition (Gray et al., 2002; Gray, 2004; Storbeck, 2012) during social interactions resulting in successful social interactions, reduced metabolic expenditure (Storbeck, 2012), and increased well-being (Beckes & Coan, 2011).

We believe the same process would be true for negative affect and threat or error detection. The goal to detect threats and errors would result in activation of cognitive processes (e.g., spatial working memory, attentional control, inhibition) necessary for behavior and a motivational component to withdraw and increased negative affect to reinforce behavior (e.g., Eysenck et al., 2007; MacLeod & Rutherford, 1992; Schwarz, 2006). Likewise, a negative state may motivate a goal to detect external threats and internal problems or cognitive errors (e.g., Clore et al., 2001; Mather & Sutherland, 2011; Schwarz, 2006). Interestingly, negative affect, facilitates the processing of threatening stimuli (Bocanegra & Zeelenberg, 2009; Phelps et al., 2006; Vuilleumier, 2005; Vuilleumier, Armony, Driver, & Dolan, 2003) and promotes processing in a systematic, bottom-up style (e.g., Phelps et al., 2006; Schwarz, 2006). As described above for positive affect and verbal working memory, we would anticipate the same reciprocal, functional relationship between negative affect and spatial working memory reducing goal competition (Gray, 2004; Storbeck, 2012), increasing the ability to detect errors/problems, and the resolution of such issues would increase psychological well-being. Unfortunately, affective disorders may arise if such goals are prevalent and persist for long durations.

Another possibility is that either verbal or spatial working memory indirectly influences changes in mood or motivation-orientation due to biological and anatomical associations. Often, the engagement of verbal working memory has been associated with an increase in dopamine in the PFC (Fried et al., 2001; Goldman-Rakic, 1997; Pochon et al., 2002; Williams & Goldman-Rakic, 1995). On the other hand, dopamine is not directly related to the holding and manipulation of spatial relations, whereas there is tentative evidence to suggest that noradrenaline may play a role (e.g., Mehta, Manes, Magnolfi, Sahakian, & Robbins, 2004; Rossetti & Carboni, 2005). Moreover, dopamine is related to motivation and reward and noradrenaline with anxiety (Lieberman & Rosenthal, 2001), and changes in dopamine and noradrenaline levels caused by task demands may have implications for changes in mood and motivation (e.g., Lieberman & Rosenthal, 2001; Pochon et al., 2002). As for motivation and affect, research using EEG often finds greater activity in the left PFC corresponding with increased positive affect or approach motivations (e.g., Ashby & Isen, 1999; Coan & Allen, 2004; Coan et al., 2001;

Harmon-Jones & Allen, 1997). Moreover, state (positive affect) and trait (behavioral activation systems—BAS) motivations result in better and more efficiently verbal working memory performance (Gray et al., 2002; Gray et al., 2005; Storbeck, 2012), suggesting a possible biological relationship among positive affect, motivation, and verbal working memory. Thus, verbal working memory, dopamine, approach motivations, and BAS are all associated with the left PFC, though the relationship is yet to be clearly defined, and these associations may have a basis in biology and may be mediated by similar neurotransmitters (e.g., dopamine, noradrenaline) or through anatomical/structural closeness (e.g., Friston, 2010).

Finally, these two possibilities may be interdependent and serve dual mechanisms for emotion and cognition working together in achieving a larger behavioral goal (Friston, 2010). For instance, a goal to make new friends at a party would result in positive affect and the activation of language related areas of the brain. Positive affect may influence and be influenced by verbal working memory through functional and/or anatomical/structural closeness (left PFC). Likewise, positive affect may influence activation within the semantic network (Bolte et al., 2003; Corson, 2002; Storbeck & Clore, 2005; Storbeck & Clore, 2008) and be influenced by activation of the semantic network (Bar, 2009), which would represent a functional relationship that too would benefit social interactions. According to Friston (2010), structural and functional connections serve to reduce the expenditure of metabolic resources. Therefore, structural and functional connections may work together to reinforce social interconnectedness by reducing mental effort and enhancing the quality and reward value of the interaction.

Limitations and Future Directions

In the current experiments, we observed changes in affective states, however our sampling method was limited. Assessing the affective states after the endorsement or dot probe tasks may have decreased their reliability. The assessment of mood in this manner could have reduced potential correlations between induced affective changes from the working memory task and the observed endorsement and attentional effects. We assessed mood after the endorsement task because we were concerned that drawing attention to changes in emotion would result in attribution effects (Schwarz & Clore, 1983; Gasper & Clore, 2000). EEG frontal asymmetries may be the best way to examine whether changes in affective states are predictive of endorsement and attentional effects (Coan & Allen, 2004; Steiner & Coan, 2011).

As mentioned above, the prefrontal asymmetries for emotion and working memory (Gray, 2001) were theoretically important for the predictions made. This approach defines emotions as motivational orientations, rather than differences in valence. However, the stimuli we used were selected based on valence and arousal dimensions, rather than approach and withdrawal dimensions. Although valence often maps onto approach (positive) and withdrawal (negative) dimensions, it does not always map in a one-to-one correspondence (e.g., anger is negative, but often elicits approach). Therefore, questions remain as to whether the bias effects we observed were toward positive and negative stimuli or approach- and withdrawal-motivating stimuli. For instance, viewing the picture of a baby is both positive and approach-oriented; therefore, participants who completed the verbal working memory task may have been biased toward the baby because they were in a good mood or because the baby picture invoked an approach-orientation. Further research would need to examine such effects by selecting stimuli based on motivational orientations.

Conclusions

Emotions can serve to prioritize the cognitive agenda (Simon, 1967). We demonstrated that the cognitive agenda can serve to bias affective processes, suggesting reciprocal interactions between working memory and emotion. The interconnectedness of specific emotion and specific cognitive processes may coexist to foster specific behaviors. Connections between approach-oriented positive affect and verbal processing may promote social behaviors and social support (Fredrickson, 2001). Conversely, connections between withdrawal-oriented negative affect and spatial processing may promote the identification of problems (Schwarz, 2006). In sum, just as emotions can tune the cognitive agenda, cognitive processes can tune affective processes, and these interactions may serve to reinforce emotion/cognition associated behaviors.

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