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Dillen, L.F. van; Hofmann, W.

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Room for Feelings: A "Working Memory" Account of Affective Processing

Lotte F. van Dillen
Psychology Institute, Leiden University, Leiden, Netherlands

Wilhelm Hofmann
Department of Psychology, Ruhr University Bochum, Bochum, Germany

Abstract

In the past decades, affective science has overwhelmingly demonstrated the unique properties of affective information to bias our attention, memory, and decisions. At the same time, accumulating evidence suggests that neutral and affective representations rely on the same working memory substrates for the selection and computation of information and that they are therefore restricted by the same capacity limitations that these substrates impose. Here, we integrate these insights into a working memory model of affective processing (WMAP). Drawing on competitive access models of working memory, we discuss its role in the various stages of affective processing, from attentional selection to maintenance and memory storage, and resulting feelings and actions. We end our overview with some open questions and future directions.

Keywords
affective processing, working memory, attention, memory, feelings, decision-making

Room for Feelings: A "Working Memory Account" of Affective Processing

In the current review, we discuss and integrate scientific evidence from various domains of experimental psychology in support of a "working memory account" of affective processing (WMAP). We define working memory as a system that coordinates information processing when multiple goals are active and that guides behavior with information that is not present in the immediate environment (D'Esposito & Postle, 2015). Working memory involves the attentional selection of perceptual information and related long-term memory representations, active maintenance of this information, and the selection of relevant outputs (e.g., Eriksson et al., 2017). As such, working memory temporarily enhances the accessibility of a particular representation (Eriksson et al., 2017). Crucially, research that started many decades ago (Miller, 1956), demonstrated there is a limit on the number of discrete representations that working memory can concurrently maintain, whether these concern images, tastes, tones, or digits. As a consequence, all available information competes for active representation in working memory and is subject to filtering or selection. The central premise of this review holds that affective representations rely on the very same working memory-related processing substrates for the selection and computation of information as any other input, and that they are therefore restricted by the same capacity limitations that these substrates impose.

Whereas we thus argue that the processing of affective information depends on limited working memory capacity, we hold that affective information has special qualities: Affective cues signal the threat to, and fulfillment of important needs, such as safety, nourishment, and procreation, that lie at the root of human existence. Accordingly, such information has strong motivational relevance (Scherer, 2009) and is typically prioritized. For some informational stimuli, this potential is nearly universal (i.e., a high drop-off, a crawling snake). For other information, it depends on the perceiver's predisposition, learning history, and current

Corresponding author: Lotte F. van Dillen, Social, Economic and Organizational Psychology Unit, Leiden Institute for Brain and Cognition, Knowledge Centre for Psychology and Economic Behaviour, Leiden University, the Netherlands.
Email: dillenlfvan@fsw.leidenuniv.nl

motivational state whether certain stimuli are interpreted as incentives or threats (i.e., high-calorie snacks, social gatherings, smartphone games). For example, due to dispositional factors (Bishop, 2008) and/or personal learning history encoded in long-term memory (e.g., early life stress, Pechtel & Pizzagalli, 2011; Pine et al., 2005), certain affective cues can become chronically relevant, resulting in less effective context-dependent filtering of such information. Likewise, specific internal need states may bias people toward certain affective cues to motivate behaviors in line with (allostatic) needs (MacCormack & Muscatell, 2019; Nummenmaa & van Dillen, 2021).

Because of its high motivational relevance, the processing of affective information has been theorized to receive priority, quickly, and unintentionally, over other forms of information (Öhman et al., 2001; Pratto & John, 1993). Indeed, numerous findings have shown how attention to both threats and rewards can occur quickly and unintentionally, within milliseconds, and triggers responses across a broad array of sensory modalities (Berridge, 2009; Bradley, 2009; Nolen-Hoeksema, Morrow, & Fredrickson, 1993). Compared to more "neutral" information, affective information is captured more readily and disengaged less easily by the attention system (Bradley, 2009). Affective information moreover biases people's long-term memory (LaBar & Cabeza, 2006; Phelps, 2004), both during encoding (McGaugh, 2004) and retrieval (Tambini et al., 2016), thus contributing to clinical conditions such as anxiety disorders (Dalgleish & Watts, 1990; Rapee et al., 1994) and posttraumatic stress disorder (Ono et al., 2016; Zeitlin & McNally, 1991). Finally, affective information (and the responses it triggers) shapes people's judgments and decisions across many domains (Bechara, Damasio, & Damasio, 2000; Feigenson & Park, 2006; Lerner & Keltner, 2000; Loewenstein & O'Donoghue, 2004) such as financial choices (Kuhnen & Knutson, 2011; Porcelli & Delgado, 2009), punitive decisions (Gummerum et al., 2020; Nelissen & Zeelenberg, 2009), and prosocial responses (Ma, Tunney, & Ferguson, 2017).

Whereas the pervasive influence of affective information on people's thoughts, feelings, and actions has thus been firmly established, this influence need not result from information processing mechanisms *specific* to affect. Instead, we argue that affective information is prioritized by general-purpose information processing mechanisms because it signals general adaptive value. It indicates to the individual a threat or incentive to which an adequate response fulfills the individual's basic needs (i.e., safety, nourishment). By the same logic, affective information would, however, *not* be prioritized over nonaffective information under circumstances where processing capacity is limited and affective information bears no relevance to people's current goals and actions. In other words, according to our account, the active ingredient is the "fit" between the information provided, characteristics of the perceiver, and the current task demands the perceiver faces, rather than the nature of the content per se that defines what makes information "affective." Importantly, we propose that working memory plays a crucial role in this task-dependent filtering of affective information such that when demands on the system increase, task-relevant information is more likely prioritized over task-irrelevant information.

A "Working Memory Account" of Affective Processing

In what follows, we will introduce a novel WMAP that addresses why affective information typically has a processing advantage but is at the same time constrained by working memory capacity limits. When we published our first empirical findings speaking to this account (Van Dillen & Koole, 2007), few studies supported it. However, during the last 15 years evidence that favors such an interpretation has rapidly accumulated. We will discuss this evidence in light of the various stages of our model, depicted in Figure 1.

We will discuss findings that show the involvement of working memory in 1) the attentional selection of affective information. Next, we will summarize (neuro)psychological research that provides insight into the role of working memory processes 2) in the maintenance and elaboration of affective information. Subsequently, we will look into the implications of our working memory account for two central outcomes of affective processing, namely 3) the subjective experience of affective states (or feelings), and/or the choices and actions that individuals make. Finally, we emphasize the cyclical nature of this process by discussing the role of working memory in affective memory formation, and by integrating our model with cybernetic theories of affective processing. We end our review by discussing the important limitations and implications of our account.

Stage 1: Attentional Selection of Affective Information Relies on Working Memory

As noted in the introduction, affective information processing is typically prioritized because of its general significance for adaptive behavior (e.g., Bradley, 2009). Whereas such selective attention mechanisms may thus serve important survival functions, extreme or chronic attentional biases to affective information have been found to concur with lower well-being (Grafton & MacLeod, 2019) and maladaptive behaviors such as overeating (Hou et al., 2011) and aggression (Van Honk et al., 2001), as well as a variety of psychopathologies that involve affective dysregulation, such as anxiety disorders (Cis & Kosler, 2010), addiction (Field & Cox, 2008), and depression (Gotlib & Joormann, 2010).

One explanation for why chronic attentional biases to affective information have these detrimental effects is that they draw heavily upon limited working memory resources, at the cost of other psychological functions (Derakshan & Eysenck, 2010; Iordan, Dolcos, & Dolcos, 2018; Moran,

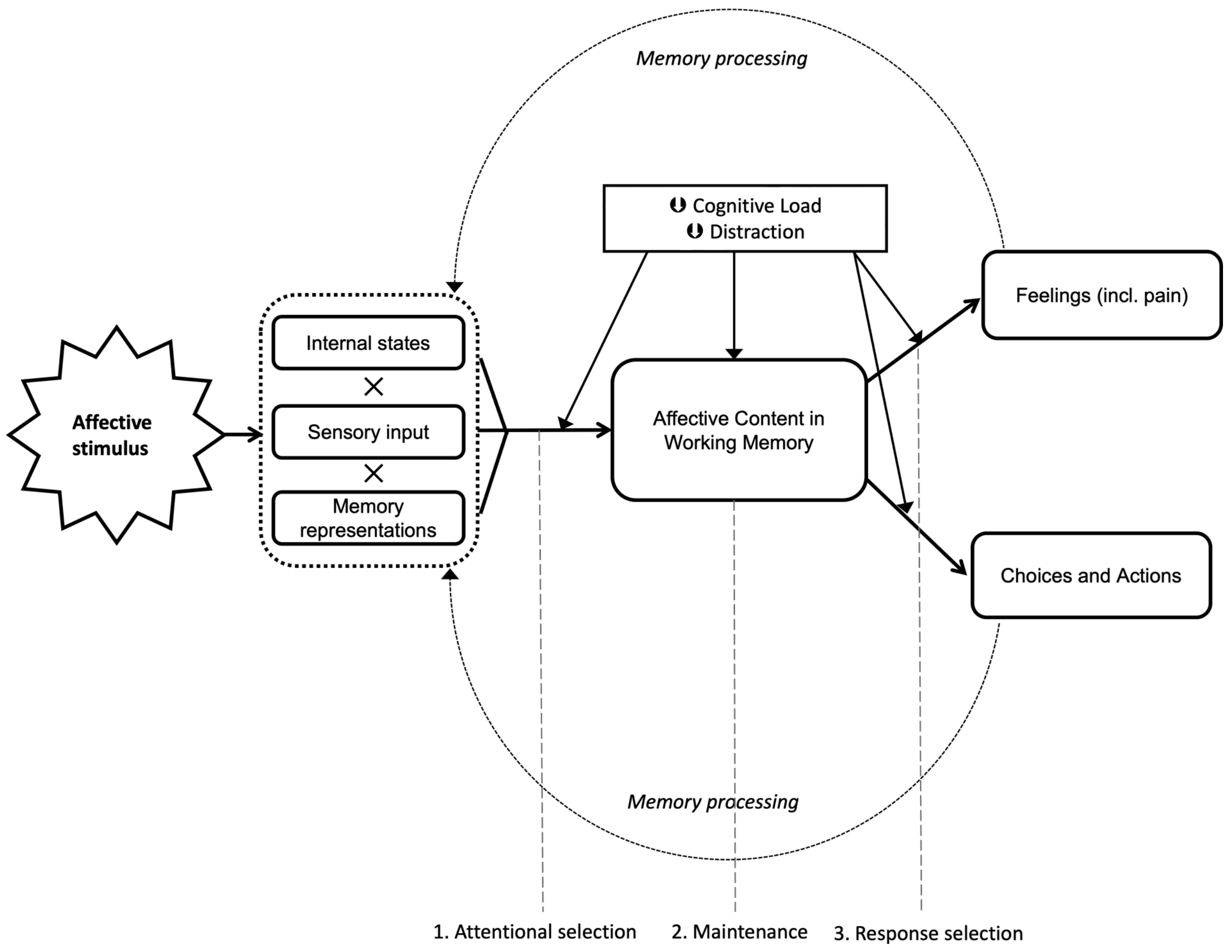

Figure 1. A "working memory account" of affective processing (WMAP).

2016; for recent meta-analyses of affective distraction from working memory performance, see Schweizer et al., 2019). Borrowing from influential working memory models (Postle & D'Esposito, 2015), we propose that information is encoded into working memory via the allocation of attention to internal representations—not only the sensory input but also internal bodily states and from semantic long-term memory, that each affects one another (i.e., the dotted box of Figure 1). As affective information has high motivational relevance, it may bias this process in a specific way, capturing attention, and accordingly gaining access to working memory (Stage 1 of Figure 1), at the cost of other potentially relevant information (Joormann & Siemer, 2004). This is nicely illustrated by the phenomenon of "feeling *hangry*," the aversive state of feeling hungry that makes people more readily agitated. Recent work has demonstrated how this is expressed in a greater misattribution of negative affect to ambiguous stimuli (or people; MacCormack & Lindquist, 2019).

Paradoxically, the idea that affective information more readily occupies limited working memory resources has also been the starting point for research on affect-regulation that has first pointed to the central involvement of the working memory system in this process. Whenever people direct their attention to a focal task (and away from affective aspects of certain information), they engage in distraction as a self-regulatory strategy. Distraction has not only been found to reduce the temptation of candy among schoolchildren (Metcalfe & Mischel, 1999; Mischel et al., 1989) but also the occurrence of depressive thoughts (Morrow & Nolen-Hoeksema, 1990; Layous et al., 2022), anxiety (Wong & Moulds, 2009), and angry ruminations (Bushman et al., 2005) in adults. Research has moreover demonstrated the effectiveness of distraction as a self-regulation strategy for a wide range of activities, such as visualizing neutral scenes (Joormann & Siemer, 2004; Rusting & Nolen-Hoeksema, 1998), sorting cards (Morrow & Nolen-Hoeksema, 1990), responding to colored lights (Christenfeld, 1997), listening to music (Aitken et al., 2002), playing the computer game Tetris (Holmes et al., 2009; Van Dillen et al., 2012), and filling out bogus questionnaires (Glynn et al., 2002). Apparently then, the effects of distraction are not restricted to a specific process or particular task, but rather rely on more general aspects of attentional processing. Indeed, as we suggest in the present integrative analysis, distraction may reduce selective attention to affective information through the enactment of working memory resources for task-related information processing.

Based on the above findings on distraction, we formulated the basic assumption of our working memory account that task-related and affective information competes over working memory resources because working memory capacity is limited (Van Dillen & Koole, 2007). When working memory demands of other activities are low, processing of affective information will by default receive priority due to attentional selection and may impact people's mental states and behavior accordingly. However, when a focal task requires more directed attention, for example, because of its high complexity, additional working memory resources are needed to perform the task effectively. As a result, fewer remaining resources are available for affective processing (Knudsen, 2007), thus effectively distracting people from processing the affective information. Attention to affective stimuli, and the subsequent processing of these stimuli, thus may depend critically on the availability of working memory resources—even though these stimuli have typically been assumed to automatically capture attention regardless of the current state or mindset of the organism (Pratto & John, 1991). Okon-Singer et al. (2007) have referred to this phenomenon as conditional automaticity: attention to affective information may be fast and unintentional, as has been documented widely, but it may still depend on the availability of working memory resources.

In an initial set of studies testing our working memory load hypotheses (Van Dillen & Koole, 2009), people categorized the gender of orthogonally varied angry and happy facial expressions, while they concurrently performed a less or more demanding focal task, such as solving simple or more complex math equations (Experiment 1) or rehearsing a one- versus eight-digit number (Experiment 2). In this context, the faces' emotional expressions are not central for performance on the gender-naming task but may still be processed because of their affective salience. Accordingly, longer response latencies to angry than to happy faces index greater attentional interference of negative information (reflecting a negativity bias, Pratto & John, 1991). Participants indeed displayed such a negativity bias, but, interestingly, only when working memory load was low. When working memory load was high, participants were as fast in response to angry as to happy faces. Importantly, picture negativity did not interfere with performance on the focal digit span task confirming that task-related processing was prioritized over affective processing. In an extension of this work (Van Dillen & Derks, 2012) in which we employed ERP methodology, we found that the N2 component and the late positive potential of the event-related brain potential, an index of affective bias at around 250 ms following stimulus presentation (Frühholz et al., 2011; Olofsson et al., 2008), was generally suppressed under high compared to low working memory load, and no longer differentiated between angry faces and happy faces. Similar results have since been obtained for fearful face processing (MacNamara et al., 2012) and for processing of negative (Schönfelder et al., 2014) and positive scenes (Barley et al., 2021). MacNamara et al. (2012) moreover demonstrated that load-induced reductions in affect-related ERP amplitudes to fearful faces could not be explained by strategic avoidance of these stimuli since eye-tracking data showed that participants fixated *more* on fearful face regions under high working memory load, not less.

One study (Hur et al., 2017) demonstrated in particular, how the "fit" between the working memory content and the affective information controlled selective attention to the newly presented information. Using modified 0-back and 2-back tasks to induce varying levels of working memory load, they demonstrated that the influence of attentional focus (on neutral vs affective stimulus aspects) on attentional selection depends on the dynamic relationship between (competing) mental representations. Participants performed the 0-back or 2-back task while they were instructed to focus on the stimulus color (neutral) or stimulus valence (emotional). During the 0-back task, i.e., when concurrent WM load was low, emotional targets facilitated performance when participants had an emotional focus, whereas they impaired performance when participants had a neutral focus. This pattern represents a typical affective bias, where task-irrelevant emotional targets (compared to neutral targets) disrupt performance, but task-relevant emotional targets facilitate performance (see also Van Dillen et al., 2011). During the 2-back task, i.e., when WM load was high, this affective bias in performance was however eliminated, suggesting that the 2-back task left no room for the processing of more peripheral target features such as emotion (or color). These findings thus point to the importance of task relevance for WM gating of affective information, in addition to the demand on its limit capacity resources.

Together, the available evidence suggests that occupying working memory with a cognitively demanding focal task can reduce selective attention to both negative and positive affective stimuli (Berggren et al., 2013; Cohen et al., 2015; King & Schaefer, 2011; Okon-Singer et al., 2007; Wiens & Syrjänen, 2013), appetitive stimuli (Van Dillen et al., 2013; Van Dillen & Van Steenbergen, 2018; Barley et al., 2021), and even when presented in a masked fashion (Uher et al., 2014). For example, King and Schaefer (2011) demonstrated how high compared to low working memory load reduced the startle eyeblink reflex, typically observed in response to emotional pictures (see for similar results; Balderston et al., 2016; Vytal et al., 2012).

Stage 2: Maintenance of Affective Information in Working Memory

As our account proposes, affective information not only draws attention more easily, as depicted in the first stage of our account; once it gains access to our working memory system, it also facilitates the maintenance of affective information, which involves the second stage of our account. We argue that the maintenance of affective information in working memory can be considered the backbone of any affective experience. It strengthens the link between attentional selection of affective information on the one hand and experiential and behavioral outcomes on the other hand (Gerin, 2004; Hofmann & Van Dillen, 2012), through a cycle of elaborations that can prolong and intensify people's affective states (Kavanagh et al., 2005; Siemer, 2005).

Several neuroimaging findings have demonstrated the involvement of working memory in the maintenance of affective information for both positive and negative stimuli (Erk et al., 2007; Van Dillen et al., 2009; Van Dillen & Van Steenbergen, 2018). One neuroimaging experiment (Van Dillen et al., 2009) disentangled whether cognitive load modulated affective responses, or, perhaps, simply reduced the accessibility of affective information for the conscious report. Participants viewed neutral and negative scenes following which their working memory was taxed to a varying degree trough simple versus more complex math equations. Concurrent with self-reported negative feelings, high compared to low working memory load was found to attenuate brain responses to negative pictures in the bilateral amygdalae, and the right insula, regions typically engaged in affective processing. Inversely, the recruitment of regions implicated in task-directed control, such as the right dorsolateral frontal cortex and the superior parietal cortex intensified under high working memory load conditions. Moreover, the decrease in activity in the insulae and amygdalae was related to the increase in activity in working memory regions of the brain, suggesting that increases in load "tuned down" actual processing in the emotional brain. This relationship was only observed during math performance, and not during picture presentation, when in fact all regions involved showed increased activity to negative compared to neutral content (i.e.,- emotional and working memory brain networks were engaged in concert for further elaboration on the affective content). In line with our working-memory account, this pattern suggests that (task-irrelevant) affective information is less likely to be maintained when task-related information needs to be prioritized, such as in the case of solving complex math equations.

Other researchers have reported similar effects of working memory load on brain responses to painful stimuli (and associated feeling states; Bantick et al., 2002; Frankenstein et al., 2001). One experiment, for example, demonstrated that brain responses to thermal stimuli in areas of the pain matrix (i.e., thalamus, insula, and the anterior cingulate cortex) are reduced significantly by high cognitive load (Bantick et al., 2002). Intriguing evidence using spinal high-resolution neuroimaging moreover indicated that the regulatory influence of cognitive load on pain processing may even reach beyond the brain and modulate responses to incoming pain signals at the earliest stages of central pain processing in the spinal cord (Sprenger et al., 2012).

In a recent neuroimaging study involving the influence of cognitive load on hedonic brain responses to high-calorie food pictures (Van Dillen & Van Steenbergen, 2018), moreover, selective responses to attractive high-calorie foods in the nucleus accumbens, a central brain region of the reward network, turned out to be significantly reduced under high compared to low load. In addition to this neuroimaging evidence, another experiment using a primed lexical decision task (Van Dillen et al., 2013, Study 2) demonstrated that concurrent load reduces hedonic associations in response to palatable food pictures, as evidenced by slower responses to subsequently presented hedonic target words. Finally, working memory load has even been found to downregulate neural processing of food odors (Hoffmann-Hensel et al., 2017). The degree of neural "working memory" activation that an individual displayed, moreover, corresponded to the decrease in activity in olfactory processing areas under higher cognitive load.

In sum, in accordance with stage 2 of our account, the (neuro)psychological evidence just described points to a central role for working memory processes in the maintenance of and elaboration of affective information. It showed that cognitive load disrupts the actual processing of both threatening and rewarding information (de Voogd et al., 2018), rather than simply interfering with the conscious reflection on this information. The depth with which affective information is further processed, in turn, determines its impact on our feelings and actions.

Stage 3 (Part 1): Feelings Require Working Memory Resources

In the previous paragraph, we discussed the second stage of our model which addressed how taxing working memory may interfere with the active maintenance of affective information. As depicted in Figure 1, the third stage of the model assumes that, as a consequence, taxing working memory should dampen people's affective states, that is, have a traceable impact on the intensity of people's phenomenological affective experiences, as well as on people's choices and actions, something we will discuss hereafter.

In line with several theorists (Kavanagh et al., 2005; Nolen-Hoeksema & Morrow, 1993), we argue that affective (feeling) states are the result of maintenance and elaboration processes in working memory. For instance, it has been consistently shown that ruminative thinking after an initial negative event, exacerbates depressive symptoms over time, and poses people with a higher risk of developing new depressive episodes (Nolen-Hoeksema & Morrow, 1993). Likewise, the highly influential Elaboration Intrusion Theory of desire (Kavanagh et al., 2005), it is illustrated how when desire emerges into consciousness, thus occupying limited working memory resources, a “vicious cycle” of reprocessing and elaboration can result, during which people repeatedly imagine desire enactment and have recurring thoughts about the resulting hedonic experience. Over the past decades, this theory has received strong empirical support (May et al., 2015).

It has also been shown that the intensity of the resulting affective state may not only depend on the presence (vs. absence) of a distracter task but also on the *degree* to which a task incorporates working memory resources. Given that working memory capacity is a continuous variable, the involvement of working memory resources by a distracter task should have a gradual impact on people’s negative feelings. The more WM resources a focal task usurps, the fewer resources are available for maintenance and elaboration of affective information, and accordingly, the more resulting affective states are dampened. Hence, a highly demanding task should reduce the intensity of people’s negative feelings to a greater extent than a moderately demanding task, whereas a moderately demanding task will still be more effective than a mildly demanding task.[1]

Consistent with this idea, quite a number of findings now suggest that cognitive load essentially narrows people’s “room” for feelings: Erber and Tesser (1992) were among the first to explore the possibility that variations in working memory load would differently impact affective states, although they labeled this process “task absorption.” In two experiments, participants viewed an emotionally arousing film clip after which they solved math equations for 10 min and then reported their moods. The authors showed that participants reported less intense negative moods in response to the film clip when they subsequently solved complex rather than simple math equations, or when they were told that effort at the distracter task was instrumental for their performance rather than unrelated. Underlying these task manipulations of complexity and effort was the assumption that these would tax mental resources to a varying degree. Erber and Tesser (1992) hence explained their findings in terms of a limited capacity model, arguing that: “… it may be that a task which demands the bulk of people’s cognitive resources “absorbs” moods by preventing further preoccupation with mood-related thoughts” (p. 342).

In a set of three experiments (Van Dillen & Koole, 2007), cognitive load of a distracter task was more systematically varied and its effect on self-reported negative affect was examined. Participants viewed a series of neutral, mildly negative, or strongly negative pictures, followed by a more or less demanding task (or no task) and a feeling scale. Across the three experiments, variations in cognitive load were found to moderate the impact of viewing negative pictures on negative feelings (Van Dillen & Koole, 2007). Participants rated less intense negative feelings after viewing negative pictures when they performed a complex task rather than no task, or a simple task. The moderating effect of performing a task on negative feelings was stronger when the task was unpredictable, than when it was predictable, and was stronger for intensely negative stimuli (both of which engage more working memory capacity; Horstmann, 2015; Siemer, 2005) than mildly negative stimuli. In line with our working memory account, these experiments thus further demonstrated how the intensity of participants’ negative feelings was the result of dynamic use of working memory resources by task-related processes on the one hand and affective processes on the other hand (see also Kron et al., 2010; Mano et al., 2013).

Similar effects of working memory load have been observed for other types of affective states. Along with modulatory effects on activity in pain-related brain areas, the abovedescribed neuroimaging studies for example observed similar effects on associated pain intensity ratings (Bantick et al., 2002; Frankenstein et al., 2001). Interestingly, Buhle and Wager (2010) found that participants reported less intense pain in response to thermal stimuli during a working memory task than in a visually matched control condition. Conversely, increasing levels of heat incrementally reduced task performance. Path analyses showed that fluctuations in pain completely mediated this effect, even within a certain heat level, pointing to dynamic competition over resources between the intensity of the pain stimulus on the one hand, and the working memory demand of the task on the other hand.

Likewise, self-reported cravings for food (Skorka-Brown, Andrade, & May, 2015; Van Dillen & Andrade, 2016), alcohol (Koukounas et al., 2019; Stafford et al., 2012), cigarettes (May et al., 2010), and even gambling (Cornil et al., 2021) have all been observed to be suppressed by task load. For instance, being exposed to attractive food pictures under high, compared to low cognitive load, curbed the development of cravings in response to such food cues (Van Dillen et al., 2013, Study 1; also see Kemps et al., 2008).

Stage 3 (Part 2): Working Memory Load Dampens Affective Influences on Choices and Actions

As we already briefly discussed, affective processes may shape our choices and actions considerably, and their influence is not always warranted. Self-regulation theorists have for example pointed to the central role of affective processing biases in self-control failure (Hofmann & Nordgren, 2015; Hofmann & Van Dillen, 2012; Loewenstein, 1996; Metcalfe & Mischel, 1999).

Likewise, the Affect-as-Information hypothesis suggests that affect/mood operates as a source of information for response selection (Clore 1992; Schwarz and Clore 1988) meaning that people draw information from their feelings to interpret their decision-making context. People tend to use affect as information in particular, when the nature of the decision-making objective is affective too (Clore et al. 1994). This merits the question of to what extent taxing working memory can modulate (unwanted) affect-driven choices and actions, as depicted as the second output of the third model stage.

One domain in which this question is particularly relevant is the domain of anger regulation. Anger easily triggers emotion-congruent ruminations that further fuel angry feelings (Bushman, 2002), and the intensity of angry feelings mediates the relationship between an initial provocation and aggression (Pedersen, Gonzales & Miller, 2000). By disrupting angry rumination, for example by taxing working memory with a neutral task, one should accordingly be able to reduce aggressive tendencies. In support of this, Bushman et al. (2005) showed that any process that distracted mental resources away from an anger provocation, such as describing "the layout of the local post office" or "clouds floating by in the sky," effectively decreased triggered displaced aggression, i.e., the displacement of anger (and the associated aggressive behavior) following an initial provocation to an unrelated mildly annoying event. Similarly, Gummerum et al. (2016) showed that playing Tetris following an autobiographical memory-based anger induction reduced participants' third party–punishment of unfair distributions to levels compared to people in a neutral state (see for similar findings also: Wang et al., 2011).

Just as cognitive load appears to reduce anger, and its influence on aggression and punishment, it may reduce the influence of disgust on moral judgments. It has been widely demonstrated that more intense feelings of disgust lead to harsher judgments of moral convictions (Haidt & Wheatly, 2005), regardless of whether the disgust is experienced in response to the transgression or to an unrelated event. Van Dillen et al. (2012) showed that when participants played a game of Tetris (distraction condition) rather than wait in front of a blank screen for the same duration (control condition), they reported less disgust, and, accordingly, made milder judgments about a moral conviction. Interestingly, a third group who were instructed to reflect on their feelings in response to a disgust film clip (rumination condition) reported more disgust, and made harsher moral judgments than the control group, suggesting that the direction of attentional resources away or toward the disgust experience moderated the strength of this incidental disgust effect.

Finally, performing a demanding working memory task may not only regulate (unwanted or unintended) affective influences on behavior in the interpersonal domain but also in the health domain. In one study (Van Dillen et al., 2013, Study 3), participants who had been exposed to tasty food pictures while performing a highly demanding distracter task not only experienced weaker cravings; Compared to control participants, they were also less likely to select an attractive but unhealthy over a less tasty but healthy snack. The decrease in craving and unhealthy snack choice was especially pronounced among participants who were generally highly responsive to tasty food cues (i.e., who scored high on the Power of Food Scale, Lowe et al., 2009), most likely because they could no longer elaborate on the hedonic qualities of the presented stimuli. These, and related findings (Van Dillen & Andrade, 2016), again point to working memory as a crucial node for affective influences on response selection, as our account proposes. High cognitive load can prevent the selective elaboration on both threats and rewards (Stage 2), so that their impact on people's choices and actions is reduced (Stage 3).

Closing the Loop: From Stimulus to Response (and Back)

For the sake of clarity, we discussed our working memory account of affective processing in "chronological order," moving from 1) attentional selection of affective information, to 2) maintenance, to 3) response selection, as depicted in Figure 1. However, in line with other cybernetic models (Adolphs & Pessoa, 2010; Marsella & Gratch, 2009; Scherer, 2009), we wish to emphasize the cyclical nature of the affective processing chain; whatever output is produced now can become input in the future, shaping an individual's mental representations, for example through memory formation and reinforcement.

As illustrated by the backward-pointing arrows in Figure 1, resulting feelings and actions from one event, can, in turn, further shape the attentional selection of novel affective information, by feeding back into an individual's mental representations. Accordingly, longer lasting affective states such as moods can arise, that transcend any specific event. Through memory consolidation, preferential attention to affective information not only impacts feelings and actions in the present situation but also shapes expectancies in the future (Aue & Okon-Singer, 2015).

In line with our reasoning, a large literature has documented the biasing influence of affective information on memory consolidation as well as retrieval (see Blaney, 1986; for overviews), and memory intrusions comprise an important aspect of many affective disorders, such as generalized anxiety disorders, depression, and most notably post-traumatic stress disorder. It, therefore, comes as no surprise that for long, clinicians and researchers have shown an interest in such affective memory biases (Beck, 1979; LaBar & Cabeza, 2006) and how these can be regulated.

Recent models of memory formation and storage emphasize that whenever a memory is formed or retrieved, there exists a limited time-window during which the memory is unstable, and during which new information can be integrated with already memorized information (Alberini & LeDoux, 2013; Baddeley, 1998; Tronson & Taylor, 2013). This process is called reconsolidation, and it is assumed that any intervention that affects reconsolidation, should affect the content and vividness of the (emotional) memory (Beckers & Kindt; 2017). Whereas most studies examining this principle have focused on pharmacological interventions (Kindt et al., 2009), and extinction learning (Schiller et al., 2010), increasingly, studies have targeted the involvement of working memory in the consolidation process.[2]

James et al. (2015) for example showed that engaging visuospatial working memory resources after the reactivation of an emotional memory reduces memory intrusions for that event. Participants first viewed a film clip depicting various traumatic events. The next day, some participants viewed stills from the clip, to reactivate the previously created trauma memory, after which they then played Tetris, a computer game that strongly engages visuospatial working memory (Lau-Zhu et al., 2017). The participants who participated in this sequence reported markedly fewer spontaneous intrusions from the trauma film over the next week compared to participants who had not played Tetris after the memory reactivation, or those who played Tetris without the prior memory reactivation. Earlier, Holmes et al. (2009) demonstrated that playing Tetris 30 min following an initial exposure to trauma film clips (i.e., during the memory consolidation phase), similarly reduced the flashback frequency. Interestingly, in both studies, recognition memory for the material was unaffected by the Tetris manipulation, suggesting that the intervention specifically impacted the emotional quality of those memories. Follow-up research moreover showed that whereas intrusive memories were downregulated by the Tetris intervention, voluntary memories were still intact (Lau-Zhu et al., 2021).

A proof-of-concept randomized controlled intervention study in an emergency department (Iyadurai et al., 2018) showed that a Tetris-based intervention within 6 h of a motor vehicle accident (trauma memory reminder cue plus 20 min game play) compared to attention-placebo control (written activity log for same duration) yielded a steeper decline of intrusion incidence. Relatedly, a Dutch study demonstrated that taxing working memory with a neutral task reduced the vividness and intensity of emotional memories of images about the Queen's Day tragedy of 2010 when a car drove at full speed into a crowd welcoming the Queen and her family (Engelhard et al., 2011).

Our approach fits well with recent emotion models that align with traditional (neural) architectures of cognition (Pessoa, 2019) and that illuminate the various stages through which affective information is selected, evaluated, integrated, and generated output (Marsella & Gratch, 2009; Scherer, 2009). Scherer's (1984; 2009) component process model (CPM), for example, describes the dynamic unfolding of emotions (and we take the liberty to generalize to affect more broadly) to be triggered by the appraisal of an event in relation to an individual's specific mental representations of internal sensorimotor and somatovisceral states, along with associations from long-term memory, to eventually generate specific action tendencies and feeling states. Perhaps not coincidentally, these stages map quite well on the working memory functions of attentional selection, maintenance, and response generation.

Moreover, the CPM and related theoretical frameworks (Adolphs & Pessoa, 2010; Moors et al., 2013; Schweizer et al., 2019) underline the importance of the dynamic, cyclical nature of affective processing, as well as the central, and causal, role of multilevel cognitive processing of both antecedent events and response options that do justice to its complexity, "linked to both the world's dynamics and the dynamics of the individual's physiological, cognitive and behavioral processes" (Marsella & Gratch, 2009). According to the CPM (Scherer, 2009): "all of these components; appraisal results, action tendencies, somatovisceral changes, and motor expressions are centrally represented and constantly fused in a multimodal integration area (with continuous updating as events and appraisals change)." We propose that working memory represents a likely candidate for such a central integration area, consistent with the idea of working memory as a global workspace (Dehaene & Naccache, 2001).

Open Questions and Future Directions

Immediately before, we defined the various stages of our WMAP, explaining the central role of working memory in 1) attentional selection and 2) maintenance of affective information as well as how this shapes our 3) feelings, choices, and actions. Our WMAP emphasizes the cyclic nature of any affective response, being both the product of sensory and mental representations and affecting them in turn. Thus, interference with this process during any stage should ultimately feed back into earlier stages as well (through memory processes, see Figure 1). Still, the extent to which working memory load interferes with affective processing may depend on the moment at which it is implemented, something that is still an open question thus far.

We have seen how distraction can reduce attentional capture of affective information as well as further elaboration of this information. This suggests that distraction may be particularly effective during the stages of attentional selection and maintenance. By loading working memory with a neutral task, people can direct their attention away from affective information with relatively little mental effort, which may be useful in situations where more willful self-regulation attempts are likely to fail, such as in the face of imminent temptations (see also Hofmann & Van Dillen, 2012) or to prevent excessive rumination (Morrow & Nolen-Hoeksema, 1990). Likewise, people seem to prefer distraction strategies over other forms of emotion regulation (e.g., reappraisal) to deal with imminent high-intensity threats (Sheppes et al., 2011), even if the distracter task is cognitively challenging (Sheppes et al., 2014).

The question of timing has been addressed to some extent in emotion regulation research, where distinctions have been made between early and late regulation strategies (Gross & Thompson, 2007; Koole, 2009) and their varying effectiveness and costs (Sheppes et al., 2009; Sheppes & Meiran, 2008). One series of studies, for instance, compared the effectiveness of distraction and reappraisal early and late in the emotion-generative process. Whereas late reappraisal was less effective than early reappraisal, distraction was effective regardless of its timing, i.e., whether it was initiated early or late (Sheppes & Meiran, 2007), and this did not vary in accord with the intensity of the initial response (Sheppes & Gross, 2011). Future research could look into the timing effects of working memory load more systematically.

Another open question for future research is how the effects of working memory load depend on the relevance of the affective source for the current context. Theoretical accounts of emotion influences on decision-making have typically distinguished between integral and incidental influences (e.g., Loewenstein & Lerner, 2013). Integral emotions are experienced, or anticipated, in the actual decision context (e.g., the anger from being betrayed informing punishment, the anticipated pleasure from helping). Incidental emotions, on the contrary, are unrelated to the actual decision context but may still shape outcomes through misattribution, especially when people are unaware of their influence (Clore, Schwarz and Conway 1994). Such “free floating” affective influences can be expected to be quite common in daily life since humans rarely find themselves in a truly neutral state (Engelmann & Hare, 2019), which points to the risks of affective bias in decision-making domains such as health and law (Decety et al., 2010; Van Dillen & Vanderveen, 2017). It would be interesting to see whether working memory interventions that neutralize people’s affective states, such as the previously described Tetris interventions, could help reduce such biases.

For example, professionals that need to inflict intentional harm (e.g., surgeons) may neutralize their affective states through distractions so as not to interfere with task performance (Decety et al., 2010). Likewise, legal professionals may tax their working memory with demanding tasks (such as Tetris) after being confronted with gruesome criminal evidence, to prevent excessive emotional bias of subsequent assessments and decisions. Yet, taxing working memory may also suppress informative emotional influences on behavior, such as empathic responses to another person’s suffering (Gu & Han, 2007; Hiraoka & Nomura, 2016; Rameson et al., 2012). Thus, behavioral contexts that require high-quality interpersonal communication, such as therapist–client interactions, may call for minimal working memory interference (Fennern & Sur, 2022). Future research could examine the strategic use of working memory strategies in the regulation of affective influences on decision-making more closely.

Finally, it is important to note that the research discussed so far has mainly focused on the short-term effects of working memory load on affective processing. Whereas taxing working memory with a distracter task can be an effective regulation strategy in the short run, it may cause important affective signals to go unnoticed (Van der Wal & Van Dillen, 2013). Because the source of the response remains unchanged, and affective information is no longer effectively integrated with other relevant information in working memory, it is less likely evaluated in light of the individual’s needs, goals, and values (Lyadurai et al., 2018; Sheppes et al., 2014; Wilson & Gilbert, 2008), thus preventing successful adaptation to more stable problematic situations (Thiruchselvam et al., 2011; but see Bonanno et al., 1995) In the domain of eating, for instance, research has shown that affective cues of sweetness or saltiness no longer inform people’s responses to novel tastes when their working memory is taxed (Davies et al., 2012) and to directly suppress the perceived intensity of sweet, salty, sour, and bitter flavors (Liang et al., 2018; Van der Wal & Van Dillen, 2013). This compromised tasting may, in turn, distort important metabolic signaling and the (anticipated) pleasure from consumption (Bernecker & Becker, 2021) and may trigger compensatory consumption of hedonic (but typically unhealthy) substances (Duif et al., 2020; Van der Wal & Van Dillen, 2013). Future research would thus benefit from taking a more long-term perspective of (aggregated) distraction-based effects on individual health and well-being.

Conclusion

In this review, we aimed to demonstrate that the processing of both affective and nonaffective information depends critically on the availability of limited working memory resources. We introduced a new model, the WMAP, which points to the central role of working memory in the various stages of information processing, from 1) attentional selection, to 2) maintenance of affective information, and 3) subsequent outcomes such as feeling states and choices and actions.

We have seen how affective influences play out in each of these stages. For example, angry ruminations (Stage 2) can function as fuel to the flame for aggressive behaviors (Stage 3) following an initial provocation (Bushman, 2002). This aggressive behavior, in turn, may evoke novel aggressive reactions from others, thus reinforcing what has been labeled “a hostility bias” (Stage 1), in which situations and people are more readily perceived as antagonistic (Nasby et al., 1980). Similarly, preferential attention to desirable targets (Stage 1) facilitates the formation of spontaneous hedonic associations (Stage 2; Van Dillen et al., 2013), heightens the intensity of cravings (Stage 3—feelings; Berridge, 2009; Kavanagh et al., 2005), enhances the motivation to attain these targets (Stage 3—choices and actions; Gable & Harmon-Jones, 2011), and actually consumes them (Stage 3—choices and actions; Van Dillen et al., 2013).

We have discussed that when working memory load of a focal task increases, however, affective information is less likely processed, reducing its impact on our feelings and actions. Thus, some room for feelings is needed, for an affective stimulus to shape our thoughts, memories, and behaviors.

In this review, we moreover discussed the paradoxical nature of this basic aspect of the human information processing system. The moderating influence of task-based working memory load on affective processing may have both beneficial and harmful consequences for our daily self-regulation problems, depending on the nature of both the stimulus and the task, of the individual's predispositions, needs, and goals, and the timing of the additional load. When and how working memory load can best be used to regulate effective responses is thus a question still open for future research.

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ORCID iD

Lotte F. van Dillen https://orcid.org/0000-0002-3003-5488

Notes

1. Note that we define the concept of feelings broadly, as any valenced experience referring to the current subjectively accessible phenomenological state of the individual (Nummenmaa et al., 2018). Accordingly, we presume a similar elaboration process to affect people's subjective experiences of concrete positive or negative emotions but also mood and other affective states like pain, taste, and cravings.
2. Working memory load has also been documented to modulate more implicit affective memory processes that have previously been conceived to be relatively independent of higher-order cognitive control processes (LeDoux, 1995), such as classical (fear) conditioning (Carter et al., 2003; Cohen et al., 2020; Straube et al., 2011) and evaluative conditioning (Davies et al., 2012; Mierop et al., 2020).

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