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Affective Working Memory: An Integrative Psychological Construct

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Abstract

When people ruminate about an unfortunate encounter with a loved one, savor a long-sought accomplishment, or hold in mind feelings from a marvelous or regretfully tragic moment, what mental processes orchestrate these psychological phenomena? Such experiences typify how affect interacts with working memory, which we posit can occur in three primary ways: Emotional experiences can modulate working memory, working memory can modulate emotional experiences, and feelings can be the mental representations maintained by working memory. We propose that this last mode constitutes distinct neuropsychological processes that support the integration of particular cognitive and affective processes: *affective working memory*. Accumulating behavioral and neural evidence suggests that affective working memory processes maintain feelings and are partially separable from their cognitive working memory counterparts. Affective working memory may be important for elucidating the contribution of affect to decision making, preserved emotional processes in later life, and mechanisms of psychological dysfunction in clinical disorders. We review basic behavioral, neuroscience, and clinical research that provides evidence for affective working memory; consider its theoretical implications; and evaluate its functional role within the psychological architecture. In sum, the perspective we advocate is that affective working memory is a fundamental mechanism of mind.

Keywords
working memory, emotion, affect, emotion regulation, emotional intelligence

In daily life feelings come and go, influencing people's thoughts, decisions, and actions in ways they may or may not recognize. Dynamic interactions between emotion and cognition manifest in numerous ways. For example, consider a person who is highly anxious about an upcoming speech and consequently finds herself unable to maintain mental focus on the content of the presentation. In this instance, the current emotional state impairs the ability to hold in mind and work with important information; that is, emotion can impair working memory abilities. In another example, consider someone working intently on an important project, carefully crafting how to pitch a new idea, when he notices a spider scurrying away across the wall. In this instance, the typical fear from seeing a spider is diminished and dissipates quickly. Here, mental focus and engaged working memory weaken an emotional reaction.

These examples capture the bidirectional ways that emotion and working memory can interact. However, there is a third possibility as well: One could focus on one's emotional reactions, actively hold those feelings in mind, and work with them in various ways. On seeing the spider, someone could focus directly on the fear it evokes, note the diminished intensity, and, in so doing, actively maintain this feeling in mind. This third possibility represents what we and others refer to as *affective working memory*, a specific type of working memory that maintains and works with feeling states (see, e.g., Barrett, Mesquita, Ochsner, & Gross, 2007; Davidson & Irwin, 1999; Mikels & Reuter-Lorenz, 2013; Mikels, Reuter-Lorenz, Beyer, & Fredrickson, 2008; R. Smith & Lane, 2015; cf. Baddeley, 2013). In other words, just as working memory serves to maintain and manipulate visual or verbal representations, it can similarly operate on emotional representations (i.e., feelings).

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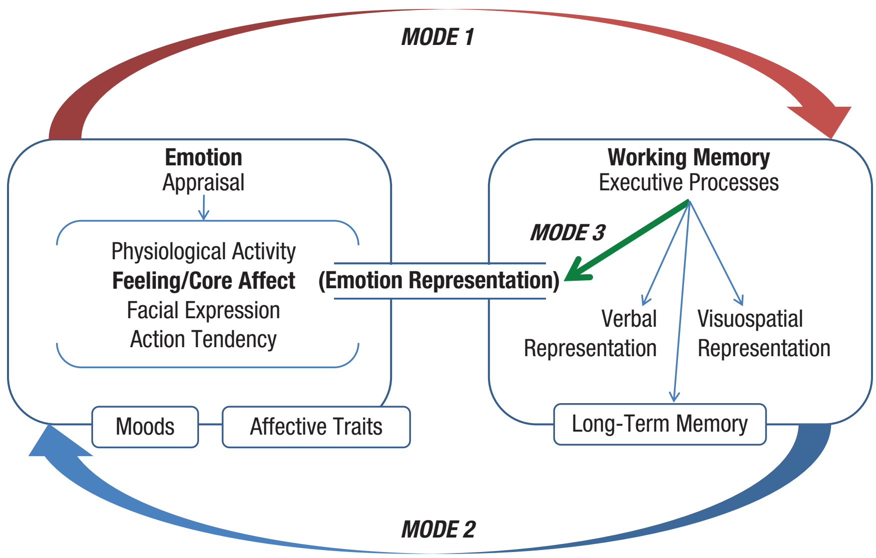

Fig. 1. Three modes of emotion and working memory interactions. Mode 1 represents the influence of affect on cognitive working memory, Mode 2 represents the influence of cognitive working memory on affect, and Mode 3 represents how emotional feelings can be mental representations in working memory (affective working memory).

Our goal here is to clarify and develop the construct of affective working memory in the context of emotion–working memory interactions more generally by characterizing the three modes by which working memory and emotion interact. These modes are depicted in Figure 1. In Mode 1, affect can influence the efficiency of ongoing cognitive working memory processes; in Mode 2, cognitive working memory can influence ongoing emotional experiences; and in Mode 3, emotional feelings themselves can be the mental representations maintained in working memory requiring specialized mechanisms that are distinct from verbal, visual, and other cognitive working memory processes. These three modes capture the broad and surging interest in how emotion and working memory interact. A PsychInfo search of "working memory" and "emotion" currently results in 1,507 publications. Of the articles published on this topic since about 1986, more than a third (approximately 680) have been published in the past few years (since 2014). This large body of work ranges from clinical science and social psychology to neuroscience.

Why Affective Working Memory?

Most of the literature on this topic to date treats working memory and affect as distinct and separate psychological systems that interact (Fig. 1, Modes 1 and 2). The distinguishing characteristic of Mode 3 is that emotional feelings are the mental representations held in working memory. That is, just as perceptual representations of stimuli from the environment (exteroceptive input) can be maintained in working memory, information about internal feeling states (interoceptive input) also can be actively maintained in the absence of the eliciting stimuli. The ability to maintain feeling states—apart from any verbal, semantic, or conceptual codes associated with emotions—is needed because the feelings themselves consist of valence, intensity, and hedonic qualities that are critical for guiding goal-directed thoughts and actions, as originally argued by Davidson and Irwin (1999).

As illustrated in Figure 1, affective working memory differs from Mode 1, which addresses how affect influences cognitive working memory processes, and from Mode 2, which entails cognitive working memory influences on emotion. Like verbal and visuospatial working memory, affective working memory is a domain-specific working memory subsystem with specialized processes for maintaining feelings and executive-control processes that likely overlap, in whole or in part, with other working memory subsystems. In the following sections, we review the three modes of emotion–working memory interaction. We then focus on empirical evidence from behavioral studies with younger and older adults as well as several brain-imaging studies that support the affective working memory construct. We go on to explain why affective working memory is relevant in translational domains, including decision making and psychiatric disorders. Finally, we consider the theoretical relevance and the potential role of affective working memory in emotion regulation, emotional intelligence, and wisdom and point to future directions in the study of affective working memory.

Conceptual and Definitional Clarity

We first ground our perspective by explaining its key constructs: emotion and working memory. Most theorists regard emotions to be particular types of affective processes (Ekman, 1994; Ellsworth & Smith, 1988; Fredrickson, 1998; Frijda, 1986; Gross, 1998; Lazarus, 1991; Levenson, 1994; Rosenberg, 1998; Scherer, 2000; C. A. Smith & Ellsworth, 1985). Emotions are generally considered to be adaptive responses to personally significant events. They differ from moods, which are relatively diffuse and often disconnected from a specific event or object, whereas emotions are acute reactions to specific events and objects. Emotions are differentiated from relatively enduring affective predispositions or traits (e.g., anxiety or depression). Affective traits can predispose a person to certain characteristic emotional responses (e.g., anxiety-prone individuals are more likely to experience fear than those that are not anxiety-prone) but are nonetheless fundamentally distinguishable from emotions per se.

Most contemporary emotion theorists agree with a general process model of emotion (e.g., Gross, 1998). This model posits that typically, when an emotion arises, appraisal of the relationship between the person and the environment triggers behavioral, physiological, and motivational changes (Ellsworth, 2013; Moors, Ellsworth, Scherer, & Frijda, 2013). Appraisal is the process of evaluating the circumstances for goal relevance, self versus other responsibility, certainty, etc. Emotional experiences differ widely because of the type and number of appraisals; a minimal number of appraisals results in coarse emotional experiences (e.g., fear or joy), whereas more complex and differentiated appraisals will produce nuanced emotional experiences (e.g., guilt or pride). Although the exact nature and composition of an emotional experience are widely debated, as depicted in the "Emotion" box of Figure 1, most theorists agree that upon appraisal, the unfolding emotional reaction at least consists of physiological reactivity, the subjective feeling of the affective state (most critical to the affective working memory construct), a facial expression, and an urge to act (i.e., an action tendency; Ekman, 1994; Fredrickson, 1998; Levenson, 1994; Rosenberg, 1998; C. A. Smith & Kirby, 2000). Although this *process model* provides a detailed account of how an emotional experience unfolds, it is relatively silent about the myriad ways that emotions interface with cognition beyond appraisal processes. In particular, the emotion-process model does not clearly specify how emotions interface with working memory.

Working memory is a form of short-term memory that is essential to goal-directed behavior. Working memory actively maintains and manipulates information held in mind for brief periods of time in the service of ongoing cognitive abilities such as reasoning, language comprehension, and problem solving (Baddeley, 1986). In contrast to long-term memory, working memory has capacity limits of about three to four items (e.g., Baddeley & Hitch, 1974; Cowan, 2001; Miller, 1956; Oberauer, Farrell, Jarrold, & Lewandowsky, 2016). The precise nature and measurement of working memory are areas of ongoing research and active debate (Cowan, 2017; Oberauer et al., 2018). The view we adopt here has been referred to as the *multicomponent view* (Cowan, 2017). This view follows largely from the work of Baddeley and Hitch (1974) and Baddeley (1986), which includes modality-specific storage, and executive processes. Early models proposed that information was held in separate stores (or buffers) on which a central executive operated (Baddeley, 1986; e.g., via rehearsal in an articulatory loop and via attention for the visuospatial sketchpad). However, rather than buffers, more recent varieties of the multicomponent view refer to the maintenance of "distributed" domain-specific representations that rely on the same brain regions that encode the perceptual stimulation but maintain the representations, even though the stimulus is no longer present (Christophel, Klink, Spitzer, Roelfsema, & Haynes, 2017; Lewis-Peacock, Drysdale, Oberauer, & Postle, 2012; Postle, 2015a, 2016). Figure 1 provides a general illustration of these in the box labeled "Working Memory."

Despite ongoing debates about the domain generality versus specificity of working memory processes and their relationship with long-term memory (e.g., Cowan, 2008; Engle, Kane, & Tuholski, 1999; Miyake & Shah, 1999; Oberauer et al., 2016), most behavioral and neuroscience evidence favors domain-specific representations, as depicted in Figure 1 (see, e.g., Baddeley, 1986; Fougnie, Zughni, Godwin, & Marois, 2015; Jonides et al., 2008). However, attentional processes (i.e., selection and inhibition) are widely considered to be core executive functions that facilitate maintenance and are likely domain-general (see. e.g., Cowan et al., 2011; Li, Christ, & Cowan, 2014), but this too is debated. Additional executive functions that operate on working memory representations include monitoring, updating, and task/set switching (for reviews, see D'Esposito et al., 1998; E. E. Smith & Jonides, 1999; for alternative views, see Cowan, 2008).

Although considerable empirical progress has been made in affective science and cognitive science by treating these key constructs separately, in daily life they are closely intertwined. In the following sections we endeavor to characterize three major types of interaction between emotion and working memory that have been the focus of empirical laboratory research, although we recognize that the real-time dynamics in daily life are far more nuanced such that multiple forms of interaction likely happen concurrently.

Three Modes of Emotion–Working Memory Interactions

We propose the three-mode framework to bring theoretical organization to the vast body of research on emotion–working memory interactions. Early in our thinking about these modes, we wrote a one-page entry in *Encyclopedia of the Mind*, in which we briefly sketched out this framework (Mikels & Reuter-Lorenz, 2013). The current article provides a broader and more developed treatment of these ideas.

Mode 1: affect can modulate working memory

This first mode of interaction seems intuitive because most people encounter it every day; the positive and negative emotions that people experience may influence how effectively they engage in ongoing cognitive tasks, especially those involving what they think about and hold in mind. Not surprisingly then, most research on working memory and affect falls under this mode of interaction. From our reading of the literature, we have discerned two important principles governing how affect can modulate working memory. First, the properties of affect (e.g., negative vs. positive affect; high vs. low arousal; trait vs. state affect) determine how it influences working memory performance.[1] Second, these properties have different influences on verbal versus nonverbal working memory and on working memory subprocesses (e.g., encoding, maintaining, retrieving, or managing information). The corpus of research addressing this mode suggests affect that is not relevant to the task being performed (i.e., task-irrelevant affect) can influence working memory performance. However, depending on the type of material being retained, the working memory subprocesses targeted, and the specific ways that affect is manifested (e.g., dispositional trait affect, induced affective states), the consequences will differ.

One primary approach to understanding how affect influences working memory focuses on individual differences, with the main finding being that trait-level negative affect impairs cognitive working memory. For instance, clinically depressed individuals demonstrate decreased visual and verbal working memory performance (Christopher & MacDonald, 2005), with extensive research implicating reductions in cognitive control as the basis for working memory impairments (for a review, see Gotlib & Joormann, 2010). Anxiety effects have also been found. For example, individuals with high levels of math anxiety can exhibit impaired verbal working memory (Ashcraft & Kirk, 2001; Elliman, Green, Rogers, & Finch, 1997). Likewise, in a study that included individuals diagnosed with social anxiety and other anxiety disorders, along with healthy controls, higher levels of anxiety symptoms were associated with poorer verbal working memory performance (Waechter et al., 2018). Indeed, a recent meta-analysis revealed a robust association between generally higher anxiety and lower working memory capacity, with larger effects for clinical than subclinical populations (Moran, 2016). Further, the strongest effects are evident in working memory tasks requiring attentional processes that exert cognitive control on different representations (e.g., verbal and visual). These results align with attentional-control theory, according to which anxiety disrupts the central executive components of working memory needed to prevent distraction from irrelevant information and control attention shifting between different tasks (Eysenck & Derakshan, 2011; Eysenck, Derakshan, Santos, & Calvo, 2007).

Thus, depression and anxiety can impair verbal and visuospatial working memory by interfering with cognitive attentional-control processes. Although research examining trait-positive affect is much more limited, interestingly, recent findings indicate that higher trait-positive affect is related to better visual working memory performance (Figueira et al., 2018). Overall then, it appears that the more intense and pervasive the negative affective disposition, the greater the detrimental impact on working memory, especially on tasks that tap its executive components.

Beyond clinical and dispositional influences, another approach common to Mode 1 is to induce positive and negative affective states and examine the effects on verbal and nonverbal working memory performance. For example, Shackman et al. (2006) found that induced anxiety disrupts spatial working memory (see also Figueira et al., 2017), whereas Gray (2001) found that induced anxiety improved spatial working memory but impaired verbal working memory (see also Darke, 1988; Ikeda, Iwanaga, & Seiwa, 1996). Conversely, induced positive affect has also been found to impair spatial working memory while improving verbal working memory (Gray, 2001; see also Carpenter, Peters, Västfjäll, & Isen, 2013; Yang, Yang, & Isen, 2013). The finding that positive and negative affective states exert opposite effects on verbal versus nonverbal working memory performance was subsequently replicated (Gray, Braver, & Raichle, 2002) and found to correspond closely with varying levels of brain activity in lateral prefrontal brain regions known to be involved in cognitive working memory, suggesting a neural signal of emotion-cognition interactions. Nevertheless, the evidence that positive and negative affect have differential and opposing effects on verbal and spatial or nonverbal working memory is mixed. For example, Storbeck and Maswood (2016) found that positive affect improved both verbal and spatial working memory, whereas other studies report that positive affect impairs verbal working memory (Allen, Schaefer, & Falcon, 2014; Martin & Kerns, 2011).

In sum, the effects of induced affective states on working memory performance are clearly mixed, with results that vary as a function of the valence of the emotion, the type of material being held in memory, and likely the processing demands of the task. Inconsistencies among the outcomes may be due in part to the affect-induction methods that are used and the extent to which the working memory measures engaged executive processes. Future research aimed at replicating valence and material-dependent effects that generalize across induction procedures would be especially valuable to clarify this mode of emotion–working memory interaction.

Affective influences can also arise from the emotional properties of task-relevant verbal and nonverbal stimuli (e.g., emotional words, pictures, or faces presented as to-be-remembered items) that could then have an impact on working memory for those materials because of the emotions they arouse. Using affectively charged stimuli to investigate emotional influences on working memory can be problematic, however, because typically the emotional state of the rememberer is not assessed or analyzed, which may contribute to differing outcomes associated with this approach. For instance, one study found that high-arousal negative images impaired spatial working memory for their locations relative to lower-arousal images (Mather et al., 2006).

Likewise, two related studies examined emotional distraction in working memory and found that highly arousing negative emotional distractors disrupted visual working memory disproportionately relative to neutral distractors (Dolcos, Kragel, Wang, & McCarthy, 2006; Dolcos & McCarthy, 2006; see also Hur, Iordan, Dolcos, & Berenbaum, 2017) and more so than positive emotional distractors (García-Pacios, Del Río, Villalobos, Ruiz-Vargas, & Maestú, 2015; Iordan & Dolcos, 2017). An extensive review of emotional distraction in working memory from behavioral and neural studies draws similar conclusions (see Iordan, Dolcos, & Dolcos, 2013). More recently, Hur et al. (2017) examined how performance on a working memory task might differ when a two-back task requires matching the hues of emotional pictures (i.e., blue or yellow) versus matching their valence (i.e., negative or neutral). Most relevant to the present discussion, they observed that the color *N*-back task was performed more slowly when the images were negative than when they were neutral, suggesting a disruptive effect of negative affect. Thus, this set of studies suggests that negative emotional material may impair working memory—consistent with the effects of dispositional affect.

In contrast, Jackson, Chia-Yun, Linden, and Raymond (2009) found—consistent with the findings of Gray (2001)—that negative stimuli (specifically angry faces) enhanced visual working memory performance relative to happy and neutral faces (for similar effects with words, see Gotoh, Kikuchi, & Olofsson, 2010). Moreover, this enhancement was found for encoding and maintenance processes in working memory but not for retrieval (Jackson, Linden, & Raymond, 2014). Likewise, evidence indicates that positive and negative emotional words and images facilitate certain working memory executive processes (namely the resolution of interference from previous material; Levens & Phelps, 2008). Nevertheless, modulatory effects of emotional stimuli on working memory performance are not consistently observed (e.g., Fairfield, Mammarella, Di Domenico, & Palumbo, 2015; Kensinger & Corkin, 2003; Truong & Yang, 2014). Moreover, Gooding and Tallent (2003) found that working memory performance for emotional expressions and facial identities is highly correlated, suggesting that maintenance of emotional and nonemotional information relies on the same cognitive working memory system.

Despite these inconsistencies in the corpus of research categorized as Mode 1, the following conclusions can be offered about how affect modulates working memory performance. First, potential impact on working memory depends crucially on whether the affective influence arises from dispositional or induced affective states relative to emotional stimuli. Although the underlying mechanism may be the same, namely the subjective feeling state of the rememberer, dispositional negative affect appears to have more reliable and consistent effects on working memory performance than induced affective states or emotional stimuli (such as images of facial expressions and emotional words). A second related generalization is that the greater the intensity of the affective disposition, the greater the impact on working memory performance. Third, there may be valence specificity: Negative affect appears to impair verbal working memory, especially for dispositional affect, whereas the effects of positive affect are less studied and equivocal. Finally, encoding, maintenance, and especially executive control of working memory may be more susceptible to affective influences than retrieval processes, although more work is needed to identify process-specific effects. It is also important to note that (a) the methods differ for studies examining the effects of affectively laden materials, (b) the emotional nature of the stimuli vary, and, consequently, (c) the emotional state of the rememberer is largely unknown. Most crucial, though, verbal or visuospatial working memory for emotional stimuli is distinct from working memory for emotional feelings, which constitutes the third mode discussed later.

Mode 2: cognitive working memory can modulate emotional experiences

This second mode concerns how cognitive working memory and individual differences in working memory capacity may modify emotional experiences. As we explain in detail below, Mode 2 is closely related to emotion regulation, in that the evidence suggests that cognitive working memory can influence emotions by enhancing or diminishing them. This mode has been studied less than Mode 1; however, we can offer two guiding principles derived from our review: (a) Cognitive working memory itself can provide one means of emotion regulation; and (b) cognitive working memory can influence other emotion regulatory strategies such as suppression and reappraisal.

Evidence that cognitive working memory can influence emotional experience (i.e., regulate emotion) comes from manipulations of working memory demand (also referred to as "cognitive load" in some reports). For example, Van Dillen and colleagues demonstrated that as the complexity of the cognitive working memory tasks increased, the intensity of self-reported negative emotional reactions decreased (Van Dillen, Heslenfeld, & Koole, 2009; Van Dillen & Koole, 2007). Neuroimaging studies of such effects yield complementary results: Cognitive working memory load is associated with decreased activity in emotion-processing regions, such as the amygdala and orbitofrontal cortex (e.g., Kellermann et al., 2012; see also Van Dillen et al., 2009; Kron, Schul, Cohen, & Hassin, 2010). Although explanations of these findings vary, the evidence suggests that working memory load can serve to regulate emotion. That is, when cognitive working memory load is high, fewer resources are available for other ongoing tasks, including the appraisal and rating of an emotional stimulus. Alternatively, with higher working memory load, affective processing may be inhibited to divert resources toward the cognitive task, which could also explain diminished effects on emotional experience (Clarke & Johnstone, 2013). These ideas converge with load theory, which posits that with higher cognitive load fewer resources are available for other forms of processing (Lavie, Hirst, de Fockert, & Viding, 2004), potentially including the processing of emotional stimuli. Regardless of the underlying mechanisms, from an emotion-regulation vantage point then, cognitive working memory load generally serves to diminish the impact of emotional stimuli.

The second empirical approach for Mode 2 examines how cognitive working memory influences concurrent yet unrelated emotion-regulatory processes. For example, when people engage in cognitive working memory tasks, their ability to actively suppress emotional facial expressions in response to emotional stimuli is diminished (Schmeichel & Zell, 2007). An individual-difference approach produced corresponding results; compared with people who have lower working memory capacity, those with high working memory capacity were better able to suppress negative and positive emotional expressions, and they demonstrated superior reappraisal abilities (Schmeichel & Demaree, 2010; Schmeichel, Volokhov, & Demaree, 2008). In related work, poorer working memory updating and greater susceptibility to interference in working memory were associated with more negative thoughts and lower reappraisal abilities (Pe, Raes, & Kuppens, 2013; Pe, Raes, Koval, et al., 2013). Moreover, better updating for positive versus negative material in cognitive working memory has been related to greater well-being and life satisfaction (Pe, Koval, & Kuppens, 2013). These studies suggest that cognitive-control processes contribute to certain forms of emotion regulation.

In sum, research addressing how cognitive working memory influences emotional experience and regulation yields more consistent results than the first mode: Cognitive working memory can influence emotion-regulatory functions (via load effects), and it seems to undergird other unrelated emotion-regulation processes. In particular, evidence indicates that cognitive working memory resources (i.e., executive processes) are needed for emotion regulation (e.g., when suppressing emotional facial expressions; Schmeichel & Zell, 2007). In addition, cognitive working memory capacity is related to emotion-regulation abilities; generally, individuals with higher cognitive working memory capacity have greater emotion-regulation abilities relative to those with lower working memory capabilities.

Mode 3: emotional feelings can be mental representations maintained in working memory

For Mode 3, emotional feelings themselves are the contents of working memory. As reviewed above, according to the emotion-process model, after appraisal, an emotional experience ensues consisting of such components as physiological reactivity, an action tendency, a facial expression, and *the subjective feeling*. Although there are multiple components of the emotion process, it is specifically the subjective feeling of the affective state that constitutes its core mental representation. Feelings have positive or negative valence, are low or high in arousal, and vary in intensity level (Barrett & Russell, 1999; Reisenzein, 1994). Working memory maintains and manipulates mental representations, and when those representations are strictly affective in nature—as is the case with the subjective-feeling state—affective working memory is implicated. The crucial distinction is that for Mode 3, emotional subjective-feeling states are the representations processed and maintained by working memory. This focus on the actual feeling differs from Mode 1, in which affect-laden stimuli are the representations processed and maintained by cognitive working memory. Although such stimuli are likely to evoke affect, we contend that Mode 3 functions specifically to maintain and work with emotional feeling states rather than maintaining representations of the stimuli that elicit the emotion.

Affective Working Memory

By analogy with cognitive working memory (e.g., Jonides, 1995), affective working memory has several defining characteristics. First, in the short term, it maintains a mental representation—the subjective emotional feeling—in the absence of the eliciting stimulus (i.e., emotion maintenance). Second, the maintained representation is instrumental for subsequent goals. That is, affective working memory involves the set of mental processes that maintain an emotional feeling that is integral to goal-directed behavior. Third, affective working memory entails actively holding in mind a feeling—in contrast to passively experiencing an emotion. In other words, working memory processes exert deliberative control over the emotional feeling. Within the context of the working memory models reviewed above, we consider affective working memory to fit within the multicomponent view. In addition, we consider affective working memory similarly to involve the maintenance of distributed neural representations (including interoceptive signals) of feelings, which is consistent with recent accounts of working memory that focus on the maintenance of distributed domain-specific representations (e.g., Christophel et al., 2017; Postle, 2015a, 2016). We posit that attentional control, as with other nonverbal forms of working memory, is required for active maintenance or some form of refreshing. We review evidence below that supports this characterization and suggest that affective working memory constitutes a neuropsychological subsystem composed of mental operations that are at least partially separable from cognitive working memory.

Desiderata for investigating affective working memory

Guided by this theoretical conceptualization of affective working memory, we developed and tested a novel paradigm in which emotional feelings are themselves the mental representations. Moreover, to ascertain whether affective working memory is distinct from cognitive working memory, we used the dissociation logic often used to test the separability of psychological processes (e.g., Baddeley, 1986; Jonides, 1995). This necessitated a parallel task requiring the maintenance of a nonemotional subjective state to contrast with emotion maintenance. Comparing performance on these two delayed-response tasks allowed us to quantify the "accuracy" of maintaining a subjective emotional feeling relative to maintaining a subjective brightness representation. The emotion-maintenance task required participants to maintain over a brief delay period the feeling elicited from viewing a static emotional image and then compare the intensity of that feeling to the intensity of another one evoked by a second image of the same emotional valence (i.e., participants pressed a button to indicate whether the feeling evoked by the second image was of higher or lower intensity than the feeling evoked by the first image). In the nonemotional analog task the subjective brightness representation derived from a static neutral image was held in memory and subsequently compared with the brightness of a second image (see Fig. 2).[2]

Behavioral and neural evidence for affective working memory

To test whether the processes supporting affective working memory are psychologically distinct, we examined the potentially disruptive effects of performing secondary tasks on performance of the emotion- and brightness-maintenance tasks, as is traditionally done (e.g., Barnes, Nelson, & Reuter-Lorenz, 2001; Logie, Gilhooly, & Wynn, 1994; Welford, 1952). Both tasks could conceivably rely on the same maintenance processes in that visual working memory could be used to maintain a perceptual representation of the first picture. To assess this possibility, we used a secondary visual search task during the maintenance interval that placed maximal demand on visual processing to disrupt visual working memory and, potentially, both tasks. Another possibility was that both maintenance tasks also engaged verbal encoding or a combination of visual and verbal encoding. For instance, participants may generate a numeric code or verbal label to characterize the first image and maintain this representation over

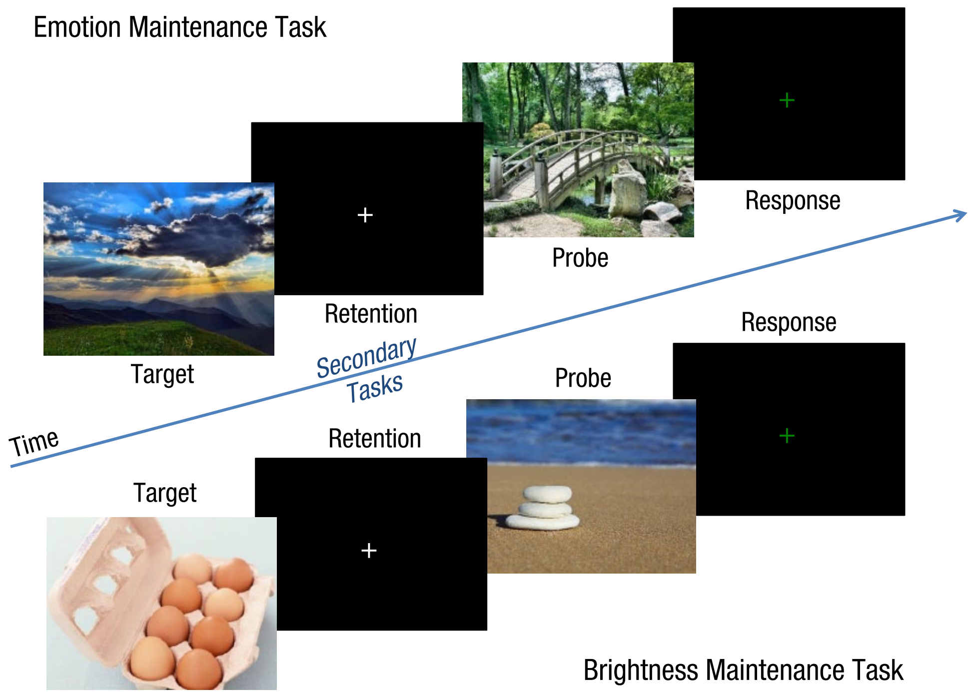

Fig. 2. Generalized schematic for two model working memory tasks. For both tasks, a target image is presented, typically for 5 s, followed by a retention interval of 3 to 10 s, and then a probe image is presented for 5 s. After viewing the probe image in the emotion-maintenance task, participants indicate whether their emotional reaction to the probe image is higher or lower in intensity relative to the feeling evoked by the target image. In the analogous brightness-maintenance task, participants indicate their relative perceptions of brightness intensity. In one experiment reported by Mikels, Reuter-Lorenz, Beyer, and Fredrickson (2008), additional secondary tasks were performed during the retention interval to demonstrate the separability of maintenance processes underlying these two tasks (see also Fig. 3). These representative images for the emotion-maintenance task were selected to evoke varying intensities of awe for a positive-emotion trial. Images evoking negative emotions were paired together and also used in our studies. Adapted with permission of the American Psychological Association, from *Emotion and Working Memory: Evidence for Domain-Specific Processes for Affective Maintenance*, by Mikels, J. A., Reuter-Lorenz, P. A., Beyer, J. A., & Fredrickson, B. L., in *Emotion*, Vol. 8. Copyright © 2008.

the delay. Thus, we also included a secondary verbal task during the retention interval intended to thwart verbal-recoding strategies (Murray, 1967, 1968; Richardson & Baddeley, 1975). If affective working memory relies on separable mechanisms that are neither verbal nor visual in nature, we reasoned that these secondary tasks should interfere minimally compared with the brightness task, which is clearly visual in nature.

Likewise, to interfere selectively with emotion maintenance, we used an emotion-regulation task (modeled after Gross, 1998; Ochsner, Bunge, Gross, & Gabrieli, 2002). For this secondary task, participants viewed an additional image during the retention interval, were instructed to think about it in a way that would make them feel less negative, and then rated the intensity of their diminished feeling during retention. We reasoned that if the emotion-maintenance task requires that people actively hold a feeling in mind, then the requirement to process another feeling should disrupt emotion maintenance during the delay.

Using these tasks, we found that performing the secondary visual and verbal tasks selectively interfered with brightness maintenance yet facilitated performance on the emotion-maintenance task (Mikels et al., 2008). This facilitation resembles the beneficial effects of articulatory suppression on visual imagery (Brandimonte, Hitch, & Bishop, 1992) and suggests that blocking verbal recoding enables higher fidelity maintenance of affective feelings (for further discussion, see Mikels et al., 2008). Moreover, performing a secondary emotion-regulation task selectively interfered with emotion maintenance, leaving brightness maintenance unimpaired (see Fig. 3). These selective-interference effects suggest separable affective working memory processes support performance in the emotion-maintenance task. Note that when participants are tested on the emotion-maintenance task across multiple testing sessions, performance is significantly correlated, indicating good reliability (Broome, Gard, & Mikels, 2012).

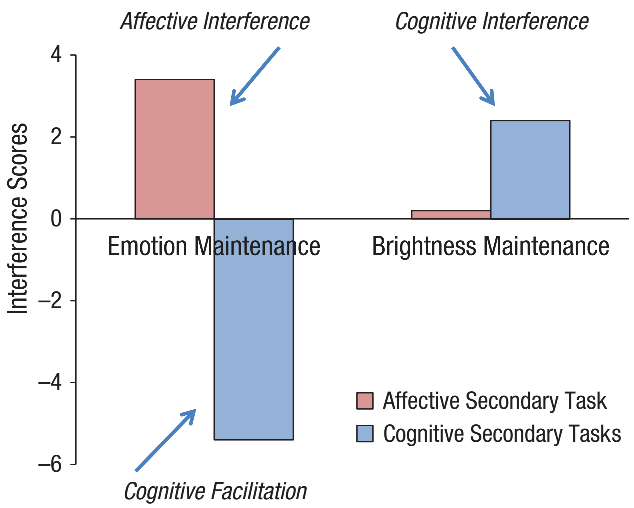

Fig. 3. Interference effects on emotion- and brightness-maintenance performance. The affective secondary task interfered only with emotion maintenance, whereas the cognitive secondary tasks interfered with brightness maintenance but facilitated emotion maintenance. As interference scores were calculated by subtracting maintenance performance with the secondary tasks from maintenance performance without the secondary tasks, positive scores indicate interference (relative performance decrement), and negative scores indicate facilitation (relative performance benefit). Adapted with permission of the American Psychological Association, from *Emotion and Working Memory: Evidence for Domain-Specific Processes for Affective Maintenance*, by Mikels, J. A., Reuter-Lorenz, P. A., Beyer, J. A., & Fredrickson, B. L., in *Emotion*, Vol. 8. Copyright © 2008.

In related work, we examined the effects of normal aging on these same maintenance tasks and found further evidence that affective and cognitive working memory processes are separable. Decades of research have documented age-related declines in many cognitive domains (Park & Reuter-Lorenz, 2009). Decline in working memory is particularly pervasive (e.g., Park et al., 2002; for a meta-analysis, see Verhaeghen, Marcoen, & Goossens, 1993), with age differences noted for all types of information, including verbal information, visual images, objects, spatial locations, and even faces (see Swanson, 2017, for a life-span perspective on domain specificity in cognitive working memory). Given such widespread declines, one might expect deficits in working memory for emotional feelings as well. The socioemotional literature on aging suggests otherwise, however, on the basis of evidence that emotional processes remain fairly stable across the life span (Carstensen, Mikels, & Mather, 2006).

Accordingly, we hypothesized that affective and cognitive working memory would dissociate with age. We expected to observe age-related decline on our brightness-maintenance task but not on our emotion-maintenance task, and this is precisely what we found. Whereas older adults showed typical decline in maintaining visual information, the ability to maintain emotional feelings was unaffected by age (Mikels, Larkin, Reuter-Lorenz, & Carstensen, 2005). In addition, although younger adults showed superior memory for negative relative to positive feelings, older adults showed the opposite pattern. This finding supports the developmental pattern referred to as the *positivity effect*, whereby the disproportionate preference for negativity in youth shifts toward positivity in later life (Carstensen & Mikels, 2005; Mikels, Reed, Hardy, & Löckenhoff, 2014). Performance on the brightness-maintenance task was notably correlated with a standard working memory measure (digit span), whereas performance of the emotion-maintenance task was not. Thus, our research with older adults dissociates emotion and brightness maintenance, supporting the proposal that separable psychological processes mediate emotion maintenance.

An additional piece of behavioral evidence indicating that the ability to deliberately maintain a feeling is at least partially separable from cognitive processing comes from a study by DeFraine (2016). Using a version of the Mikels et al. (2008) task, this study found that people could actively hold a feeling in mind while also doing a mental arithmetic task and that the intensity of the feeling was relatively unchanged (DeFraine, 2016). In contrast, mental arithmetic did reduce the intensity of feelings in response to passively viewed images. These results suggest that the cognitive processes needed for mental arithmetic are not necessary for active emotion maintenance, consistent with the idea that affective working memory depends on domain-specific processes.

Although the neuroscience evidence pertaining directly to affective working memory is scant, the results from a handful of studies also suggest there may be distinct neural underpinnings of active emotion maintenance. First, early neuroimaging evidence indicated that when people were instructed to actively maintain subjective affective experiences induced by viewing negative emotional images, there was greater amygdala activation during the subsequent delay period compared with passive viewing of the same images (Schaefer et al., 2002). These results suggest that the deliberate, active maintenance of negative emotion operates in part by modulating the level of amygdala activity. The region-of-interest approach used by Schaefer et al. (2002) focused on the amygdala and did not include cortical regions that may have also been involved. However, more recent work from Waugh, Lemus, and Gotlib (2014) indicates that emotion maintenance has a unique cortical signature compared with a non-maintenance (passive) condition.[3] They found that the active maintenance of the feelings evoked by an emotional image was associated with greater activation in the dorsomedial frontal cortex (MPFC) and in the dorsolateral prefrontal cortex (LPFC). The authors speculate that dorsal MPFC involvement is associated with the maintenance and elaboration of the emotional state over the delay, whereas the dorsal LPFC was involved in the information manipulation associated with comparing the two feeling states. Although this interpretation is speculative, it aligns well with related research indicating that regions of the MPFC play an important role in attending to one's internal affective state (R. Smith, Baxter, Thayer, & Lane, 2016; R. Smith, Fass, & Lane, 2014).

Finally, a recent study by R. Smith et al. (2018) presented emotional images followed by a maintenance period that required people to actively maintain the emotional feeling evoked by the emotional image, or a visual memory of the image itself. Although both maintenance tasks activated canonical working memory regions typically found for cognitive tasks, the emotion-maintenance condition was uniquely associated with greater activation in MPFC regions (including the anterior cingulate). Note that these prefrontal regions have extensive connectivity to the insula and subcortical emotion regions and are consistently implicated in the top-down control of emotion (Etkin, Egner, & Kalisch, 2011; for a neural model of conscious emotional states, see R. Smith & Lane, 2015). Given the nature of the task, it is likely that the MPFC regions were primarily involved in affective-maintenance processes specifically. Future research will be needed to determine precisely which prefrontal regions are involved in maintenance versus manipulation (potentially MPFC vs. dorsal LPFC, respectively). Taken together with the behavioral and life-span findings, these converging lines of neural evidence support the proposal that active emotion maintenance is distinct from passive emotional experience and is at least partially separable from cognitive working memory.

Translational relevance of affective working memory

Evidence for distinct affective working memory processes has translational implications for a variety of populations. Preserved affective working memory abilities in older age may underlie the sparing of other aspects of emotional functioning. In later life, affective working memory processes could potentially circumvent declines in the deliberative cognitive processes that are critical to optimal functioning and decision making. To test this idea, Mikels et al. (2010) examined the efficacy of different decision strategies in younger and older adults. Strategies that involve holding the details of decisions in working memory improved the decision quality of younger adults but impaired that of older adults. In contrast, when participants were encouraged to hold in mind their emotional reactions to decision options and base their decisions on their feelings, the age difference disappeared; older and younger adults made decisions of equally high quality. Thus, emotion-focused strategies may be beneficial in the decision making of older individuals.

The translational importance of the affective working memory construct is further documented in clinical studies that used the abovementioned emotion-maintenance paradigms. One application is the study of emotional processes in schizophrenia. The emotions experienced in response to positive and negative emotional stimuli by people with and without schizophrenia have been shown to be highly similar (Cohen & Minor, 2010). However, people with schizophrenia have motivational deficits and problems with goal-directed behavior (e.g., Gard, Fisher, Garrett, Genevsky, & Vinogradov, 2009), which could be due to how emotional feelings are processed. This possibility was supported in a study by Gard et al. (2011) that found a decreased ability to maintain negative and positive emotional feelings in affective working memory in individuals with schizophrenia, an impairment that was related to motivational deficits. Regarding affective disorders, individuals with bipolar disorder demonstrate a heightened reactivity to positive but not negative stimuli (e.g., Gruber, 2011). It is noteworthy that people with bipolar disorder have a deficit in maintaining negative but not positive emotional feelings (Gruber, Purcell, Perna, & Mikels, 2013). Difficulties in maintaining and processing negative feelings could play a mechanistic role in the enhanced processing of positive feelings, which is associated with the manic state. Thus, specific deficits in basic affective working memory processes could conceivably contribute to higher-level emotional symptoms that characterize these clinical disorders and provide potential targets for interventions.

In sum, these converging lines of behavioral, neuroscience, and clinical evidence provide foundational support for affective working memory, an additional domain-specific subsystem that can be readily incorporated into most current models of working memory, which are characterized by domain-specificity. For goal-directed tasks, processes involved in actively maintaining feelings are separable from those involved in maintaining nonemotional representations. In addition, active emotion maintenance requires control processes that are at least partially separable from cognitive-control processes. Each facet of affective working memory certainly warrants further investigation. The next section considers several especially fertile directions for future research.

Future Directions, and Implications of Affective Working Memory

First and foremost, as this review makes clear, more work is needed to delineate the potential overlap and separability of affective working memory and other working memory processes to characterize the architecture and interrelations of these systems. New applications of the tasks reviewed in this article and the development of new paradigms to investigate affective working memory and emotion–working memory interactions will help to achieve these goals, behaviorally and at the neural level. Indeed, neuroimaging evidence reveals activity in medial prefrontal loci that is unique for active emotion maintenance, along with other activity that overlaps with cognitive-control areas (R. Smith et al., 2018; Waugh et al., 2014). Future neuroimaging research that investigates the interactions between executive and affective brain networks (Iordan, Dolcos, & Dolcos, 2018) will also be helpful for delineating the neural bases of emotion-cognition dynamics. Understanding the extent of separability versus overlap in executive-control processes may also have implications for other mental abilities. Certain shared executive control functions could, for example, integrate active affective and cognitive representations in the service of reasoning, problem solving, and decision making.

Other characteristics of affective working memory that are currently unknown and warrant further research include its capacity limits and time course. We suspect that it may be difficult to hold more than two feelings active at the same time—note that the task we developed (Mikels et al., 2008) explicitly requires comparing two activated feeling states. However, future research is needed to examine how many feelings can be actively maintained and if performance suffers as a result in increased working memory load. In addition, load could also be related to arousal, such that high-arousal emotions may be more demanding to maintain than low-arousal emotions; such arousal effects constitute another area for future research. Another common approach in working memory research is to examine forgetting functions, that is, how the amount of information maintained diminishes over time. In the verbal domain, the number of items retained over varying retention intervals is typically used as an index of working memory capacity and forgetting. For affective working memory, though, a more appropriate index may be the fidelity with which an emotional state is maintained over an interval—similar to current work in the visual domain (e.g., Ma, Husain, & Bays, 2014; Postle, 2015b). Evidence that affective working memory is more limited in capacity than other forms of working memory would provide further support for its separable status as a working memory subsystem and may be a critical individual-difference dimension relevant to emotional intelligence and wisdom, as discussed below.

Theoretically, affective working memory could be usefully applied to other perspectives and domains. Recent constructivist theoretical models of the emotion process (e.g., Barrett et al., 2007) have proposed that emotional experiences involve the application of conceptual knowledge to “core affect.” Core affect can be likened to what is traditionally considered the subjective feeling. Within the constructivist framework, affective working memory could be the mental workspace that maintains core affect, whereas interactions with verbal and visual working memory could apply conceptual knowledge. Thus, the framework we propose here is potentially compatible with other theoretical models of emotion.

Affective working memory may also prove to be fundamental to the field of emotion regulation. Although some recent work has examined emotion regulation in the context of instrumental goals for maintaining or increasing negative emotions (e.g., Tamir, 2009), the core processes involved in emotion maintenance versus emotion downregulation have received limited attention. As described above, an emotion-regulation task interfered with emotion maintenance, suggesting an overlap of some processes. In many respects, self-focused rumination may be the one form of emotion regulation most likely to involve both cognitive and affective working memory processes. This form of rumination involves focused attention on a current feeling, its causes or consequences, resulting in the active maintenance or an increase in that feeling (Nolen-Hoeksema & Morrow, 1993; Nolen-Hoeksema, Morrow, & Fredrickson, 1993). Given the central role of attention on a current feeling in the conceptualization of rumination, affective working memory would constitute the underlying mechanism. The link between affective working memory and rumination underscores the role of emotion-maintenance processes in emotion dysregulation. Specifically, rumination is associated with multiple psychopathologies from depression and anxiety to binge behaviors (Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). Given the potential role of affective working memory in rumination coupled with the evidence for affective working memory differences in bipolar disorder and schizophrenia reviewed above, considering the role of affective working memory in emotion dysregulation and psychopathology may prove fruitful for future research.

Likewise, the efficiency of affective working memory may be critical to emotional intelligence (EI). EI broadly involves emotion-perception accuracy, adaptive use of emotions in thought and behavior, emotional understanding and appraisal, and the management of emotions (Mayer, Barsade, & Roberts, 2008; Salovey & Mayer, 1990). Here again, cognitive and affective working memory may enable one to work effectively with one's feelings: Above all, the feeling state must be held in mind (beyond visual and verbal representations), which implicates affective working memory. Within this workspace for feelings, executive processes and other cognitive operations could "work with" the affective representations. Moreover, individual differences in affective working memory could relate to differences in EI; individuals with a greater ability to maintain emotions may have higher EI abilities. Accordingly, affective working memory could constitute a core mechanism underlying EI.

Finally, affective working memory may be fundamental to the wisdom construct by providing the mental workspace for affective feelings. A core facet of wisdom is the integration of emotion and social/personal knowledge to make optimal decisions (Baltes & Staudinger, 2000; Staudinger & Glück, 2011). Affective working memory likely plays a central role in the use of affective representations for decision making (see e.g., Mikels, Maglio, Reed, & Kaplowitz, 2011) and prospection about future feelings (i.e., affective forecasting; Wilson & Gilbert, 2003). Wisdom involves not only effective emotion regulation but also the simultaneous consideration and integration of negative and positive feelings. An intriguing direction for future research would be to investigate the potential contributions of affective working memory to mixed emotions—that is, affective working memory might provide the essential workspace for maintaining and integrating feelings of both positive and negative valence and for counterfactual episodic thinking about emotional autobiographical memories (De Brigard & Parikh, 2019).

Integration Across the Modes of Emotion–Working Memory Interactions

Our conceptual three-mode framework is intended to organize the prevalent lab-based approaches used to investigate emotion–working memory interactions. However, in the real world, these three modes may themselves interact dynamically and concurrently. For example, affective working memory may interfere with cognitive working memory, or affective states may themselves interfere with affective working memory as well as cognitive working memory.

One recent brain imaging study by Iordan et al. (2018) captures some of this complexity by investigating the effects of emotionally distracting autobiographical memories from one's past on cognitive working memory performance. Iordan et al. (2018) manipulated whether participants focused on the emotional aspects (i.e., the feelings) of the memories or the memory's spatial/temporal context (i.e., where, when, and with whom the event occurred). Behaviorally, the emotion-focus condition resulted in more interference of the ongoing visual working memory task (e.g., more errors) than the context-focus condition, which demonstrates that active maintenance of an emotional feeling state can interact with visual working memory. In addition, the context-focus condition also decreased the emotionally disruptive consequences of remembering an unpleasant personal memory, which demonstrates that attention can help to reduce (i.e., regulate) the detrimental effects of affect on visual working memory performance. As the authors point out, these findings have implications for affective disorders, such as posttraumatic stress disorder, anxiety disorders, and depression. Insofar as rumination involves the excessive active maintenance of negative affect and thoughts from past memories, working memory processes may become dysfunctional.

More generally, though, approaches that cut across the modes and examine interactions between cognitive and affective systems could provide insight into the mechanisms of clinical disorders. As this study suggests, a focus on contextual versus affective features of the memories may be a useful clinical intervention. Ultimately, studies like this one highlight the dynamic and complex interactions between emotion and working memory and remind us that even a three-mode framework is only an initial step toward fully understanding this important domain.

Conclusions

We propose three modes by which emotion and working memory interact. The first two treat emotion and working memory as relatively separate constructs with mutual influence. The third mode focuses on feelings that can be actively maintained and worked with: affective working memory. We reviewed evidence to support this construct and described its applied utility, clinical relevance, and potential role in other higher-order constructs, including emotion regulation, EI, and wisdom. Affective working memory and the emotional feeling states it maintains and works with thus constitute a core mental capacity that may be essential for myriad higher-level processes. The study of affective working memory and its fundamental role in thought and behavior holds great promise for making inroads along the complex frontier between emotion and cognition.

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Notes

1. Working memory performance is typically measured by assessing memory accuracy for small sets of items after a brief delay. Simple span tasks are thought to rely on rote memory of the items, whereas complex span measures may require that the items be manipulated, or they may include an intervening task, and thus place more demands on executive-control operations. Some reports use working memory-capacity scores as the dependent measure. Calculations of capacity vary but are derived from measures of performance accuracy (e.g., Wilhelm, Hildebrandt, & Oberauer, 2013; Shipstead, Lindsey, Marshall, & Engle, 2014). We refer to either *working memory capacity* or *working memory performance* here to align with the terminology used in the reports we summarize. Working memory capacity can also serve as an individual-difference variable, an approach used to assess the effects of working memory on emotion as described in the section on Mode 2.

2. "Accuracy" on the emotion-maintenance task has been determined in two different ways across our studies. First, we have examined concordance with normative ratings, a measure of agreement between each participant's relative-intensity assignments when comparing two successive images in the working memory task and those derived from the normative ratings (e.g., Mikels et al., 2008). Second, we have assessed subjective accuracy on the basis of individualized intensity ratings obtained in a separate phase of the study, in which each participant provides intensity judgments for each image used in the working memory task. These individualized (rather than normative) intensity assignments are then used to assess performance accuracy or agreement with responses in the working memory phase of the study (e.g., Broome, Gard, & Mikels, 2012; Mikels et al., 2005). Both approaches yield comparable results, and the same procedures were also used to assess performance on the brightness-maintenance task.

3. The maintenance condition in this study required viewing two sequential images separated by a delay with instructions to maintain the feeling from the first image so as to compare it with the feeling from the second image. The nonmaintenance condition also involved viewing two sequential images separated by a delay, but then a rating was to be provided only for the second image. Consequently, the nonmaintenance condition did not require maintenance of the feelings from the first image.

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