Dealing with negative feelings

The role of working memory in emotion regulation

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geboren te Arnhem

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The basic law of the mind:

As you see – so you feel
As you feel – so you think
As you think – so you will
As you will – so you act

K. Sri Dhammananda

Contents

Chapter 1.

Dealing with negative feelings: The role of working memory in emotion regulation

Though negative emotions are inherently painful and aversive, getting rid of them is often remarkably difficult. Negative emotions are in many ways adaptive, by alerting people to potential threats and obstacles in the environment (Öhman, 2007). However, persistent negative emotions can impair psychological functioning. For instance, chronically activated negative emotions can interfere with cognitive performance (Eysenck & Calvo, 1992), impact social behavior (Forgas, 1994), or lower self-esteem and result in less optimistic life-expectations (Lyubomirsky, Tucker, Caldwell, & Berg, 1999). Moreover, chronic stress can undermine people's physical health; increasing the risk on cardiovascular disease (Kemp, Malhotra, Franco, Tesar, & Bronson, 2003) and weakening the immune system (Kemeny & Schedlowski, 2007).

No matter how sheltered people might lead their lives, some amount of negative emotion is probably unavoidable. Accordingly, it seems important to look for ways in which people may protect themselves against the potentially disruptive impact of negative emotions. One promising approach in this regard consists of minimizing the extent to which people attend to negative information. Attention to emotional information occurs very early in the emotion generation process (Gross & Thompson, 2007). Hence, by controlling attention to negative information, people may inhibit any negative emotional experiences before they have taken full swing (Dandeneau, Baldwin, Baccus, Sakellaropoulo, & Pruessner, 2007). The idea of attentional control has long been recognized by emotion regulation theorists (Ochsner & Gross, 2005; Parkinson & Totterdell, 1999; Nolen-Hoeksema & Morrow, 1993). Nevertheless, surprisingly little is known about its basic mechanisms. The central aim of the present work is therefore to investigate the processes that underlie the regulation of negative emotions through attentional control.

The following paragraphs first review the literature on why negative emotions are so pervasive, and suggest that this pervasiveness can at least partly be explained by the attentional priority of negative information. Next, it is described how negative emotions may be regulated through the control of attention to negative information. A working memory model of distraction is discussed, which suggests that the processing of negative information may depend critically on the availability of working memory resources. The present review concludes by considering some important limitations and implications of a working memory model of distraction.

The Pervasiveness of Negative Emotions

The meaning of the term emotion and related constructs such as mood, affect, or stress has been subject to recurrent debates within psychology (Russell, 2003). Accordingly, it is useful to be explicit about the way in which these terms are used in the present context. The current analysis refers to negative emotional states in the broadest sense, encompassing all mental states that can have a negative valence, such as discrete emotions, moods and feelings. Although in everyday language there exist important differences between various types of emotional processes, research indicates that the functional differences between them are fuzzy (Oatley & Jenkins, 1996). Moreover, specific emotions, moods and feelings all involve changes in core affect, i.e., basic states of feeling good or bad, aroused or calm (Russell, 2003). As such, the regulation of discrete emotions, moods, and feelings likely involve some common principles. These common principles are the focus of the present discussion.

Negative emotional states are a pervasive aspect of psychological functioning (Kuhl & Beckmann, 1994; Nolen-Hoeksema, 1998; Watkins, 2008) and their influence extends to many domains of human life, such as intimate relationships, social networks, parenting, and professional performance (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001). Moreover, when people process information, they tend to give more weight to negative than to positive aspects. For instance, people’s mood states are influenced more strongly by negative than by positive events (David, Green, Martin, & Suls, 1997), and people become more distressed about losing money than they are happy about gaining it (Kahneman & Tversky, 1984).

Because of the biological significance of negative emotional stimuli, the human brain may be designed in a way that negative information easily captures attention (Anderson & Phelps, 2001; Öhman, 2007). In line with such an automatic vigilance account (Pratto & John, 1991), research has demonstrated how processing of negative information can occur quickly and unintentionally

(Dijksterhuis & Aarts, 2003; Eastwood, Smilek, & Merikle, 2001; Robinson & Compton, 2006; Smith, Cacioppo, Larsen, & Chartrand, 2003, see also Chapter 4), and triggers responses across a broad array of sensory modalities (Bradley, Cuthbert, & Lang, 1996; Nolen-Hoeksema, Morrow, & Fredrickson, 1993; Shapiro, Jamner, Goldstein, & Delfino, 2001).

Negative information not only draws attention more easily, it also facilitates attention to other negative information, which may result in a vicious cycle of negative thinking that can prolong and intensify people's negative emotional states (Bower & Mayer, 1989; Bradley et al., 1996; Nolen-Hoeksema et al., 1993; Siemer, 2005; Watkins, 2008). For example, individuals, who tend to engage in negative ruminative thinking after an initial negative event, display exacerbated depressive symptoms over time, and are at a higher risk of developing new depressive episodes (Morrow & Nolen-Hoeksema, 1990; Nolen-Hoeksema, 2000). Moreover, people with such a ruminative response style were found to display poorer problem solving skills (Lyubomirsky et al., 1999), less cognitive flexibility (Davis & Nolen-Hoeksema, 2000) and increased procrastination (Ward, Lyubomirsky, Sousa, & Nolen-Hoeksema, 2003).

One explanation for the detrimental effects of negative information processing on human performance is the idea that emotions, for instance, through negative thought intrusions, draw upon limited information processing resources (Ellis, Moore, Varner, Ottaway, & Becker, 1997; Eysenck, Derakshan, Santos, & Calvo, 2007). More specifically, negative emotions may increase the allocation of attention to aversive information, at the cost of task-related information (Davis & Nolen-Hoeksema, 2000; Joormann, 2004; Luu, Tucker, & Derryberry, 1998). In line with this, Meinhardt and Pekrun (2003) demonstrated how the amplitude of event-related brain potentials which indicate the allocation of attention to task-related processes, were smaller when participants performed a task in a negative compared to a neutral state. Paradoxically, the idea that negative emotions occupy limited processing resources has also been the starting point for research on an effective way to deal with negative emotions, namely distraction.

Distraction from Negative Emotion

Whenever people direct their attention away from a focal event, they engage in distraction. Distraction depends on the availability of a compelling substitute to occupy one's thoughts, in order to prevent the occurrence of unwanted thoughts (Gerin, Davidson, Christenfeld, Goyal, & Schwartz, 2006). In a comprehensive study of emotion regulation strategies, Parkinson and Totterdell (1999) observed that people may use various distracting activities, such as "making plans", "tidy up" or "do something one has been putting off doing" as ways to regulate their negative emotional states (Parkinson & Totterdell, 1999). Despite negative emotions' pervasive qualities, people thus indicate that they can actively regulate their negative emotional states by seeking out diverting activities.

To account for the effects of distraction in dealing with depression, Nolen-Hoeksema (1987) proposed a response styles theory. The theory suggests that individuals who distract themselves from their negative state will experience relief from their depressive symptoms, whereas individuals who engage in ruminative thinking in response to an initial negative emotional event will experience amplification and prolongation of their depressive states. Even though individuals may focus on their depressive symptoms to try to understand and repair this aversive state, according to response styles theory, this focus will often only make individuals more depressed. In contrast, distracting responses may take the individual's mind off his or her symptoms of depression, such that dysfunctional response patterns are prevented (Morrow & Nolen-Hoeksema, 1990, p.519).

A number of research findings have confirmed the effectiveness of distraction strategies for regulating negative emotions (Glynn, Christenfeld, & Gerin, 2002; Joormann & Siemer, 2004; Nolen-Hoeksema & Morrow, 1993; Rusting & Nolen-Hoeksema, 1998). For instance, one study (Gerin et al., 2006) examined the effects of distraction on participants' blood pressure responses to angry provocations. Following an anger induction, which resulted in a blood pressure rise, participants were asked to wait in an isolated cubicle. In the no-distraction condition, the cubicle was devoid of any stimuli; in the distraction condition, the cubicle contained a panel on which more than 30 brightly colored cards and posters were placed. In addition, magazines and small toys were placed in easy reach. Although blood pressure remained high for the participants who waited in the no-distraction condition, blood pressure levels returned to baseline quickly when participants waited in the distraction condition.

Research has demonstrated the effectiveness of distraction across a wide range of activities, for example visualizing scenes such as walking through a shopping mall or sitting in a double-decker bus driving down the street (Joormann & Siemer, 2004; Rusting & Nolen-Hoeksema, 1998), sorting cards (Morrow & Nolenhoeksema, 1990), responding to colored lights (Christenfeld, 1997) and filling out bogus questionnaires (Glynn et al., 2002). Apparently then, the effects of distraction on emotion are not restricted to the engagement of a specific task type, but rely on more general aspects of attentional processing. As such, a deeper understanding of the underlying mechanisms of distraction may be derived from basic theories of attention.

A Working Memory Model of Distraction

Attention may be defined as the enhanced processing of some aspects of the environment while ignoring others (Johnston & Dark, 1986). As such, attention selects from the constant stream of information, the information that is most relevant for current behavior. The concept of attention is among the most intensely studied topics within psychology and cognitive neuroscience (Corbetta & Shulman, 2002; Hopfinger, Buonocore, & Mangun, 2000; Posner & Petersen, 1990). Attention is thought to be controlled by two mechanisms: Bottom-up processes that are driven by salient information properties and top-down processes that are controlled in accord with people's ongoing plans and behaviors (Buschman & Miller, 2007; Corbetta & Schulman, 2002; Egeth & Yantis, 1997).

Bottom-up attention filters select information on the basis of salient aspects that are likely to be important for adaptive behavior (Egeth & Yantis, 1997). These could be aspects such as novelty, or predictability (Desimone & 1995) or other features with a strong biological relevance (Öhman, 2007). The nervous system responds to these particular aspects in a strong and automatic manner, such that this information is prioritized in further processing (Li et al., 1993; Desimone et al., 1994). For instance, the enhanced neural activity of the human amygdalae in response to aversive stimuli is thought to underlie automatic vigilance for negative information (Anderson & Phelps, 2001; Davis & Whalen, 2001).

Top-down attentional control, on the other hand, is directed by the plans and actions people are engaged in, and modulates the role of bottom-up attention filters (Corbetta & Shulman, 2002; Knudsen, 2007). Top-down control may be crucial for flexible behavior. Without top-down attentional control, people would be unable to adjust to new or complex situations, control their impulses, or resist temptations (Norman & Shallice, 1986). Moreover, top-down attentional control plays a central role in higher cognitive processes, such as executive functioning (Cohen et al., 1997), intelligence (Gray, Chabris, & Braver, 2003) and language (Baddeley, 2003). A key system in top-down control is working memory. Working memory is a mental device that holds a limited amount of information for periods of seconds such that this information can be evaluated and manipulated in accord with people’s behaviors and concerns (Baddeley, 1986).

Working memory is of particular importance when different types of information compete over attention, and threaten to interfere with the current task goal (Teasdale, Proctor, Lloyd, & Baddeley, 1993, Unsworth & Engle, 2007). Working memory thus not only temporarily holds information for further processing, it also controls attentional capture of new information (Corbetta, Kincade, & Shulman, 2002; Egner & Hirsch, 2005; Koivisto & Revonsuo, 2007; Einhäuser, Rutishauser, & Koch, 2008). The control of working memory on attention increases when a central task becomes more demanding, such that salient information aspects that usually grab attention through bottom-up processes, but that do not bear any relevance to task performance, will less likely be processed under these demanding circumstances (Knudsen, 2007). For instance, researchers demonstrated how novel stimuli capture attention only when working memory load of a central task is low but not when it is high (Spinks, Zhang, Fox, Gao, & Tan, 2004).

The relevance of working memory has long been established in research on ‘cold’ cognitive processes (Baddeley, 1986; Cohen et al., 1997; Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000). Yet, the functions of working memory may extend beyond the cognitive domain, and may also play a role in ‘hot’ emotion processing (Davidson & Irwin, 1999; Pessoa, 2008; Van Dillen & Koole, 2007). The idea that emotion processes occupy working memory resources is increasingly accepted in the emotion literature (Ashcraft & Kirk, 2001; LeDoux, 1996; Ochsner & Gross, 2005, see also the previous section on the pervasiveness of negative emotions). In view of these findings, the use of working memory resources may also underlie distraction from negative emotions.

In line with this reasoning, researchers (Van Dillen & Koole, 2007) proposed a working memory model of distraction from negative emotion. The basic assumption of the model is that task-related and emotion-related information compete over working memory resources because working memory capacity is limited. When working memory demands of other activities are low, processing of negative information will by default receive priority because of its adaptive value, and may accordingly impact people’s emotional states. However, when a focal task is more demanding, for example, because of its high complexity, more working memory resources are needed to perform the task effectively, such that less resources will be available for emotional processing. The unfolding of an emotional response to a negative event thus may depend on the availability of working memory resources. The working memory account of distraction from negative emotions leads to a number of theoretical implications.

A first implication of the working memory model is that effective distraction may not only depend on the presence of a demanding 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 linear impact on people’s negative emotional states, such that a highly demanding task reduces the intensity of people’s negative emotions to a greater degree than a moderately demanding task, whereas a moderately demanding task will still be more effective than a mildly demanding task. Moreover, research has shown that the involvement of working memory in a task can fluctuate over time (Ashcraft & Kirk, 2001; Jostmann & Koole, 2006), such that dynamic changes in task demands can be expected to influence people's emotional states on a moment-to-moment basis.

A second implication is that the effects of working memory load on emotion may interact with emotional intensity. Strongly negative stimuli have an even stronger impact on information processing resources than mildly negative stimuli (Mogg et al., 2000; Schimmack, 2005). Therefore, people's negative emotional states may not only be affected by varying task demands, but also by varying the intensity of negative information. If strongly negative information incorporates more working memory resources than mildly negative information, a working memory account thus implies that taxing people's working memory with a highly demanding task should reduce people's emotional responses to strongly negative stimuli to a greater degree than people's responses to mildly negative emotional stimuli.

A third implication of the working memory model is that taxing working memory may modulate the automatic vigilance for negative information. Even though negative information is generally more attention grabbing than positive or neutral information (Eastwood, Smilek & Merikle, 2001; Pratto & John, 1991), a working memory account of distraction from negative emotion suggests that attention to negative information may be attenuated when the information is irrelevant for current behavior. Given that working memory facilitates attention to task-relevant information, while it minimizes interference of task-irrelevant information, increasing working memory demand of a central task may thus result in decreased interference of negative information. Thus, although attention to negative information is assumed to be fast and automatic (Robinson & Compton, 2006; Dijksterhuis & Aarts, 2003), a working memory account thus proposes that attention to negative information can be controlled by top-down working memory processes.

A final implication of the working memory model is that working memory load may modulate emotional processing in the brain. The neural circuits of both working memory (DeFockert, Rees, Frith, & Lavie, 2001; Duncan & Owen, 2000; Jonides et al., 1993) and emotion (Dalgleish, 2004; Damasio et al., 2000; Davidson et al., 2002) are well defined. Moreover, research suggests that cognitive mechanisms for attention interact with limbic regions in emotional processing (Hariri, Bookheimer, & Mazziotta, 2000; Mayberg et al., 1999; Northoff et al., 2004). If emotional information competes with non-emotional information for the limited processing capacity of working memory, this may therefore be reflected in the dynamics of the brain systems involved. More specifically, a working memory account suggests that the increased engagement of working memory regions in response to greater task demands may go hand in hand with the decreased involvement of regions implicated in emotional processing.

In summary, the working memory model holds that the competition of task-related and emotion-related processes over working memory resources can be influenced by varying both task demands as well as the intensity of emotional stimuli, such that distraction from negative emotion is the result of the dynamic interplay between these two processes. Moreover, taxing working memory should not only distract people from their negative emotional states, but should also lead to decreased attentional interference of task-irrelevant negative information. Finally, the interaction of cognitive and emotional circuits in the brain suggests that increased activation of working memory regions should modulate emotional brain responses.

Empirical Support for a Working Memory Model of Distraction

The present working memory account provides a new theoretical framework for the process of distraction from negative emotion. Nevertheless, a number of empirical findings provide some initial support for the various assumptions of the model.

In a classic series of studies on the effect of nitrogen narcosis, or diver's drunkenness, Baddeley and colleagues (1966) demonstrated that divers' anxiety about being at open-sea deteriorated their underwater performance on a simple motor task (removing screws from a plate as quickly as possible), yet failed to affect their performance on a demanding verbal reasoning task (Baddeley & Flemming, 1976). Subsequently, Baddeley explained these divergent findings in terms of a limited resource model of attention, arguing that contrary to the simple screw-plate task, the reasoning task may have been sufficiently demanding to reduce attention to potentially worrying environmental cues (Baddeley, 2007).

The first systematic exploration of the role of processing resources in distraction from negative emotion was conducted by Erber and Tesser (1992). These investigators examined the effect of the amount of effort that participants invested in a distracter task. In two experiments, participants viewed an emotionally arousing film clip after which they solved math equations for ten minutes and then reported their moods. In one experiment effort investment in the math task was made more or less motivationally relevant to participants, by stating that effort was only mildly or highly indicative of performance. In the other experiment, task effort was manipulated by varying the complexity of the equations. In both experiments task effort was found to modulate negative mood, such that participants displayed less negative moods in response to the negative movie clip when they were told that task effort was instrumental for performance rather than performance unrelated, or when they subsequently solved complex rather than simple math equations.

Erber and Tesser (1992) explained their findings in terms of a limited capacity model, arguing that: "... it may be that a task which requires the bulk of people's cognitive resources 'absorbs' moods by preventing further preoccupation with mood-related thoughts" (p. 342). Such a limited resources account is consistent with the working memory model of distraction. However, Erber and Tesser's findings may not be conclusive. Even though the investigators proposed a role for limited processing resources in distraction, they did not specify the exact nature of these resources. Moreover, although task effort is assumed to involve the allocation of working memory resources (Jansma, Ramsey, de Zwart, van Gelderen, & Duyn, 2007), varying task effort is no established manipulation of working memory load. Hence, a more systematic examination of the use of working memory resources in distraction from negative emotion would be to manipulate working memory load of a task directly.

In a set of three experiments (Van Dillen & Koole, 2007) working memory load of a distracter task was systematically varied. In all three experiments, 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 mood scale. Thus, the use of working memory resources in distraction could be examined on a moment to moment basis. The central prediction across the three experiments was that participants' moods would be modulated by the working memory load of the distracter task, such that participants would report less negative moods when task load was high than when task load was low, or absent. Because strongly negative stimuli engage more information processing resources than mildly negative stimuli (Schimmack, 2005), varying task load was predicted to have a greater moderating impact on mood responses to strongly, rather than mildly negative stimuli. Accordingly, participants' momentary moods were expected to be the result of dynamic changes in the use of working memory resources for processing both the emotional stimuli and the distracter task.

In the first experiment, the effect of working memory load on distraction was examined by manipulating the absence or presence of a math task. Hence, a math task followed a picture in only half of the trials, whereas the other half of the trials did not contain a task. In line with predictions, participants reported less negative moods after viewing negative pictures when they subsequently performed a math task rather than no math task. Performing a math task did not influence participants' moods in response to neutral pictures. Moreover, participants still reported more negative moods in response to strongly negative pictures than to weakly negative pictures when a math task was absent. When a math task was present, participants reported equal amounts of negative moods to strongly and mildly negative pictures.

In the second experiment the role of working memory load in distraction was examined by manipulating the complexity of the distracter task. Previous research has found that complex math tasks make greater demands on working memory capacity than simple math tasks (Ashcraft, Donley, Halas, & Vakali, 1992). In half of the trials, neutral, mildly negative, and strongly negative pictures were followed by a complex math task whereas in the remaining trials, pictures were followed by a simpler math task. In line with a working memory model of distraction, participants reported less negative moods in response to negative pictures when they performed a complex rather than a simple math task. Task complexity did not influence participants' moods in response to neutral pictures. Moreover, working memory load again interacted with emotional intensity, such that participants reported more negative moods in response to strongly rather than mildly negative pictures when they performed a simple math task, whereas participants reported equal amounts of negative mood when they performed a complex math task.

In the third experiment, the effect of working memory load on distraction was investigated by manipulating the predictability of a math task (Baddeley, Chincotta, & Adlam, 2001), such that following picture presentation, participants either performed an announced math task, a sudden math task or no task. When a task is unpredictable, people cannot rely on already activated knowledge structures from long-term memory. Consequently, more working memory resources have to be allocated to unpredictable tasks than to predictable tasks (Baddeley, Chincotta, & Adlam, 2001). Because working memory load in this experiment could vary between high load (sudden task), intermediate load (announced task) or, no load (no task), the investigators could examine the linear effect of working memory load on distraction from negative mood. In line with predictions, participants negative moods decreased with increasing working memory load of a task, such that participants reported most negative moods in response to negative pictures when no task was present, intermediate negative moods when they performed a predictable task, and least negative moods when they performed a sudden task. In addition, the effect of working memory load again interacted with emotional intensity. Whereas participants still reported more negative moods in response to strongly compared to mildly negative pictures when they performed a predictable task, or no task, they reported equal amounts of negative moods to strongly and mildly negative pictures when they performed a sudden task.

In summary, across three experiments, variations in working memory load were found to moderate the impact of viewing negative pictures on mood (Van Dillen & Koole, 2007). Participants reported less negative moods 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 mood was stronger when the task was unpredictable, than when it was predictable. Finally, performing a task had a stronger moderating impact on negative mood when participants had viewed strongly rather than mildly negative pictures. In line with a working memory account, these experiments thus demonstrated how distraction from negative emotion is the result of a dynamic use of working memory resources by both task-related and emotion-related processes

Though an automatic vigilance account suggests that attention to negative information is fast and unintentional (Pratto & John, 1991), a working memory model of distraction predicts that when working memory load of a current task is high, attention to negative information can be attenuated when it bears no relevance for the task (Knudsen, 2007). This idea was tested in a recent set of studies (Van Dillen & Koole, 2008), in which people had to evaluate the gender of angry and happy facial expressions, while they concurrently performed a more or less demanding focal task. Working memory load of the task was manipulated by varying the presence or absence of a math task (Experiment 1) or by varying the mental rehearsal of a one- versus eight-digit number (Experiment 2). Emotional expression of the faces is irrelevant for performance on the gender-naming task. Accordingly, longer response latencies to angry than to happy faces index greater attentional interference of negative information (Pratto & John, 1991). In line with an automatic vigilance account, participants indeed responded more slowly to angry than to happy faces, but only when working memory load of the concurrent task was low. When working memory load was high, participants were as fast in response to angry as to happy faces. In line with a working memory account, working memory load thus modulated attentional interference of negative information.

The foregoing findings provide initial support for a working memory model of distraction. By systematically varying both task demands and emotional stimulus intensity, it was demonstrated that changes in people's moods could be explained by the dynamic use of working memory resources for both task-related and emotion-related processing (Van Dillen & Koole, 2007). Moreover, it was shown that loading working memory not only modulated the intensity of people's negative emotional states, but also the degree to which negative information interfered with attention (Van Dillen & Koole, 2008).

Neuropsychological Support for a Working Memory Model of Distraction

With the introduction of functional magnetic resonance imaging (fMRI), a powerful imaging technique has become available to examine the neural mechanisms of various psychological phenomena. Due to this development, knowledge about neuropsychological processes rapidly accumulates, and enables researchers to test increasingly refined predictions about the workings of the brain. As such, the neural circuits of both working memory (DeFockert et al., 2001; Jonides et al., 1993) and emotional processes (Dalgleish, 2004; Damasio et al., 2000) are now well understood. Moreover, research suggests that these circuits may oftentimes operate in a coordinated manner (Mayberg et al., 1999; Northoff et al., 2004). The assumption that both emotional and non-emotional information compete for the limited processing capacity of working memory, may therefore be tested in the brain. More specifically, a working memory account predicts that task load increases involvement of cognitive brain regions while it decreases the activity of brain regions involved in emotional processing.

A recent experiment (Van Dillen, Heslenfeld, & Koole, 2008) investigated this idea using fMRI, such that participants' brain responses could be measured throughout the experiment. In this experiment, which had a similar experimental design as the previously described series of studies on distraction (Van Dillen & Koole, 2007), participants received a set of 128 trials that consisted of a neutral or negative picture followed by either a simple or complex math equation and a mood scale. The imaging experiment replicated the effect of task load on subjective negative emotions (Van Dillen & Koole, 2007), such that participants reported less negative moods in response to negative pictures when they subsequently performed a complex rather than a simple math task.

More importantly, task load was found to modulate emotional brain responses. Performing a complex task compared to a simple task attenuated responses to negative pictures in the bilateral amygdalae, and the right insula, such that activity in these regions no longer differentiated between negative and neutral valence. Inversely, performing a complex rather than a simple task resulted in increased activity in regions implicated in cognitive processing, for example the right dorsolateral frontal cortex and the superior parietal cortex. Subsequent correlation analyses revealed that during task performance, the decreased engagement of 'emotional regions' went hand in hand with the increased engagement of 'cognitive regions'. Accordingly, the present findings demonstrate how working memory processes may underlie both cognitive and emotional systems of the human brain. In line with a working memory account, taxing working memory with a demanding task attenuated neural responses in regions involved in emotional processing, while it resulted in increased activity in regions involved in cognitive processing.

Other researchers have reported similar effects of working memory load on brain responses to painful stimuli (Bantick et al., 2002; Frankenstein, Richter, McIntyre, & Remy, 2001; Tracey et al., 2002; Valet, 2004). In one fMRI experiment, participants performed a counting Stroop task during which they received painful thermal stimulation. The counting Stroop task consisted of naming the number of words on screen regardless of the words' meaning. Working memory load of the task was manipulated by varying the possible interference of the words with the counting task (Bush et al., 1998), such that in the high load condition, participants had to count interfering number words, e.g. 'eight' or 'five', while in the low load task they had to count neutral words, e.g. 'cat' or 'frog'. Results showed that performing the interfering counting task compared to the neutral counting task, significantly reduced pain intensity scores to thermal stimuli, as well as activity in areas of the pain matrix (i.e., thalamus, insula, the anterior cingulate cortex, or ACC). The ACC is known to be involved not only in pain processing, but also in the allocation of attentional resources (Turken & Swick, 1999). Possibly, loading working memory thus modulates pain responses by attenuating attention to pain-related information.

Even though the working memory model of distraction is a new theoretical framework, the foregoing neuropsychological experiments provide some initial support for its main assumptions. Moreover, these findings are in line with behavioral findings and demonstrate how taxing working memory may not only modulate emotional experiences and attention to negative information, but also emotional responses in the brain.

When Distraction Fails

The foregoing work suggests that taxing working memory with a demanding task often helps people to find relief from their negative emotional states. However, this strategy may not benefit all individuals at all times. For instance, in one study, depressed college students were able to distract themselves from negative unwanted thoughts initially, but eventually experienced a resurgence of depressive symptoms (Wenzlaff, Wegner, & Roper, 1988). This resurgence could be explained by the fact that the students distracted themselves from their unwanted thoughts by entertaining other negative thoughts, even though they acknowledged that positive distracters would probably be more effective. Depressed individuals may experience difficulties selecting appropriate distracting activities because their depressive state enhances the accessibility of negative information (Joormann & Siemer, 2004; Lyubomirsky & Nolen-Hoeksema, 1993). In line with this, depressed students did engage in more positive distraction when this was provided by the investigators and was made highly accessible (Wenzlaff, Wegner, & Roper, 1988).

In a similar vein, a growing body of research suggests that people with relatively low working memory capacity suffer more from the intrusive qualities of negative information than people with relatively high working memory capacity (Klein & Boals, 2001b; Feldman-Barrett, Tugade, & Engle, 2004; Brewin & Smart, 2005). Top-down working memory control is needed to discriminate task-relevant from task-irrelevant information on the basis of contextual cues (Unsworth & Engle, 2007). Individuals with low working memory capacity may thus experience difficulties regulating their negative emotional responses because they lack the resources to validly assess the relevance of negative information within a wider context (Brewin & Beaton, 2002; Conway & Engle, 1994; Dalgleish et al., 2007; Klein & Boals, 2001a; Unsworth & Engle, 2007).

A model that highlights the significance of relevance checking is Scherer's (2001) Sequential Evaluation Check (SEC). This model proposes that the nature of the unfolding response to an emotional stimulus depends on a series of appraisals of which the initial check is responsible for determining whether the stimulus will receive attention. Contrary to the prevailing literature on the negativity bias (Pratto & John, 1991), the SEC model suggests that this initial check is not about the valence of emotional stimuli, but rather about their relevance. Even though negative information commonly is highly relevant for people's ongoing behavior and accordingly receives prioritized processing, this reasoning implies that negative information may be neglected when it has no implications for people's current activities. In accord with a working memory account, the SEC model thus predicts that irrelevant negative information will less likely be processed the more working memory demand of a central task increases (Van Dillen & Koole, 2008).

Scherer's sequential evaluation model (2001) implies that the more relevant emotional information will be for task performance, the more likely this information will receive attention. Indeed, several neuro-imaging studies have shown how the relevance of emotional stimuli for the task may modulate neural responses to these stimuli (Hariri, Bookheimer, & Mazziotta, 2000; Lange et al., 2003; Nakamura et al., 1999; Northoff et al., 2004; Smith, Stephan, Rugg, & Dolan, 2006; Vuilleumier & Driver, 2007). For instance, in one fMRI study, Nakamura and colleagues (1999) showed how brain activity in the right inferior frontal cortex in response to emotional faces was affected by the evaluation instructions participants received, such that responses in these areas were greater when participants had to judge the expression valence of the faces than when they had to indicate their attractiveness, or the background color of the facial stimuli.

In summary, although taxing working memory helps people distract themselves from negative emotion, distraction may not be effective for all individuals under all circumstances. One factor that may modulate the effectiveness of distraction may be the (perceived) relevance of negative information for people's current behavior, such that negative information more likely impacts people's emotional states when it is relevant, than when it is irrelevant.

Conclusions and Future Directions

Persistent negative emotions are a major cause of mental suffering (Nolen-Hoeksema, 2000). Various theorists have suggested that the perseverance of negative emotional states can be at least partially explained by the strong impact of negative information on human information processing (Eysenck, Derakshan, Santos, & Calvo, 2007; MacLeod, Mathews, & Tata, 1986). In line with this, the present analysis considered how controlling processing of negative information may be used to regulate negative emotional states. This analysis gave particular emphasis on the role of working memory processes in the control of negative information. More specifically, it was suggested that the development of a negative emotional response may depend critically on the availability of working memory resources.

Emotion regulation involves many domains of psychological functioning and the study of emotion regulation cuts across various scientific disciplines (Frijda, 1986; Gross, 2007; Oatley & Jenkins, 1992). Accordingly, any theory on emotion regulation should aim at integrating findings from these various domains. By providing a working memory account, the present review combined and explained findings on distraction from negative emotions from diverse backgrounds and disciplines into a single theoretical framework. Moreover, the present review considered recent empirical tests of a working memory model of distraction across a range of response modalities, including subjective experience, brain activity and behavioral responses, in an attempt to encompass the breadth of emotion regulation phenomena.

Distracting oneself by taxing working memory may be particularly effective to deal with the immediate impact of negative emotions, in order to cool down and view things from a more neutral perspective (Rice, Levine, & Pizarro, 2007). Yet, distraction is unlikely to be the ultimate solution to all of people's emotional problems. For instance, distraction may not be the most efficient way to deal with more structural causes of negative emotional states, such as low job satisfaction or family problems. Because taxing working memory leaves the source of negative emotional responses unchanged, responses to more stable negative situations may easily rebound once people cease to distract themselves (but see, Bonanno, Holen, Keltner, & Horowitz, 1995). Moreover, research has shown how structurally diverting attention away from a negative emotional experience, for example by suppressing it, or by keeping it secret, may result in detrimental effects on both mental and physical well-being (Pennebaker & Susman, 1988; Polivy, 1998; Wenzlaff, Rude, Taylor, Stultz, & Sweatt, 2001).

On the contrary, by attending to negative experiences, for example by talking or writing about it, people have been found to find relief from mental suffering and show improved well-being (Donnelly & Murray, 1991; Esterling, Antoni, Fletcher, Margulies, & Schneiderman, 1994; Pennebaker & Chung, 2007). In a similar vein, mindfulness training (Brown, Ryan, & Creswell, 2007; Kabat-Zinn, 2003; Teasdale, Segal, & Williams, 1995) teaches individuals to become more aware of their negative thoughts and feelings, and to relate to them in a wider, decentered perspective as "mental events" rather than as aspects of the self (Teasdale et al., 2000, p.616). Consequently, people can detach from their negative depressive thoughts and prevent the escalation of negative thinking patterns.

Some negative emotions are thought to trigger more negative ruminative thinking than other emotions. Because distraction from negative emotion is assumed to function through the reduction of negative thought intrusions (Nolen-Hoeksema, 1998; Siemer, 2005), the impact of distraction on specific emotions thus may vary. For example, shame responses more readily result in negative thinking patterns and impact people’s depressive mood more strongly than guilt responses, because shame involves a negative evaluation of the self in terms of internal, global, stable attributions whereas guilt involves the negative evaluation of a specific behavior in terms of more specific, unstable attributions, (Orth, Berking, & Burkhardt, 2006; Tangney, Wagner, & Gramzow, 1992). Possibly then, distracting people with a demanding task may be particularly desirable to prevent the negative consequences of shame, while distraction may be less appropriate for regulating guilt.

In a related vein, emotional responses to positive events may not trigger ruminative thinking to the same degree as emotional responses to negative events (Feldman, Joormann, & Johnson, in press; Fiedler et al., 1993). In fact, positive emotional states are thought to impact people’s cognitions quite differently than negative emotions, resulting, for example, in increased cognitive flexibility (Baumann & Kuhl, 2005; Dreisbach & Goschke, 2004). Hence, a working memory model of distraction may have different implications for positive emotions than for negative emotions. In line with this, a recent set of studies failed to find an effect of working memory load on distraction from positive mood (Van Dillen & Koole, 2006; though see Erber & Tesser, 1992).

One interesting question would be whether taxing working memory with a demanding task would not only regulate emotional states, but also bodily needs more generally, such as hunger, fatigue, or sexual arousal. For example, when working towards a solid deadline, people sometimes forget to eat, while people in a lively conversation may loose track of time and fail to notice they are getting tired. Several studies on the role of attention in subjective pain experience provide some support for this idea (Christenfeld, 1997; Frankenstein et al., 2001; Bantick et al., 2002). Moreover, research on craving has demonstrated how desire-related thoughts, like negative thoughts, are particularly powerful in drawing attention and capturing working memory resources (Kavanagh, Andrade, & May, 2005). Possibly then, loading people's working memory with a demanding task may similarly distract people from their cravings as they may distract people from their negative feelings. In support of this idea, May and colleagues (May, Andrade, Panabokke, & Kavanagh, 2004) found that visualizing a game of tennis reduced craving in smoking-deprived individuals. Future research is needed to examine the role of working memory in distraction from bodily needs.

Coda

At any moment in time, humans can only keep a few things in their minds. This is a basic aspect of human life. Ironically, this fundamental limitation of human information processing may also have some beneficial consequences. Because the processing of both emotional and non-emotional information depend on the availability of limited resources, people can distract themselves from their negative emotions by replacing these with an engaging task. As such, in dealing with negative feelings, people need not focus on what they are currently feeling, but instead may focus on what they are currently doing.

Overview of This Dissertation

The present dissertation examines how processing of negative emotional information may depend on the availability of working memory resources. The central hypothesis under investigation is that the more working memory is being used by a distracting activity, the less room may remain for negative emotions to persist. In the current chapter (Chapter 1), the theoretical background and main empirical findings (as discussed in Chapters 2 to 4) of this working memory model of distraction from negative emotion were discussed, as well as some of its major limitations and implications. The remainder of the dissertation consists of the three empirical chapters that each deal with a specific aspect of a working memory model of distraction. Chapter 2 provides an initial test of the effect of loading working memory on people's emotional experiences. Chapter 3 is aimed at replicating and extending the findings of Chapter 2 and examines the effect of working memory load on both emotional experience as well as circuits within the emotional brain. Finally, in Chapter 4, the effect of working memory load on attentional interference of negative information was investigated.

The reader may find some repetition in the following chapters in terms of methodology and theoretical background. This is deliberate and allows for each chapter to be read without cross-referring to other chapters. Indeed, each of the following chapters comprises a published or submitted article that can be read on its own.

Chapter 2.

Clearing the mind: a working memory model of distraction from negative mood

This chapter is based on Van Dillen, L.F., & Koole, S.L. (2007). Clearing the mind: a working memory model of distraction from negative mood. *Emotion, 7, 715-723.*

Action seems to follow feeling, but really action and feeling go together; and by regulating the action, which is under the more direct control of the will, we can indirectly regulate the feeling, which is not.

- William James (1899, p. 500)

One of James' important insights was that people's actions and feelings are closely intertwined. Although feelings often prompt subsequent actions, actions influence feelings as well. For example, when people feel frustrated after a long day at work, they may exercise at the gym in order to feel better (Byrne & Byrne, 1993). By studying outside of campus, students can prevent being lured into the thrills and pleasures of student life (Fishbach & Shah, 2006). And by foregoing practice when feeling uncertain about their performance, people can shield themselves against the disappointment of failure (Jones & Berglas, 1978; Tice, 1991).

In the present research, we highlight an additional way in which people's actions may regulate their feelings. More specifically, we investigate how actions that load working memory can distract people from their negative moods. In the following paragraphs, we begin by reviewing previous research on distraction from emotion. Next, we suggest that a key aspect of distraction is the use of limited processing capacity in working memory. The more working memory is being used by a distracting activity, the less room will remain for negative moods to persist. To test this notion, we present three experiments that analyzed the effectiveness of varying demands on working memory in distracting individuals from negative mood. Notably, the present research focused on the regulation of negative mood, because of its relevance to understanding mood disorders like chronic anxiety and depression (Nolen-Hoeksema, 2000) and because regulation of negative mood has received most attention in the emotion regulation literature (Gross, 1998).

Distraction from Emotion

An act of distraction involves intentionally or unintentionally drawing one's attention away from a focal event. In the case of mood regulation, a distracting activity draws the person's attention away from his or her mood, so that the person's mood becomes more neutral. As such, the concept of distraction plays an important role in leading theories of emotion regulation (Bishop, Duncan, & Lawrence, 2004; Rusting & Nolen-Hoeksema, 1998; Trask & Sigmon, 1999).

Empirical research has confirmed that distraction can indeed have an important influence on people's moods. For example, depressed individuals who are distracted from their dysphoric mood states show alleviation of their depressive symptoms (Joormann & Siemer, 2004; Morrow & Nolen-Hoeksema, 1990). Likewise, angry individuals who are distracted show reduced anger (Gerin, Davidson, Christenfeld, Goyal, & Schwartz, 2006; Rusting & Nolen-Hoeksema, 1998). Distraction can also decrease individuals' cardiovascular responses to negative mood (Gerin et al., 1996; Glynn et al., 2002).

Unfortunately, distraction may not always be that easy. People often find it difficult to distract themselves from their negative moods (Fiedler, Nickel, Asbeck, & Pagel, 2003; Josephson, Singer, & Salovey, 1996; Wegner, Erber, & Zanakos, 1993). Indeed, many individuals engage in prolonged negative ruminations when they would prefer to entertain more pleasant thoughts (Koole, Smeets, van Knippenberg, & Dijksterhuis, 1999; Kuhl, 1994; Martin & Tesser, 1996). These and other observations suggest that distraction involves more than simply turning one's attention elsewhere. Additional processes may be needed before distraction can be effective.

For distraction to be successful, people's feelings may need to be replaced by something else. In line with this idea, Morrow and Nolen-Hoeksema (1990) found that performing either motor movements (i.e., walking back and forth to sort giant cards) or a cognitive task both helped to distract participants from a previously induced depressive mood. However, the cognitive task was more effective than the motor movements in neutralizing participants' moods. To explain these findings, Morrow and Nolen-Hoeksema suggested that participants could still ruminate about their negative moods while they were moving about. Accordingly, the motor task might not have fully distracted participants from their mood states. By contrast, performing the cognitive task required participants to generate task-related thoughts which replaced mood-related thoughts. Thus, effective distraction may involve replacing emotionally charged thoughts with more neutral thoughts.

The differential effectiveness of various distracting activities was further explored by Erber and Tesser (1992). These investigators manipulated the amount of effort that participants invested in distracting activities, such as solving math equations. Task effort was manipulated by making investment in the task more or less motivationally relevant to participants, or by varying the complexity of the task. The results showed that distracting activities were more effective in neutralizing positive and negative moods to the extent that participants invested high rather than low effort in the distracting activity. Effortful cognitive activities are thus more distracting than other types of activities, presumably because effortful cognitive activities leave little room for mood states to persist.

A Working Memory Model of Distraction

Through which mechanisms might effortful cognitive activities prevent the continuation of negative moods? In the present article, we suggest that working memory is a likely candidate. Working memory is an assembly of structures and processes that is used for temporarily storing and manipulating information in memory (Baddeley, 1986). Because the capacity of working memory is limited, different activities compete over its resources. The more working memory capacity is used by one activity, the less can be used by another concurrent activity. We suggest that the same principle applies to mood-related processing. The more working memory a person needs to perform a distracter task, the less working memory will be left to maintain the person's current mood state.

Our working memory model of distraction from emotion assumes that mood-congruent cognitions are an integral part of the phenomenal experience of mood. This assumption has received strong empirical support: Negative affective states evoke mood-congruent cognitions (Blaney, 1986; Bower & Mayer, 1989; Siemer, 2005), even after the original stimulus that caused this state is no longer present (Bradley, Cuthbert, & Lang, 1996). People's cognitions thus often serve to sustain, and even intensify their initial negative affective response (Bradley et al., 1996; Nolen-Hoeksema, Morrow, & Fredrickson, 1993; Siegle, Steinhauer, Thase, Stenger, & Carter, 2002). Indeed, in a recent study, self-reported negative moods and mood-congruent cognitions were found to operate in a strictly parallel fashion (Siemer, 2005). The prevention of mood-congruent cognitions is thus a plausible mechanism that may underlie the effects of distraction.

This working memory account has important implications for understanding how different task demands may influence distraction from negative mood. First, any changes in task demands should distract from negative mood primarily to the extent that these task demands implicate working memory capacity. Second, the extent to which people use their working memory capacity can vary dynamically from moment to moment (Ashcraft & Kirk, 2001; Jostmann & Koole, 2006). It thus follows that dynamic changes in task demands can influence people's mood states on a moment-to-moment basis. Third, working memory capacity is a continuous variable, such that working memory can be used at low, medium, or high degrees (or take any intermediate value). Accordingly, a working memory account implies that varying task demands should have a linear effect on mood regulation. If a given task requires much working memory capacity, then distraction from negative mood should be relatively high. If a given task requires intermediate amounts of working memory capacity, then distraction from negative mood should be intermediate. If a given task requires low working memory capacity, then distraction from negative mood should be relatively low.

A more subtle but equally important implication of the present account involves the impact of task demands on processing of negative stimuli that vary in emotional intensity. Negative stimuli are generally more attention-grabbing than neutral or positive stimuli (Dolcos & McCarthy, 2006; Pratto & John, 1991). This processing advantage is stronger for strongly negative stimuli than for mildly negative stimuli (Schimmack, 2005). Strongly negative stimuli trigger more mood-congruent processing and, correspondingly, employ more working memory capacity than mildly negative stimuli (see for empirical evidence Klein & Boals, 2001b). A working memory account thus predicts an interaction between task demands and emotional intensity of negative stimuli. Distracter tasks that occupy working memory capacity may exert a greater influence on emotional processing of strongly rather than weakly negative stimuli.

The Present Research and Hypotheses

In the present research, we sought to test some of the predictions of the working memory model of distraction from negative mood. In three experiments, participants were presented with a series of neutral and negative pictures that varied in affective intensity. After viewing each picture, participants performed either a more or a less demanding task (or no task) and then reported their moods. Accordingly, the present research examined the role of distraction on moment-to-moment mood changes.

In Study 1, we investigated the effect of task presence and exposure to strongly versus weakly negative pictures on participants' moods. In line with a working memory model of distraction, we expected the intensity of negative mood reports to decrease when working memory load of a subsequent task would increase. Strongly negative pictures can be presumed to have a greater impact on working memory than weakly negative pictures (Schimmack, 2005). We therefore expected that a demanding task would attenuate participants' negative moods to a greater degree in response to strongly rather than mildly negative pictures.

Our main goal in Study 2 was to establish whether distraction depends on the amount of working memory capacity being used by the task, and not only on the redirection of attention away from the affective stimulus and towards the task. To this end, we experimentally varied the complexity of the distracting task by having participants solve both simple and more complex equations. In this way, we manipulated the amount of information to be held in working memory. In addition, we wanted to replicate the interaction between task demands and emotional intensity of negative stimuli. We thus expected complex tasks to have a greater impact on further processing of strongly negative stimuli than on further processing of weakly negative stimuli.

In Study 3, we wanted to vary working memory load while keeping qualitative task parameters constant. Therefore, we varied working memory load by manipulating both the presence and the predictability of the math task. When a task is unpredictable, people cannot rely on already activated knowledge structures from long-term memory. Consequently, more working memory capacity has to be allocated to unpredictable tasks than to predictable tasks (Baddeley, Chincotta, & Adlam, 2001). We predicted a linear effect of working memory load on distraction from negative mood: The more working memory capacity is used to perform a task, the less is used for mood-related processing, and thus the more a previously induced mood should decrease. Predictable math tasks were hence expected to induce more distraction than no task, and unpredictable math tasks were expected to induce more distraction than predictable math tasks.

Study 1

Study 1 provided an initial investigation of the influence of working memory processes on moment-to-moment mood changes. Participants were presented with neutral or negative pictures, followed by either a math task or no task, upon which participants reported their moods. We expected participants to experience less intense negative moods in negative trials with a task, than in negative trials without a task. Moreover, because the math task was assumed to interfere with mood-congruent processing, we expected that the math task would not influence mood during neutral trials. Finally, we examined whether affective intensity and task presence would interact, as expected by a working memory account of distraction. We thus predicted that mood ratings after strongly negative pictures would be more attenuated by performing a distracting task than mood ratings after mildly negative pictures.

Method

Participants and Design

Thirty-eight paid volunteers at the VU University Amsterdam (12 men and 26 women, average age 22) took part in the experiment. The experimental design was 2 (math task: no task versus math task; within participants) x 3 (picture negativity: neutral, mildly negative, or strongly negative; within participants). The main dependent variables consisted of participants' negative mood ratings and their math performance.

Procedure and Equipment

Upon arrival in the laboratory, participants were led to individual cubicles with a personal computer. The experimenter explained that the remaining instructions would be administered via a computer-program and left. After a brief introduction and filling out some personality questionnaires, participants proceeded with a picture viewing task. During this task, participants were presented with either neutral or negative pictures. These pictures had been selected from the International Affective Picture System (Lang et al., 2001). Based on published normative valence ratings (ranging on a scale of 1 [most unpleasant] to 9 [most pleasant]), we selected two sets of 60 pictures, namely a negative set (valence ratings under 2.50) and a neutral set (valence ratings between 4.00 and 5.00). The negative pictures were further divided into two categories of either strong negative valence (30 pictures with normative IAPS scores lower than 2.20) or mild negative valence (30 pictures with normative IAPS scores of 2.20 and higher). In this way, we investigated whether the affective intensity of the pictures would differentially impact mood ratings in trials with, and without a task. Negative pictures included images of scenes with burn victims, physical assaults, and angry faces. Neutral pictures depicted scenes of people in conversation, scenes of nature or buildings, household objects, and neutral faces.

The picture viewing task consisted of 120 trials. During each trial, a negative or neutral picture appeared on screen for 4 seconds. During half of the trials, participants also had to solve a math task after viewing the picture. In between the picture and the math task, an announcement of the math task was displayed on the screen for one second. The math task consisted of a moderately complex equation, such as ‘2*8 + 12 = 28’. Each equation combined a summation or subtraction with a product or a division. Participants judged whether the equation was correct by a keyboard response. Participants had 4 seconds to make this response. Both participants’ responses and their response times were recorded. At the end of each trial, participants rated, with a keyboard response, how unpleasant they felt at that moment on a 9 point scale (1 = *not at all*, to 9 = *very much*). In between trials, participants were asked to relax for 4 seconds. Before the 120 experimental trials, participants first received four practice trials to become familiar with the task. After the picture viewing task, participants were thanked for their efforts, debriefed, and paid by the experimenter.

Results

Math performance

A 3 (picture negativity) ANOVA showed no effect of picture negativity on participants' correct responses, $F(2, 36) < 1$, or on participants' response times, $F(2, 36) = 1.76$, *ns*.

Negative mood

We only analyzed the correct trials (74 %) to rule out possible influences of erroneous responding on participants' negative mood ratings. For instance, giving a wrong response might increase participants' negative moods. Throughout Studies 1-3, analyses of all trials or the incorrect trials did however not yield any differential results. Relevant means are displayed in **Table 1**.

To analyze participants moods, we conducted a 2 (math task) x 3 (picture negativity) ANOVA of participants' mood ratings. This analysis yielded a main effect of picture negativity: $F(2, 36) = 69.56$, $p < .001$. As expected, contrast analyses revealed a linear effect of picture negativity, $F(1, 37) = 134.52$, $p < .001$, such that participants reported most negative moods after strongly negative pictures ($M = 4.67$), less negative moods after mildly negative pictures ($M = 4.44$) and the least negative moods after neutral pictures ($M = 2.56$).

The ANOVA further yielded the predicted interaction between task and picture negativity, $F(2, 36) = 28.60$, $p < .001$. We proceeded by analyzing the effect of task separately for each picture negativity condition. Analysis of the neutral pictures yielded no effect of task, $F(1, 37) = 1.21$, *ns*. We therefore focused our further analyses solely on the negative trials. In the negative trials, the analyses produced an effect of task for both the strongly negative, as well as the mildly negative trials ($F(1, 37) = 60.35$, $p < .001$ and $F(1, 37) = 38.92$, $p < .001$, respectively). These effects indicate that, across both strongly and mildly negative trials, participants reported less negative moods in negative trials with a task, than in negative trials without a task.

Table 1. Mean Negative Mood as a Function of Picture Negativity and Task (Study 1; Standard Deviations between Brackets)

	Picture Negativity		
Task	Neutral	Mild	Strong
Absent	2.58_a (1.13)	4.82_b (1.64)	5.32_c (1.84)
Present	2.55_a (1.17)	4.06_d (1.47)	4.01_d (1.59)

Note. Ratings ranged from 1 (*not at all*) to 9 (*very much*). Means that do not share subscripts differ within rows and columns at $p < .05$.

Another valid way to interpret the picture negativity by task interaction in the negative trials is to consider the effect of picture negativity separately for each task condition. This analysis yielded an effect for picture negativity in the negative trials without a task $F(1, 37) = 28.45$, $p < .001$. In these trials, participants reported significantly less intense negative moods following mildly negative pictures ($M = 4.83$) than following strongly negative pictures ($M = 5.32$). There was, however, no effect of picture negativity on negative mood in trials with a task, $F(1, 37) < 1$. ($M = 4.01$ and $M = 4.07$ respectively for mildly versus strongly negative pictures). Thus, strongly negative pictures only elicited more negative moods than mildly negative pictures in trials without a math task. In trials with a math task, strongly and weakly negative pictures induced equal amounts of negative mood.

Discussion

The results of Study 1 showed the predicted effects of task presence on moment-to-moment ratings of negative mood. In line with a working memory model, participants reported less negative moods after negative pictures followed by a math task than when negative pictures were not followed by a task. Performing a math task did not influence participants' moods during neutral trials. Also in line with a working memory model, performing a math task interacted with the intensity of the negative pictures. Specifically, participants' moods after strongly negative pictures were more attenuated by performing a math task than moods after mildly negative pictures. Indeed, when a task was present, mood ratings after strongly negative pictures no longer differed from mood ratings after mildly negative pictures. This is in line with the idea that strongly negative pictures have a greater impact on working memory capacity than mildly negative pictures, so that the processing of these pictures should be affected more by additional working memory demands.

Study 2

Although the results of Study 1 fit with a working memory model of distraction, Study 1 only manipulated the presence or absence of a demanding task. As such, it is hard to say whether the effects of task presence on negative mood resulted from variations in processing capacity, as our analysis suggests, or whether these effects resulted merely from an attentional shift away from the current mood state. We conducted Study 2 to address this ambiguity.

In Study 2, participants solved a math equation in each trial. To vary involvement of working memory, we manipulated task complexity during the different trials. In half of the trials, neutral and negative pictures were followed by the same math equations as in Study 1. In the remaining trials, pictures were followed by much simpler equations. Previous research has found that complex math tasks make greater demands on working memory capacity than simple math tasks (Ashcraft, Donley, Halas, & Vakali, 1992). Thus, if the effects of the math tasks in Study 1 were due to their differential demands on working memory capacity, distraction from negative moods should be greater after performing complex rather than simple math tasks. On the other hand, if the results of Study 1 were due mainly to a shift in attention away from the negative mood state, performing complex and simple math tasks should induce similar levels of distraction from negative moods.

Study 2 again examined whether picture negativity and task presence would interact. As in Study 1, we predicted that mood ratings after strongly negative pictures would be more attenuated by task complexity than mood ratings after mildly negative pictures.

Method

Participants and Design

Thirty-nine paid volunteers at the VU University Amsterdam (7 men and 32 women, average age 20) took part in the experiment. The experimental design was 2 (task complexity: simple versus complex) x 3 (picture negativity: neutral, mildly negative, or strongly negative), both factors within participants. The main dependent variables consisted of participants' negative mood ratings and their math performance.

Procedure and Equipment

The procedure of Study 2 was similar to Study 1. Participants again performed the picture viewing task. This time, all pictures were followed by a math task. The complexity of the math task was varied experimentally. In half of the trials, the math task consisted of an equation similar to the moderately complex equations used in study 1, such as '2*8 + 12 = 28'. Each of these equations always combined a summation or subtraction with a product or a division. In the remaining trials, the math task consisted of a much simpler equation, such as '7 + 2 = 9'. Each of these equations only consisted of either a summation or a subtraction.

Results

Math performance

A 2 (task complexity) x 3 (picture negativity) ANOVA revealed a main effect for task complexity, $F(1, 38) = 234.41$, $p < .001$. This effect can be seen as a manipulation check. Participants performed better on the simple math trials than on the complex math trials (M = 96% correct versus M = 70% correct), irrespective of picture negativity. Participants were also faster on the simple math equations than on the complex math equations, $F(1, 38) = 1770.78$, $p < .001$ (M = 1932 ms versus M = 3021 ms).

Negative mood.

We analyzed negative mood ratings in a 2 (task complexity) x 3 (picture negativity) ANOVA. Relevant means are displayed in **Table 2**. In this analysis, we again only used affect ratings of the correctly answered math-trials (83% of all responses). The analysis revealed a main effect of picture negativity on participants' mood ratings: $F(2, 37) = 52.05$, $p < .001$. A contrast analysis revealed the expected linear effect of picture negativity, $F(1, 38) = 86.13$, $p < .001$. On average, participants reported strongest negative moods after trials with strongly negative pictures, intermediate negative moods after mildly negative pictures, and least negative moods after trials with neutral pictures (respectively $M = 4.31$, $M = 4.06$ & $M = 2.65$).

Table 2. Mean Negative Mood as a Function of Picture Negativity and Task Complexity (Study 2; Standard Deviations between Brackets)

	Picture Negativity		
Task	Neutral	Mild	Strong
Simple	2.61_{a} (1.00)	4.16_{b} (1.26)	4.71_{c} (1.43)
Complex	2.66_{a} (1.12)	3.97_{bd} (1.31)	3.92_{d} (1.38)

Note. Ratings ranged from 1 (*not at all*) to 9 (*very much*). Means that do not share subscripts differ within rows and columns at $p < .05$.

The ANOVA further yielded the predicted interaction between task complexity and picture negativity, $F(2, 37) = 13.62$, $p < .001$. We again did not find an effect of task complexity in the neutral trials, $F < 1$. To better understand the interaction, we proceeded by analyzing the negative trials (mildly versus strongly negative). We first analyzed the effects of task complexity separately in each negativity condition. These analyses did not yield a significant effect of task complexity in the mildly negative trials, $F(1, 38) = 2.64$, *ns.*. Nevertheless, at a descriptive level, participants did report less negative moods in response to mildly negative pictures followed by a complex task ($M = 3.97$) rather than a simple task (*M* = 4.16). By contrast, the analyses revealed a highly significant effect for task complexity in the strongly negative trials, $F(1, 38) = 29.13$, $p < .001$. Participants reported less negative moods after strongly negative pictures followed by a complex math equation rather than a simple math equation (*M* = 3.92 versus *M* = 4.71).

As in Study 1, we then considered the effect of picture negativity (mildly versus strongly negative) separately for each task condition. In the negative trials with a simple task, the analysis yielded an effect for picture valence, $F(1, 38) = 21.05$, $p < .001$. In trials containing a simple task, participants reported more negative moods following strongly negative pictures than following mildly negative pictures (*M* = 4.71 versus *M* = 4.16). By contrast, in negative trials with a complex task, there was no effect of picture valence on participants' negative moods, $F(1, 38) < 1$. In trials containing a complex task, participants reported as much negative mood in response to strongly negative pictures as in response to mildly negative pictures (*M* = 3.97 versus *M* = 3.92).

Recall that we found an effect of task complexity on participants' response times. To rule out that differences in task duration could explain the effect of task complexity on negative mood ratings in the negative trials, we therefore repeated our analyses with participants' response time differences between the complex and the simple trials as a covariate. A 2 (task complexity) ANCOVA analysis of the negative mood ratings in the negative trials still revealed a strong effect for task complexity, ($F(1, 38) = 27.07$, $p < .001$). Moreover, when entered as a covariate, response time differences were unable to account for the effects of task complexity on negative moods, $F(1, 37) < 1$.

Discussion

The results of Study 2 replicate and extend Study 1. Because each trial now contained a math task, we could investigate the impact of varying working memory load on negative mood. In line with predictions, participants reported less negative moods after strongly negative pictures followed by a complex task than after strongly negative pictures followed by a simple task. Participants also reported somewhat less negative moods in response to mildly negative pictures followed by a complex rather than a simple task. However, the latter effect of task complexity did not reach statistical significance. Thus, while an increase in task complexity resulted in a decrease in mood ratings across both strongly and mildly negative pictures, this decrease was much smaller for mildly negative pictures. This is in line with the assumption that an increase in working memory load should have a greater impact on additional processing of strongly negative stimuli than on additional processing of weakly negative stimuli. These findings thus further support our working memory model of distraction from negative mood.

A possible confound in Studies 1 and 2, however, was task duration. As the results showed, participants took less time to solve simple equations than to solve complex equations. Although the effects of task complexity remained unchanged when we statistically controlled for this difference, we cannot rule out the possibility that qualitative differences between the two types of equations, other than their complexity, impacted participants’ moods. This problem could not simply be resolved by using shorter timeframes, because doing so might make the complex task too difficult, and thereby undermine participants' motivation to invest effort in the task. We therefore took another approach in Study 3 to address this problem.

Study 3

In Study 3, we varied the predictability of the complex math task that was used as a distraction, while keeping all other task parameters constant. Unannounced or novel stimuli make greater demands on central executive resources, and thus on working memory (Baddeley et al., 2001; Spector & Biederman, 1976). In this regard, it is important to note that, in our experiments, participants had limited time (4 seconds) to perform the math task. Even though one can argue that in absolute terms, announced and unannounced math tasks require the same amount of working memory, announced math tasks entail working memory earlier, but more evenly distributed over time. Unannounced math tasks under a time limit on the other hand, ‘pull up’ all required working memory at once, thus making a much greater demand on total working memory capacity at one moment. Unannounced tasks should hence be more potent distracters from negative mood than announced tasks. An important advantage of this approach was that, because the actual task was always the same, this ruled out possible confounding factors due to qualitative differences between tasks.

Another advantage of varying task predictability was that we could examine the linearity of the effect of working memory load on negative mood. We manipulated task predictability by randomly presenting trials without a task, trials with an announced task, and with an unannounced task. On the basis of our working memory model of distraction from negative mood, we expected participants to report least negative moods in the negative trials with an unannounced task (high working memory load), intermediate negative moods in the negative trials with an announced task (intermediate working memory load), and most negative moods in negative trials without a task (no working memory load).

Finally, as in Studies 1 and 2, we predicted that higher working memory load would interfere especially with the further processing of strongly negative pictures. We therefore expected that strongly negative pictures would induce more negative moods than mildly negative pictures especially in trials where working memory load was low, or absent, such as in the trials with the announced task or no task. By contrast, we predicted that strongly negative pictures would induce equally negative moods as mildly negative pictures in trials where working memory load was high, such as in the trials with an unannounced math task.

Method

Participants and Design

Forty paid volunteers at the VU University Amsterdam (12 men and 28 women, average age 20) took part in the experiment. The experimental design was 3 (task type: unannounced, announced , or no task) x 3 (picture negativity: neutral, mildly negative, and strongly negative), both within participants. The main dependent variables consisted of participants' math performance and their negative mood ratings.

Procedure and Equipment

The procedure was similar as in Studies 1 and 2. This time, one third of the neutral and negative pictures were followed by an unannounced math task, one third by an announced math task, while the remaining pictures were not followed by a math task. To announce the math task, the word ‘som’, which is

Dutch for ‘calculation’, was displayed on screen one second before the task appeared. In this way, we experimentally varied the predictability of the math task. The math task following two-thirds of the pictures consisted of equations similar to the equations used in Study 1 and the complex equations used in Study 2.

Results

Math performance

A 3 (task type) x 3 (picture negativity) ANOVA revealed a main effect for task type on math performance, $F(2, 38) = 40.98$, $p < .001$. Participants gave more correct responses in the announced math trials than in the unannounced math trials (M = 73% versus M = 65%). The analyses revealed no effect for task type on response times. Thus, participants solved the announced math tasks equally quickly as the unannounced math tasks, F (2, 38) = 1.55, *ns*, (M = 2474 versus M = 2534).

Negative mood.

We analyzed participants’ negative mood ratings in a 3 (task type) x 3 (picture negativity) ANOVA for repeated measures. In this analysis, we again only used mood ratings of the correctly answered math-trials (79% of all responses). Relevant means are displayed in **Table 3**. The analysis yielded a main effect for picture negativity: $F(2, 38) = 70.40$, $p < .001$. The analysis further yielded the expected interaction between picture negativity and task type, $F(4, 36) = 4.26$, $p < .01$.

In order to understand these effects, we proceeded by analyzing the effect of picture negativity and task type separately using linear contrast analyses. As in Studies 1 and 2 these analyses yielded a linear effect for picture negativity, $F(1, 39) = 125.46$, $p < .001$. Participants reported more negative moods after strongly negative pictures than after mildly negative pictures (M = 4.96 versus M = 4.52) and least negative moods after neutral pictures (M = 2.94).

Furthermore, in line with our predictions, there was a linear effect for task type for both the strongly negative, as well as the mildly negative trials ($F(1, 39)$ = 19.46, $p < .001$ and $F(1, 39) = 33.19$, $p < .001$, respectively). Thus, participants’ negative moods linearly decreased as working memory load increased, irrespective of the intensity of the negative pictures. As in Studies 1 and 2, we did not find a linear effect for task type on the mood ratings in the neutral trials $F(1, 39) = 2.01$, *n.s.*. Accordingly, we restricted our further analyses exclusively to the negative trials.

Next, we considered the effect of picture negativity (mildly versus strongly negative) separately by task type. This analysis revealed a significant effect for picture negativity on the negative mood ratings in trials containing an announced task, $F(1, 39) = 21.30$, $p < .001$, and trials without a task, $F(1, 39) = 29.40$, $p < .001$. By contrast, there was no effect for picture negativity on the mood ratings in the trials containing the unannounced task, $F(1, 39) < 1$. Thus, when trials contained an announced task, or no task, participants reported significantly less negative mood after mildly negative pictures ($M = 4.52$ versus $M = 4.78$ for announced, and no tasks) than after strongly negative pictures ($M = 5.12$ versus $M = 5.35$ for announced, and no tasks). In negative trials with an unannounced task, however, participants' negative moods after strongly negative pictures ($M = 4.40$) did not differ significantly from their moods after mildly negative pictures ($M = 4.26$).

Table 3. Mean Negative Mood as a Function of Picture Negativity and Task Type (Study 3; Standard Deviations between Brackets)

	Picture Negativity		
Task Type	Neutral	Mild	Strong
No task	3.09_a (1.55)	4.78_b (1.73)	5.35_d (1.94)
Announced task	2.88_a (1.32)	4.52_c (1.83)	5.12_e (1.94)
Sudden task	2.92_a (1.27)	4.26_f (1.70)	4.40_f (1.73)

Note. Ratings ranged from 1 (*not at all*) to 9 (*very much*). Means that do not share subscripts differ within rows and columns at $p<.05$.

Discussion

In Study 3, we manipulated working memory load by varying task predictability, while the actual task was always the same. In this way, Study 3 controlled for qualitative differences between tasks such as duration. As expected, working memory load had a linear effect on participants' negative mood ratings. Participants reported more negative moods after negative pictures without a subsequent task (no load) than after negative pictures followed by an announced task (intermediate load), while they reported even less negative moods in trials with an unannounced task (high load). Moreover, in the trials with an unannounced task, participants reported as much negative moods after strongly negative pictures as after mildly negative pictures. In the trials with an announced task or no task, participants reported more negative moods after strongly negative pictures than after mildly negative pictures. Apparently, when task load was high, strongly negative pictures no longer elicited more mood-related processing than mildly negative pictures.

General Discussion

In the present research, we proposed that people can distract themselves from negative feelings by loading their working memory capacity. In line with this model, three experiments showed that variations in working memory load moderate the impact of viewing negative pictures on mood. Participants reported less negative moods after viewing negative pictures when they had to solve complex math problems rather than no math problems (Study 1) or simple math problems (Study 2). The moderating effect of math problems on negative mood was stronger for unannounced math problems, which presumably use more working memory capacity (Spector & Biederman, 1976), than for announced math problems (Study 3). Solving math problems had no effect on mood after participants viewed neutral pictures (Studies 1-3). Finally, solving math problems had a stronger moderating impact on negative mood when participants had viewed strongly rather than mildly negative pictures (Studies 1-3). The latter findings fit well with a working memory model, given that strongly negative stimuli use greater working memory capacity than mildly negative stimuli (Schimmack, 2005).

The present studies show that distraction from negative mood involves more than simply redirecting one's attention away from the emotional stimulus. However, we do not mean to say that attention is irrelevant to distraction from negative mood. Processes of selective attention are critical for the operation of working memory (Baddeley & Hitch, 1974; Engle, Tuholski, Laughlin, & Conway, 1999). This can be illustrated by the way we manipulated working memory in our research, namely by varying the complexity or the predictability of a distracter task. When performing a simple or predictable task, people can rely on more habitual processes, such that attention can still shift to mood-related information. When people are confronted with a more complex, or unexpected task, however, people can no longer rely on habitual processes, but instead need to focus their full attention on the task (Baddeley, 1996; Norman & Shallice, 1980).

The present findings fit well with neuropsychological findings about the interaction of higher cognitive mechanisms for attention and controlled processing with (lower limbic) regions involved in emotional processing (Cohen, Lohr, Paul, & Boland, 2001; Drevets & Raichle, 1998; Mayberg et al., 1999). For example, participants, when they had to judge emotional pictures on some non-valenced criteria, namely picture format, displayed less involvement of limbic regions while watching the affective pictures, than when they had to judge the pictures' valence, or had to indicate if the pictures evoked any feelings (Northoff et al., 2004). Increased involvement of the cognitive system may thus lead to a decreased involvement of the emotional system (Hariri, Bookheimer, & Mazziotta, 2000; Northoff et al., 2004), and vice versa (Bishop, Duncan, & Lawrence, 2004; Dolcos & McCarthy, 2006; Mitchell, Richell, Leonard, & Blair, 2006).

It is informative to compare distraction with suppression of emotional thoughts, another well-established emotion regulation strategy (Roemer & Borkovec, 1994; Wenzlaff, Wegner, & Roper, 1988). In both strategies, people alter their emotional states by preventing emotion-related cognitions to enter awareness. However, during emotional thought suppression, the active inhibition of emotional thoughts may actually make emotion-related material more accessible (Howell & Conway, 1992; Wenzlaff et al., 1988), resulting in mood rebounds (Wegner, Erber, & Zanakos, 1993; Wenzlaff & Luxton, 2003). Because distraction does not require the active suppression of emotional thoughts, it should not result in mood rebounds. In support of this, research has shown that when people were distracted following a negative mood induction, subsequent rumination did not again deteriorate their moods. When people however ruminated immediately after the negative mood induction, their negative mood states persisted (Trask & Sigmon, 1999).

Although distraction seems a relatively efficient emotion regulation strategy, it may not necessarily be the most optimal approach under all circumstances. First, for a distracter task to be effective, it should not elicit negative feelings by itself. Ashcraft and Kirk (2001), for example, demonstrated that people high on math-anxiety performed more poorly on a math task than people low on math anxiety, because anxious thoughts incorporated working memory capacity and thus interfered with efficient task performance. For people high on math anxiety then, the math task no longer functioned as a neutral cognitive distracter, but as a negative affective stimulus in itself, producing negative feelings instead of replacing them with neutral thoughts. Low emotionality of the distracter task is therefore an important boundary condition for distraction from negative mood.

Second, distraction may not be the most effective way to resolve more structural causes of negative mood, such as, for example, problematic relationships, or difficulties at work. This is because distraction leaves the source of the negative emotion itself intact. In highly distressing situations, it may be helpful to distract oneself initially, in order to step back and put things in perspective. In the end, however, distraction is no substitute for problem solving. For example, workaholics often explain their excessive work habits by stating that it helps them forget about problems in their private life (Robinson, 2001). At the same time, there exists an inverse relationship between marital satisfaction and obsessive working in the research literature (Matthews, Conger, & Wickrama, 1996; Robinson, 2001). In these and related instances, distraction from negative mood may actually contribute to a vicious cycle of maladaptive behavior. Identifying the costs and benefits of distraction from negative mood clearly constitutes an important task for future research.

Limitations and Future Perspectives

The present research demonstrates how increasing working memory load of a distracter task may attenuate negative mood. It is not clear, however, whether the model also applies to distraction from positive mood. Recent studies in our lab, using a similar paradigm as the present studies, failed to find an effect of working memory load on positive mood (Van Dillen & Koole, 2006; though see Erber & Tesser, 1992). As such, distraction from positive mood may not operate according to the same principles as distraction from negative mood. It is conceivable that positive emotional stimuli may impact cognitive processes through a different route than negative emotional stimuli (Isen, 2002). For example, positive emotional states do not always result in mood-congruent processing (Fiedler et al., 2003), and can increase both cognitive flexibility (Baumann & Kuhl, 2005), as well as distractibility (Dreisbach & Goschke, 2004). Clearly, the question how distraction from positive mood may operate deserves more attention in future research.

Although the present research demonstrated that distraction can attenuate negative moods in response to negative pictures, distracted participants still reported less negative moods in response to neutral pictures. Physiological responses to emotional stimuli take several minutes to return to baseline, even when people are distracted (Glynn et al., 2002). These physiological responses may thus continue to impact participants' negative moods after four seconds, the interval we used between the picture display and the mood scale. Extending this interval from several seconds to several minutes may effectively reduce negative mood to neutral levels. In line with this, Erber and Tesser (1992) found a complete neutralization of negative mood when participants solved moderately complex math equations for ten minutes after the mood induction. The exact relationship between the duration and the effectiveness of distraction from negative moods represents a fruitful topic for future inquiry.

Future work is also needed to clarify the effects of type of working memory load on distraction from emotion. Baddeley and colleagues (Baddeley & Hitch, 1974) proposed that working memory consisted of two storage buffers (the phonological loop for verbal information and the visuospatial sketchpad for nonverbal information), which are assumed to be relatively independent. For example, anxiety has been shown to have a disproportionate effect on verbal working memory while leaving visuospatial working memory performance (implicated in nonverbal working memory) unaffected (Ikeda, Iwanaga, & Seiwa, 1996). Thus, verbalization of mood-related information seems to interfere particularly with verbal working memory (Gray, 2001). Further research should address whether a distracter task that implicates a different working memory device than mood-related processing still results in attenuation of negative moods.

Concluding Remarks

In everyday life, the effectiveness of distraction from negative mood is widely recognized, given that people are often advised to ‘move on’ when in a negative state by seeking out alternative activities. Nevertheless, distraction is typically used as an explanatory construct rather than as a phenomenon that needs to be explained. In the present research, we sought to deepen our understanding of the underlying mechanisms of distraction from negative mood by proposing a working memory model. By loading working memory, people can attenuate the impact of negative events on their moods. Thus, in keeping with William James’ early observations on the close interplay between actions and feelings, the present research highlights distraction as one important type of action through which people may regulate their feelings.

Chapter 3.

Switching off the emotional brain: An fMRI study of the effects of task load on the processing of negative and neutral images

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This chapter is based on Van Dillen, L.F., Heslenfeld, D.J., & Koole, S.L. Switching off the emotional Brain: An FMRI study of the effects of task load on the processing of negative and neutral Images. *Submitted for publication.*

Negative emotional experiences are an inescapable aspect of human life. Although brief episodes of negative emotions can be adaptive (Öhman, 2007), negative emotions may become problematic when they persist over time. Indeed, there is mounting evidence that enduring negative emotional states impair both psychological and physical health (Lyubomirsky, Tucker, Caldwell, & Berg, 1999; Sapolsky,). It is therefore vital for people to develop ways of effectively dealing with negative emotion.

One important way of dealing with negative emotion consists of minimizing the amount of attentional resources that are devoted to processing negative information (Ochsner & Gross, 2005; Nolen-Hoeksema & Morrow, 1993; Van Dillen & Koole, 2007). More specifically, performing an attention-demanding task has been found to attenuate the emotional impact of negative stimuli (Erber & Tesser, 1992; Erthal et al., 2005; Glynn, Christenfeld, & Gerin, 2002; Morrow & Nolen-Hoeksema, 1990; Pessoa, McKenna, Gutierrez & Ungerleider, 2002; Van Dillen & Koole, 2007; in press). For instance, participants reported less negative feelings in response to negative pictures when they subsequently tried to solve complex rather than simple math equations (Van Dillen & Koole, 2007).

In recent years, the neurological effects of task load on processing of emotional stimuli have begun to receive more systematic research attention. Several studies have demonstrated that activity in emotion processing regions of the brain in response to negative emotional stimuli, such as the amygdalae, depend on the availability of attentional resources for processing of these stimuli (Erk, Klezcar, & Walter, 2007; Okon-Singer, Tzelgov & Henik, 2007; Mitchell et al., 2007; Pessoa et al., 2002; Van Reekum et al., 2007). For example, in one study, negative visual distracters engaged the amygdalae during participants' judgements whether two bars were like oriented or not (Pessoa et al., 2002), but only when the difference in orientation of two bars was easy to judge. When the orientation of the two bars was difficult to judge, so that the central task became more attentionally demanding, the amygdalae no longer differentiated between the negative and neutral distracters. In another study (Erk, Klezcar, & Walter, 2007), amygdalae responses to negative scenes were smaller when participants concurrently performed a working memory task that was highly rather than moderately demanding.

Although past work has made important progress, it remains unclear precisely how task load influences the emotional brain. One possibility, which has been proposed in prior work, is that task load prevents the processing of the emotional impact of negative stimuli altogether. From this perspective, task load may cause an emotionally relevant stimulus to simply bypass emotional circuits. Given that most prior research relied on demanding distractor tasks that visually competed with emotional information (Erthal et al., 2005; Okon-Singer, Tzelgov & Henik, 2007; Pessoa et al., 2002), task load may have led participants to overlook some of the emotional information. Moreover some emotion regulation theorists have proposed that attentional deployment strategies (such as providing people with an additional task load) may allow people to manage unwanted emotions even before these emotions have been fully aroused (Gross, 2001).

Another possibility, which is highlighted in the present work, is that task load is capable of down-regulating emotional circuits even after these circuits have been mobilized. This would imply that emotional brain regions operate quite flexibly, in that they can still be modulated by contextual demands after the initial emotional response has unfolded. Behavioral research indeed suggests that task load can still modulate emotional processing even after the initial emotional response has already been triggered (Gerin et al., 2006; Glynn, Christenfeld & Gerin, 2002; Van Dillen & Koole, 2007). For instance, in one study (Gerin et al., 2006), participants' elevated blood pressure levels in response to an anger induction returned to baseline more quickly when they subsequently performed an engaging task rather than no task. Perhaps then, performing a demanding task may similarly down-regulate the unfolding of the emotional brain response.

The present research was designed to investigate the neural dynamics by which task load modulates the emotional brain response, even after this response has already been initiated. In an experimental study, participants were exposed to neutral or negative emotional pictures, after which they performed an arithmetic task that made varying demands on processing resources (Ashcraft & Kirk, 2001), and rated their emotional state (Fig.1). Throughout the experiment, participants' brain responses were monitored using functional magnetic resonance imaging (fMRI). We predicted that, relative to exposure to neutral pictures, exposure to negative pictures would activate both negative experiences and emotional brain circuits such as the amygdalae and the insulae (Phan, Wager, Taylor, & Liberzon, 2002). In addition, we predicted that task load would increase activation in brain regions implicated in cognitive processing, such as the dorsolateral frontal cortex and the superior parietal cortex (Duncan & Owen, 2000; Rypma, Prabhakaran, Desmond, Glover, & Gabrieli, 1999).

Most importantly, we hypothesized that task load would modulate subjectively reported emotional states and the activation of emotional brain circuits. That is, we predicted neural activity in regions implicated in emotional processing to decrease with increases in task load. Although the negative pictures should initiate a greater response in emotional brain areas than neutral pictures, we expected that the unfolding of this response over time would be attenuated when participants subsequently performed a highly demanding arithmetic task rather than a moderately demanding arithmetic task. In short, we predicted that task load would modulate the unfolding of the emotional brain response, even after this response was already initiated.

Method

Participants and Design

Seventeen volunteers at the VU University Amsterdam (13 women, average age 20) took part in the experiment. All participants were right-handed and native Dutch speakers. The participants did not report any history of neurological or psychiatric problems. The ethical review board of the VU Medical Centre approved of the study and all volunteers provided written informed consent (according to the Declaration of Helsinki) after the study procedure had been explained to them. They were paid €20 for participation. The experimental design was 2 (task load: high versus low) x 2 (picture valence: neutral versus negative), both factors within participants.

Procedure and Equipment

Participants were invited to the lab to participate in a brain-imaging experiment. Before starting with the actual experiment, participants were instructed about the experimental set-up. Participants were then led to the scanner-room and positioned supine in the whole-body scanner, where they completed the actual experiment. All stimuli were back-projected onto a screen and viewed by participants through an angled mirror. The experiment consisted of a picture viewing task that contained four blocks of 32 experimental trials (128 trials in total). The order of the blocks was counterbalanced between participants and trials within blocks were displayed in random order. Each trial consisted of a picture followed by an arithmetic task and a mood scale. The pictures were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2001). Based on published norms (ranging on a scale from 1 [most unpleasant] to 9 [most pleasant]), we selected two sets of 64 pictures, a negative set (valence ratings lower than 2.50) and a neutral set (valence ratings between 4.00 and 5.00). Negative pictures included images of scenes with burn victims, physical assaults, and angry faces. Neutral pictures depicted scenes of people in conversation, scenes of nature or buildings, and neutral faces.

In each trial, a negative or neutral picture appeared on screen for 4 seconds. After picture presentation, participants had to perform an arithmetic task. The complexity of the task was randomly varied. In half of the trials, the arithmetic task consisted of a more complex equation such as '2*8 + 12 = 28'. These equations always combined a summation or subtraction with a product or division. In the remaining trials, the arithmetic task consisted of a much simpler equation, such as '7 + 2 = 9'. The latter equations only consisted of either a summation or a subtraction. Participants judged whether the equation was correct by pressing a button with either their left or right index finger. Participants had 4 seconds to make this response. For nine participants, the right button represented the correct response and the left button the incorrect response, while for eight participants this order was reversed.

At the end of each trial, participants rated, with a button response, how unpleasant they felt at that moment (from 1 = *not at all*, to 8 = *very much*). For eight participants, this scale was reversed (ranging from right to left). In between trials, participants were asked to relax. To avoid systematic overlap of BOLD responses within and between trials, the interval between the arithmetic task and the mood scale, as well as the interval between the mood scale and the next trial, was set randomly to either 4,000 or 8,000 ms. The duration of each trial accordingly was 20, 24 or 28 seconds. The onset of each trial was synchronized to the onset of an fMRI volume. See **Fig.1** for a schematic depiction of a trial.

Prior to the presentation of the first block, participants were given a block of 16 practice trials to get familiar with the experimental set-up and the scanner. After the experiment, participants were thanked for their efforts, debriefed, and paid by the experimenter.

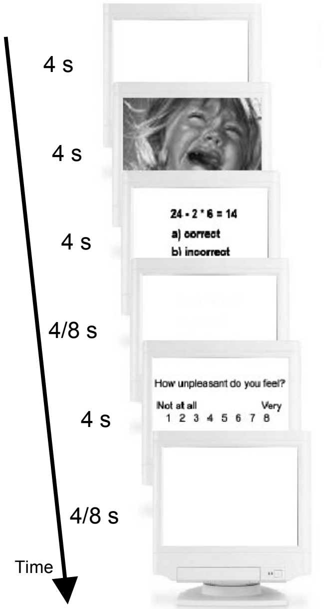

Figure 1. Schematic depiction of a trial.

A personal computer controlled presentation of the experimental trials and recorded participants' responses. The experimental trials were presented in E-prime (Psychology Software Tools, Inc., Pittsburgh, USA). Participants responded by pressing fiber-optic buttons (Lumitouch Photon Control, Burnaby, Canada).

MRI Procedure and Analysis

Brain imaging was performed on a 1.5 T Siemens Sonata scanner (Siemens Medical Systems, Erlangen, Germany) equipped with a volume head coil. Functional volumes consisted of 24 near axial slices acquired using an EPI sequence with the following parameters: repetition time = 2 s, echo time = 50 ms, flip angle = 90°, slice thickness = 4.2 mm, slice gap = 0.84 mm, acquisition matrix = 64 x 64 pixels, in-plane resolution = 3 x 3 mm. Series of 392 volumes were acquired in each of the four blocks of trials. Images were on-line motion corrected. After the functional session, a three-dimensional structural scan was acquired using a T1-weighted MP-RAGE sequence with the following scanning parameters: repetition time = 2730 ms, echo time = 3.43 ms, inversion time = 1000 ms, flip angle = 7°, 160 sagittal slices, slice thickness = 1 mm, acquisition matrix = 256 x 224 pixels, in-plane resolution = 1 x 1 mm.

Preprocessing and statistical analyses of the MRI data were performed using BrainVoyager 2000 software (Brain Innovation, Maastricht, The Netherlands). The first 2 volumes were discarded in order to avoid differences in T1 saturation. Voxel time-series of the remaining volumes were high-pass filtered (0.01 Hz), temporally smoothed (2.5 s FWHM Gaussian kernel), and corrected for slice acquisition times. Finally, volumes were 3D spatially smoothed (6 mm FWHM Gaussian kernel). Each functional run was manually co-registered to the individual 3D structural scan, re-sampled, and transformed into Talairach space (Goebel et al., 2001; Talairach & Tourpoux, 1988). A multirun/multisubject GLM design matrix was constructed to model the relevant brain responses for each run and participant (Friston, Holmes, Price, Buchel, & Worsley, 1999). The matrix consisted of regressors predicting hemodynamic responses to each combination of picture valence and working memory load.

FMRI data were first analyzed at each voxel (whole brain) and then specifically for a number of regions of interest (ROI’s). Voxel time series were standardized and corrected for serial correlations. The random-effects whole-brain analysis served to identify brain regions that responded in any way to negative pictures in our task. ROI’s were defined on the basis of the whole-brain activation obtained in response to negative pictures that were followed either by a simple or a complex arithmetic task. The statistical threshold for this random-effects whole-brain analysis was $p = .05$ after Bonferroni correction for multiple comparisons.

Results

Arithmetic performance

To investigate whether our manipulation of task was successful, we analyzed participants’ correct responses and response times. Analyses of variance

(ANOVA's) revealed that participants performed better on simple arithmetic tasks than on complex arithmetic tasks (*M* = 97% correct, *SD* = 1.09 versus *M* = 84% correct, *SD* = 5.56; F (1, 16) = 161.59, $p < .0001$), irrespective of picture valence. Participants were also faster on simple than on complex arithmetic equations, F (1, 16) = 858.38, $p < .0001$ (*M* = 1929, *SD* = 160 versus *M* = 3083, *SD* = 145). These effects confirm that the complex arithmetic equations were more difficult than the simple arithmetic equations.

Self-reported negative emotion

To examine whether task load modulates participants' self-reported negative emotion, we analyzed the effect of both working memory load (high, low) and picture valence (negative, neutral) on their self-reports. As expected, this ANOVA yielded a significant effect of picture valence, F(1, 16) = 11.78, p = .003. On average, participants reported more negative emotion after trials with negative pictures than after trials with neutral pictures (respectively, *M* = 4.55, *SD* = 1.08 versus *M* = 3.15, *SD* = 1.14).

The analysis further yielded the predicted interaction between task load and picture valence, F(1, 16) = 5.25, p = .036. To interpret this effect, we analyzed the effects of task load separately in each valence condition. In line with previous research using the same paradigm (Van Dillen & Koole, 2007), there was no effect of task load in the neutral trials, F < 1. By contrast, task load had a significant effect in the negative trials, F(1, 16) = 7.84, p = .013. Participants reported less negative emotion when negative pictures were followed by a complex arithmetic equation rather than a simple arithmetic equation (*M* = 4.40, *SD* = 1.07 versus *M* = 4.70, *SD* = 1.10). Thus, in line with previous findings (Dan Dillen & Koole, 2007), task load modulated participants' self-reported negative emotion.

Brain regions involved in both emotion and task-related processes

To investigate whether task load modulated the unfolding of participants' emotional brain responses, we first identified brain regions that responded to negative emotional pictures in our task. This yielded a number of areas, such as the bilateral amygdalae, the bilateral inferior insulae, the right dorsolateral frontal cortex and the right superior parietal cortex. In **Table 1** and **Appendix A**, the regions of interest (ROI's) are given, with their *xyz*-coordinates and cluster sizes.

Table 1. Brain areas responding to negative emotional pictures ($p < .05$, corrected) and showing a picture valence x task load interaction ($p < .05$).

Brain region (Brodmann area, hemisphere)	Talaraich coordinates (mm)			Volume (ml)	F_{int}	
	x	y	z		9-12 s	13-16 s
Cognitive regions						
Dorsolateral frontal cortex (BA 6/44, right)	40	2	30	0.210	14.77**	50.95**
Superior parietal cortex (BA 7, right)	24	-59	53	0.331	9.06**	25.33**
Dorsal occipital cortex (left)	-22	-79	19	13.979	4.80	22.65**
Dorsal occipital cortex (right)	23	-77	18	13.129	--	17.01**
Ventral occipital cortex (left)	-22	-64	-5	30.286	--	5.29
Parahippocampal cortex (right)	34	-19	-16	0.643	--	5.92
Emotional regions						
Amygdala (left)	-19	-5	-9	0.211	7.83	8.62**
Amygdala (right)	22	-8	-10	0.450	7.02	6.17
Inferior insula (right)	31	-3	-9	0.173	4.74	4.82

Note. F_{int} = *F*-value of picture valence x task load interaction. -- = regions do not show an interaction between picture valence and task load in the corresponding time window. Degrees of freedom are 1 and 16, ** $p < .01$.

Subsequently, for each region and participant, we computed the hemodynamic response to each picture/load combination by means of a deconvolution analysis, for the first 16 s following picture onset. Activation in response to the neutral and negative pictures peaked at time = 6 s after picture onset (see **Fig.2**), which corresponds to the delay of the hemodynamic response. Moreover, analyses of variance revealed that, at this point, selected regions indeed responded more strongly to negative than to neutral pictures (all $p < .05$, see **Appendix A**). Initially, negative pictures thus engaged these brain regions to a greater degree than neutral pictures.

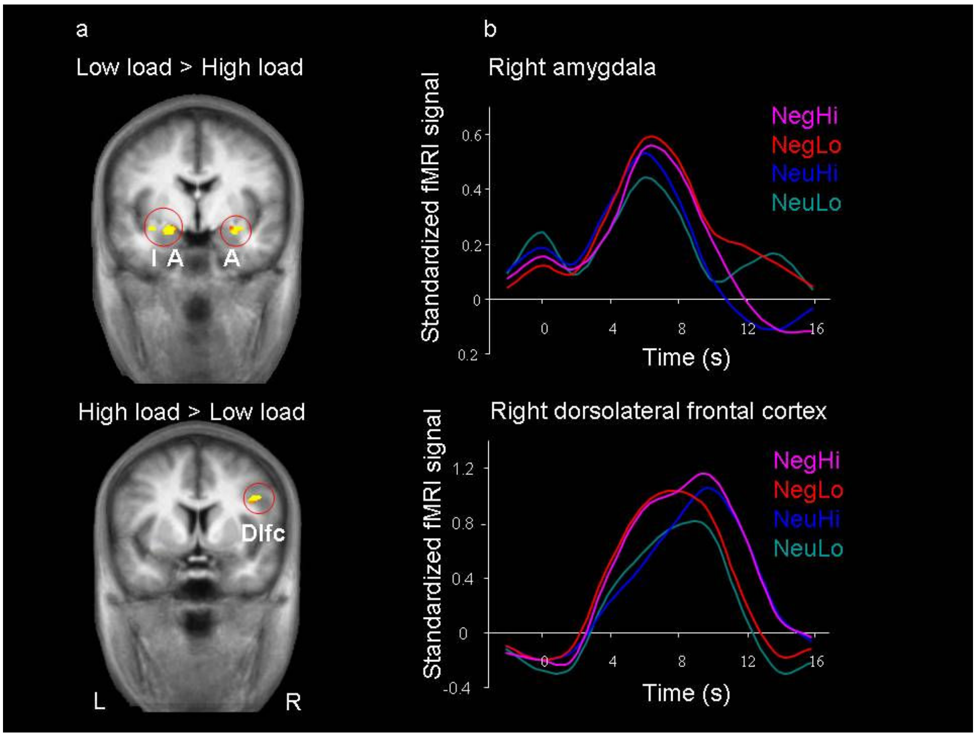

Figure 2. (**a**) Two coronal views of the averaged brain (n =17) in Talairach space (y=2 and y=-5 mm, resp.) on which areas are displayed that responded significantly to negative pictures ($p < .05$, corrected for multiple comparisons) and in which activity was either greater when working memory load was low compared to high (upper row; bilateral amygdalae [A] and right inferior insula [I]), or in which activity was greater when working memory load was high compared to low (lower row; right dorsolateral frontal cortex [Dlfc]). (**b**) Deconvolved averaged timecourses of the brain responses in the right amygdala and right dorsolateral frontal cortex for each trial type; negative (Neg) or neutral (Neu) pictures that were followed by either a high (Hi) or a low (Lo) working memory load task. Picture onset was at time = 0 s, task onset was at time = 4 s.

Because the task was introduced 4 s after picture onset, any effect of task load on the response to the picture would thus be expected at about 10 s and onwards. In line with this, activation in cognitive processing regions, such as the right dorsolateral frontal cortex, peaked at time = 10 s (see **Fig.2**). In order to assess the timing of the effects of our manipulations more precisely, the hemodynamic responses of the selected regions were broken into two time windows of two fMRI volumes each (9 – 12 s, and 13 – 16 s). These time windows were then further tested in subsequent analyses of variance for effects of picture valence and task load. The results of the analyses are given in **Table 1**.

If task load indeed modulates the temporal unfolding of emotional responses in the brain, this would imply an interaction effect between picture valence and task load on participants' brain activity. We indeed found significant statistical interactions between picture valence and task load in several regions during both the first (9 – 12 s) and second (13 – 16 s) time window following task onset. During the first time window we found interaction effects in right dorsolateral frontal cortex ($F(1, 16) = 14.77$, $p = .001$), right superior parietal cortex ($F(1, 16) = 9.06$, $p = .008$), the left dorsal occipital cortex ($F(1,16) = 4.80$, $p = 0.044$), the left amygdala ($F(1,16) = 7.83$, $p = 0.01$), the right amygdala ($F(1, 16) = 7.02$, $p = .018$), and the right inferior insula ($F(1, 16) = 4.74$, $p = .045$). During the second time window, we found significant statistical interactions between picture valence and task load in right dorsolateral frontal cortex ($F(1, 16) = 50.95$, $p < 0.0001$), right superior parietal cortex ($F(1, 16) = 25.33$, $p = .0001$), left dorsal occipital cortex ($F(1, 16) = 22.65$, $p = .002$), right dorsal occipital cortex ($F(1, 16) = 17.01$, $p = .001$), left ventral occipital cortex ($F(1, 16) = 5.29$, $p = .035$), right parahippocampal cortex ($F(1, 16) = 5.92$, $p = .027$), left amygdala ($F(1, 16) = 8.62$, $p = .01$), right amygdala ($F(1, 16) = 6.17$, $p = .025$) and right insula ($F(1, 16) = 4.82$, $p = .043$; see **Table 1** for an overview). Because pair-wise comparisons (see below) did not yield any significant effects for activity in right parahippocampal cortex, this region was therefore excluded from subsequent analyses.

The effect of task load on brain responses to negative pictures

Recall that we predicted a smaller neural response in emotion regions to negative pictures when followed by a complex task (high load), rather than a simple task (low load) while we expected neural responses in cognitive processing regions to display the opposite pattern. To test these predictions, we directly compared the responses to negative pictures followed by either a complex or a simple arithmetic task in the regions that showed interactions between picture valence and task complexity. Note that these comparisons result in a positive *t*-value if the response is greater in the high load than the low load trials, and a negative *t*-value if the response is greater in the low load trials.

During the first time window, the left amygdala ($t(16) = -2.91$, $p = .010$) and the right amygdala ($t(16) = -1.97$, $p = .066$) showed weaker responses to negative pictures followed by a complex task rather than a simple task. During the second time window, the left amygdala ($t(16) = -4.29$, $p = .001$), right amygdala ($t(16) = -5.11$, $p = .0001$), and right insula ($t(16) = -2.25$, $p = .039$) showed weaker responses to negative pictures followed by a complex task rather than a simple task (see **Table 2, Figure 2**). These regions are known to be involved in the processing of emotional stimuli (Ochsner et al., 2004; Phan et al., 2002). Thus, increased task load led to reduced activation in emotion circuits.

During the first time window, right dorsolateral frontal cortex ($t(16) = 7.94$, $p < .0001$), right superior parietal cortex ($t(16) = 6.62$, $p < .0001$), and left dorsal occipital cortex ($t(16) = 5.01$, $p = .0001$) showed greater activation to negative pictures followed by a complex task rather than a simple task. During the second time window, right dorsolateral frontal cortex ($t(16) = 3.43$, $p = .003$), right superior parietal cortex ($t(16) = 2.43$, $p = .027$), left dorsal occipital cortex ($t(16) = 2.52$, $p = .023$), and left ventral occipital cortex ($t(16) = 1.97$, $p = .066$) showed greater activation to negative pictures followed by a complex task rather than a simple task (see **Table 2, Figure 2**). These regions are known to be involved in cognitive processing and to respond to increasing task load (De Fockert et. al., 2001; Duncan & Owen, 2000; Rypma et. al., 1999). Thus, as expected, performing complex arithmetic sums engaged brain regions that support cognitive processes.

Table 2. Brain areas showing a picture valence x task load interaction (*p* < .05) and displaying an effect of task load on responses to negative pictures.

Brain region (Brodmann area, hemisphere)	Talaraich coordinates (mm)			T_{neg}	
	x	y	z	9-12 s	13-16 s
Cognitive regions					
Dorsolateral frontal cortex (BA 6/44, right)	40	2	30	7.94**	3.43**
Superior parietal cortex (BA 7, right)	24	-59	53	6.62**	2.43*
Dorsal occipital cortex (left)	-22	-79	19	5.01**	2.52*
Dorsal occipital cortex (right)	23	-77	18	--	0.88
Ventral occipital cortex (left)	-22	-64	-5	--	1.97†
Emotional regions					
Amygdala (left)	-19	-5	-9	-2.91*	-4.29**
Amygdala (right)	22	-8	-10	-1.97†	-5.11**
Inferior insula (right)	31	-3	-9	-1.11	-2.25*

Note. T_{neg} = *t*-value of effect of task load after negative pictures; with positive *t* meaning greater response to high than to low load, and negative *t* meaning greater response to low than to high load. -- = regions that do not show an interaction between picture valence and task load in the corresponding time window. Degrees of freedom = 16, ** *p* < .01, * *p* < .05, † *p* < .1

The effect of picture valence on brain responses under low versus high load

Another way to look at the interaction effect between picture valence and task load is to investigate the effect of picture valence within each task load condition. If non-emotional information competes with emotional information for limited processing capacity, then performing a high load task, compared to a low load task, should attenuate brain activity in response to negative pictures towards the level of activity induced by neutral pictures. In other words, the effect of picture valence should be greater under low, than under high task load conditions.

Table 3. Brain areas showing a picture valence x task load interaction ($p < .05$) and displaying an effect of picture valence under low, but not under high task load in the first time window (9 – 12 s).

Brain region (Brodmann area, hemisphere)	Talaraich coordinates (mm)			Neg-Neu	
	x	y	z	Low Load	High Load
		Cognitive regions			
Dorsolateral frontal cortex (BA 6/44, right)	40	2	30	2.66^{*}	0.89
		Emotional regions			
Amygdala (left)	-19	-5	-9	3.56^{**}	$2.04^{\dagger}$
Amygdala (right)	22	-8	-10	4.00^{**}	$1.82^{\dagger}$
Inferior insula (right)	31	-3	-9	2.48^{*}	$1.89^{\dagger}$

Note. Neg-Neu = t-value of effect of picture valence; with positive t meaning greater response to negative than to neutral pictures, and negative t meaning greater response to neutral than to negative pictures. Degrees of freedom = 16, ** $p < .01$, * $p < .05$, † $p < .1$

During the first time window, pairwise comparisons revealed an effect for picture valence on emotional brain responses only when participants performed a simple task. Thus, when task load was low, left amygdala ($t(16) = 3.56$, $p = .003$), right amygdala ($t(16) = 4.00$, $p = .001$), as well as right insula ($t(16) = 2.48$, $p = .025$) displayed a significantly greater response to negative than to neutral pictures. However, when task load was high, the difference between brain responses to negative and neutral pictures in left amygdala ($t(16) = 2.04$, $p = .058$), right amygdala ($t(16) = 1.82$, $p = .084$), and right insula ($t(16) = 1.89$, $p = .088$) was much smaller. During the second time window, responses to neutral and negative pictures no longer differed, independent of task load. For an overview of these results, see **Table**

3. Thus, in regions involved in emotion processing, high task load reduced brain activity in response to negative pictures to the level of activity induced by neutral pictures more rapidly than low task load.

Interestingly, not only limbic regions showed greater activity in response to negative than to neutral pictures only when task load was low, right dorsolateral frontal cortex also revealed an effect of picture valence only when participants performed the simple arithmetic task; $t(16) = 2.66$, $p = .017$. When task load was high, responses to negative pictures no longer differed from responses to neutral pictures; $t(16) = 0.89$, *ns.*. However, contrary to activity in limbic regions, overall activity in right dorsolateral frontal cortex in response to neutral and negative pictures was greater in the high load than in the low load trials (see **Figure 2, Table 2**). In line with our hypothesis, it thus seems that task load modulates the temporal unfolding of the emotional brain response. The more processing resources a person needs to perform a cognitive task, as evidenced by the increased recruitment of right dorsolateral cortex under high task load, the less will be left for emotional responses to proliferate.

Interrelation of brain regions involved in emotion and task processing

We examined the interrelations of neural activity in the amygdalae and right insula on the one hand and the right dorsolateral frontal cortex on the other hand. To this end, we first computed an index of the amount of modulation of picture valence by working memory load. We did this by calculating the difference between responses to negative pictures followed by a simple task and neutral pictures followed by a simple task, minus the difference between responses to negative pictures followed by a complex task and neutral pictures followed by a complex task, separately for each participant, ROI, and fMRI time window. Note that because of the double subtraction, the sign of the working memory load effect is lost. We then correlated these indices of the modulation of the valence effect across participants between ROIs, separately for each time window.

We found that activation in left amygdala correlated with activation in right dorsolateral frontal cortex ($r = .52$, $p = .027$) during the 9^{th} - 12^{th} second following picture onset. Moreover, activation in right inferior insula correlated with activation in right dorsolateral frontal cortex during the 9^{th} - 12^{th} second following picture onset (although marginally significant; *r* = .43, *p* = .075) and the 13th - 16th second following picture onset (*r* = .47, *p* = .049). Whereas activation in right dorsolateral frontal cortex was greater in response to high compared to low working memory load, activation in limbic regions was smaller in response to high compared to low working memory load (see previous section, **Table 2** and **Fig.2**). In line with predictions then, there was a systematic relationship between activity in regions implicated in emotional processing (amygdala, right insula) and activity in right dorsolateral frontal cortex, which is consistent with the idea that these systems operate in a coordinated manner (Pessoa, 2008).

Discussion

The present research examined how task load modulates the unfolding of the emotional brain response. Importantly, in the present paradigm, the emotional stimulus and the task load were presented in succession. Thus, participants solved an arithmetic equation following each neutral or negative picture. This temporal separation made it possible to investigate the dynamic unfolding of the interplay between cognitive and emotional neural structures. Previous research has proposed that task load may 'short-circuit' emotional processing in the brain, such that activity in emotional brain regions is inhibited altogether. In the present research, however, we suggest that even when emotional circuits have already been engaged, performing a demanding task may still attenuate processing in the emotional brain.

In support of our hypotheses, the present findings show that both cognitive regions (right dorsolateral frontal cortex) and emotion regions (bilateral amygdalae, right insula) showed greater activity in response to negative pictures than in response to neutral pictures when participants performed a mildly demanding task, whereas this was no longer the case when participants performed a highly demanding task. Consistent with previous work (Cohen et al., 1997; Prabhakaran et al., 2000), high task load further resulted in an increase in activity in cognitive regions (right dorsolateral frontal cortex, right superior parietal cortex, dorsal occipital cortex, left ventral occipital cortex). More importantly, task load also resulted in a decrease in brain regions involved in emotion processing (bilateral amygdalae, right insula). Finally, during task performance, activity in cognitive regions (right dorsolateral frontal cortex, left dorsal occipital cortex) was related to activity in emotion regions (bilateral amygdala, right insula). Together, these findings suggest that emotional and cognitive circuits in the brain operate in a coordinated manner to deal with changing task demands.

The present findings go beyond a simple reciprocal modulation of cognitive and emotion circuits in the brain, in that increases in activity in cognitive brain regions not necessarily resulted in decreases in activity in emotional brain regions. That is, during picture display, activity in both dorsolateral frontal cortex as well as limbic regions, i.e. the bilateral amygdalae and the insulae, was greater in response to negative pictures than to neutral pictures. Only when participants performed the arithmetic equations neural responses in cognitive and emotional regions began to differentiate. Whereas activity in the right dorsolateral frontal cortex increased even more, performing the arithmetic equations resulted in a decrease in neural activity in limbic regions. In line with previous findings (Erk, Klezcar, & Walter, 2007), right dorsolateral frontal cortex was thus “shared” by task-related and emotion-related processing. Accordingly, our results reveal an integration effect for processing negative emotion and task load in right dorsolateral frontal cortex.

One potential explanation for these findings is that the right dorsolateral frontal cortex is engaged more with increasing task load, in order to sustain priority to processing of the central task at the cost of the further processing of emotionally salient, but task irrelevant negative stimuli (see Erk, Klezcar, & Walter, 2007, for a similar argument). Theorists have proposed that the lateral frontal/prefrontal cortex may function as a key neural substrate of the central bottleneck of information processing (Dux, Ivanoff, Asplund & Marois, 2006; Herath et al., 2001; Marois and Ivanoff, 2005). As such, the lateral frontal cortex may be critical for mental operations such as cognitive control, decision-making, and modality-independent selection of task-relevant information (Badre et al., 2005; Brass et al., 2005; Bunge et al., 2003). The present research findings suggest that the role of the lateral frontal cortex in controlling information processing may extend beyond the cognitive domain, and may similarly control processing of emotional information.

Cognitive emotion regulation strategies may build upon more general information processing systems such as working memory and cognitive control that typically engage (frontal) cortical regions such as the dorsolateral frontal cortex (Ochsner & Gross, 2008). Indeed, a recent study revealed a role of the lateral frontal cortex in inhibiting emotional distraction in healthy adults during a working memory task (Johnson et al., 2005; Dolcos and McCarthy, 2006). Performing a working memory task engaged the lateral frontal cortex to a greater degree when the participants were distracted by negative emotional pictures rather than neutral or scrambled pictures. Moreover, participants who displayed greater activity to emotional distracters in the lateral frontal cortex judged emotional distracters as less distracting and less emotional.

The present research findings potentially have important implications for psychopathologies that are characterized by both emotional and cognitive deficits, like depression and anxiety (Harvey et al., 2005; Luu, Tucker, & Derryberry, 1998; Mayberg et al., 1999). Emotional stimuli can have a lasting effect on amygdala activity (Cuthbert et al., 2000), specifically in depressed individuals (Siegle et al., 2002). Moreover, research has shown that people are inclined to ponder over a negative experience, which may subsequently intensify and prolong people's negative emotional states (Nolen-Hoeksema, Morrow & Frederickson, 1993). Placing people in a quiet environment in order to let them 'cool down' from an emotional response may therefore not necessarily result in a more neutral mind state. Although more research is needed in this area, it is conceivable that cognitively demanding tasks may eventually be used as a therapeutic tool. Having people perform an engaging task may alleviate the intensity of acute emotional responses, such that people become more receptive to long-term therapeutic interventions.

More broadly speaking, the present work attests to the close coordination between cognitive and emotional functioning. In line with previous research, our findings demonstrated that further engagement of cognitive circuits result in a decrease in activity in emotional circuits (Drevets & Raichle, 1998; Keightley et al., 2003; Mayberg et al., 1999), especially when processing load of a central task is high. Depending on the threats and challenges that people face, cognitive and emotional systems are recruited in a flexible manner, such that people can deal effectively with the ever changing demands of their environment.

Appendix A.

All statistical regions of interest (ROIs). Brain areas responding to negative emotional pictures ($p < .05$, corrected) and showing a greater response to negative than to neutral pictures at picture onset ($t = 7 - 8$ s.).

Brain region (Brodmann area, hemisphere)	Talaraich coordinates (mm)			Volume (ml)	F_v
	x	y	z		
Cognitive regions					
Dorsolateral frontal cortex (BA 6/44, right)	40	2	30	0.210	61.56**
Superior parietal cortex (BA 7, right)	24	-59	53	0.331	13.63**
Fasciculus uncinatus (BA 34, left)	-28	7	-11	0.353	43.23**
Dorsal occipital cortex (left)	-22	-79	19	13.979	12.13**
Dorsal occipital cortex (right)	23	-77	18	13.129	8.63*
Ventral occipital cortex (left)	-22	-64	-5	30.286	6.47*
Parahippocampal cortex (left)	-30	-25	-14	0.763	0.15
Parahippocampal cortex (right)	34	-19	-16	0.643	0.34
Medial anterior temporal cortex (BA 38, right)	34	-4	-23	0.221	8.53*

Note. F = Fvalue of picture valence, all negative > neutral. Degrees of freedom are 1 and 16, * p <.05, ** p <.01.

Appendix A.

All statistical regions of interest (ROIs). Brain areas responding to negative emotional pictures ($p < .05$, corrected) and showing a greater response to negative than to neutral pictures at picture onset (t = 7 - 8 s.).

Brain region (Brodmann area, hemisphere)	Talaraich coordinates (mm)			Volume (ml)	F_v
	x	y	z		
Emotional regions					
Amygdala (left)	-19	-5	-9	0.211	51.89**
Amygdala (right)	22	-8	-10	0.450	5.32*
Inferior insula (left)	-31	-1	-9	465	10.94**
Inferior insula (right)	31	-3	-9	0.173	5.32*
Pulvinar (left)	-18	-24	0	0.118	25.89**
Pulvinar (right)	19	-24	0	0.986	8.31*
Subcortical regions					
Locus ceruleus	0	-30	-28	0.244	2.60
Superior colliculus (left)	-6	-24	0	0.934	77.66**
Superior colliculus (right)	6	-24	0	0.800	57.21**

Note. F = Fvalue of picture valence, all negative > neutral. Degrees of freedom are 1 and 16, * p <.05, ** p <.01.

Chapter 4.

How automatic is “automatic vigilance”?: The role of working memory in attentional interference of negative information

This chapter is based on: Van Dillen, L. F. & Koole, S.L. (in press). How automatic is “automatic vigilance”?: The role of working memory in attentional interference of negative information *Cognition and Emotion*.

Negative information draws attention more readily than positive or neutral information (Öhman, Flykt, & Esteves, 2001; Pratto & John, 1991). Regardless of whether it is a snake in the grass, an angry face in a crowd, or a fly in the ointment; negative stimuli have the power to disrupt people's ongoing activities and to make them wonder what is going on. Apparently, the human mind is configured such that people instantly notice potential dangers in their environment (Öhman, 2007).

The attention-grabbing power of negative information has recently become the focus of experimental research. In one pioneering series of studies, people were slower to name ink color of negative words than of positive or neutral words (Pratto & John, 1991). This attention-grabbing effect of negative information has been replicated numerous times, across different tasks and different types of stimuli (Eastwood, Smilek, & Merikle, 2003; Öhman, Flykt, & Esteves, 2001; Smith, Cacioppo, Larsen, & Chartrand, 2003). To account for these findings, theorists have proposed that detecting threats was vital to the survival of our pre-human ancestors. Natural evolution may thus have equipped people with an *automatic vigilance* mechanism (Pratto & John, 1991), that rapidly and unintentionally screens the environment for potential dangers (Dijksterhuis & Aarts, 2003). This vigilance for negative information may thus be part of the innate functional architecture of the human brain (Anderson & Phelps, 2001; Öhman, 2007).

Attending to negative information is fast and unintentional. But is it truly unavoidable? Perhaps not. The type of stimulus-driven perceptual processing that underlies interference of negative information is known as bottom-up attentional control (Yantis, 2000). Recent theories of human cognition suggest that attention is not always under the influence of bottom-up processes. Indeed, attention can also be directed by top-down processes that control attention in accord with people's current plans and behaviors (Corbetta & Shulman, 2002). Although the balance between top-down and bottom-up processes may vary, most tasks involve a combination of both influences. Thus, the question arises whether attention to negative information may be guided by top-down processes.

If top-down processes guide attention to negative information, then changes in the processing demands of a central task can be expected to modulate attentional interference of negative information. Consistent with this, recent research has demonstrated that task load moderates attentional interference of negative visual distracters (Erthal et al., 2005; Okon-Singer, Tzelgov & Henik, 2007; Pessoa, McKenna, Gutierrez & Ungerleider, 2002). For example, in one study (Erthal et al., 2005), negative visual distracters slowed down participants’ judgements whether two bars were like oriented or not, but only when the difference in orientation of two bars was substantial. When the orientation of the two bars differed only slightly, such that the central task became more demanding, negative visual distracters no longer interfered with the visual judgement task. In a neuro-imaging study using a similar paradigm, brain regions responding differentially to emotional faces, did so only when task load was low (Pessoa et al., 2002).

Although increased task load may reduce attention to negative information, the precise mechanism that underlies this effect is unclear. In the present work, we suggest that attention to negative information is controlled by working memory processes. Working memory is an assembly of mental structures and processes that are used for temporarily storing and manipulating information (Baddeley, 1986). Unitary store models of working memory (Barrouillet et al., 2007; Conway & Engle, 1994) have proposed that because working memory capacity is limited, different types of information compete over its resources. Under high processing load, working memory facilitates attention to task-relevant information at the expense of task-irrelevant information (Knudsen, 2007; Lavie & De Fockert, 2005). As such, working memory can override more unintentional, stimulus-driven responses. Therefore, it is conceivable that attention to salient, but task-irrelevant negative information is similarly subject to top-down control by working memory processes.

In recent years, the idea that working memory is involved in processing negative information has received growing support. Specifically, studies have shown that loading working memory can reduce the emotional impact of negative stimuli (Erber & Tesser, 1992; Van Dillen & Koole, 2007). For instance, negative stimuli induce less negative feelings when these pictures are followed by a task that makes high rather than low demands on working memory (Van Dillen & Koole, 2007). Likewise, negative stimuli lead to smaller neural responses in the amygdalae, an important circuit in the emotional brain, when people perform a demanding working memory task (Erk, Kleczar, & Walter, 2007; Van Dillen, Heslenfeld, & Koole, 2008). Findings of this sort suggest that working memory plays a major role in dealing with negative information.

A working memory account can easily accommodate past findings that task load can reduce interference of negative information (e.g. Erthal et al., 2005). Specifically, when task load is high, working memory may facilitate attention to task-related information at the cost of task-irrelevant information. However, a working memory account also goes beyond prior work in several ways. First, prior work has typically investigated the competition over attentional resources between task-related and emotion-related information in the visual field. Yet, an important function of working memory is to maintain task-related information even when the task itself is not visually present, for example, during mental rehearsal (Knudsen, 2007). Thus, working memory may still modulate attention to negative information when task load is mentally rather than visually represented. Second, working memory not only controls the direction of attention to objects in the visual field. Indeed, working memory may also control attention to certain features of an object (Liu, Slotnick, Serences & Yantis, 2003). Under high working memory load, task-relevant features will thus receive more attention than task-irrelevant features. If working memory processes are involved, then loading working memory capacity may disrupt attentional interference of task-irrelevant negative features, even when the object itself is in the focus of visual attention.

We designed the present research to investigate the above predictions about the role of working memory resources in the interference of negative information. We conducted two studies using a modified emotional Stroop task. In this task, participants judged the gender of a series of angry and happy faces. Because emotional expressions are irrelevant to gender naming, longer response latencies to negative compared to positive faces indexed greater attentional interference of negative stimulus features (Pratto & John, 1991). In Study 1, we manipulated working memory load by varying the presentation of a math equation. In Study 2, we manipulated working memory load by varying the digit-span of numbers that participants had to retain (Sternberg, 1966). in both studies, working memory load was induced prior to the gender-naming task, such that there was no competition between task-related and emotional objects in the visual field.

Overall, working memory load was expected to induce a general slow-down in response times (Barrouillet, 2007). More importantly, however, we expected that working memory load would moderate attentional vigilance for negative information during the gender-naming task. Under low working memory load, we predicted that participants would display vigilance for negative but task-irrelevant stimulus features (cf. Pratto & John, 1991), such that they would respond more slowly to angry faces than to happy faces. By contrast, we predicted that vigilance for negative stimulus features would be eliminated under high working memory load, such that participants would respond equally fast to angry and happy faces.

Study 1

Method

Participants and Design

Forty-one paid volunteers at the VU University Amsterdam (30 women, 11 men, average age 21) took part in the experiment. The experimental design was 2 (math task: no task versus math task; within participants) x 2 (target expression: positive versus negative; within participants). The main dependent variables consisted of participants' math performance (both correct responses and response times) and their response times to the gender decision task.

Procedure and Equipment

Upon arrival in the laboratory, participants were led to individual cubicles with a personal computer. The experimenter explained that all instructions would be administered via a computer-program and left. After a brief introduction, participants proceeded with a gender-naming task in which participants had to indicate the gender of pictures of either male or female faces displaying either a happy or an angry expression. The faces were drawn from the The Karolinska

Directed Emotional Faces (KDEF) database (Lundqvist, Flykt, & Öhman, 1998). We selected pictures of fourteen individuals (seven men and seven women) facing directly into the camera and displaying either a happy or angry expression. Accordingly, the total set consisted of twenty-eight pictures. Each of the pictures was displayed twice; once without a math task, and once accompanied by a math task. Trials with and without a math task were presented in a random order.

The gender-naming task consisted of 56 trials. Each trial was announced by a row of four asterisks (****) which remained in the center of the screen for one second. Before the 56 experimental trials, participants first received four practice trials to become familiar with the task. During each trial, a picture of either an angry or a happy male or female face appeared on screen for 2 seconds. Participants had to decide as quickly as possible, by making a keyboard response, whether the face on the screen was male or female. In half of the trials (28 trials), the gender-naming task was combined with a math task, which places considerable demands on working memory (Ashcraft & Kirk, 2001). The math task consisted of a moderately complex equation, such as ‘4 * 8 + 11 = ?’. Each equation combined a summation or subtraction with a product or a division and was presented on screen for five seconds. In the other half of the trials, participants were presented with a blank screen for the duration of the math equation. In these trials, participants thus only performed the gender-naming task. Trials containing either a math task or no task were presented in a random order.

Subsequently, a picture of a face was presented, and participants performed the gender-naming task. Following the gender-naming task, the answer of the math-equation appeared on screen, such as ‘43’, and participants had two seconds to judge whether it was correct by making a keyboard response. In one half of the trials, this was the correct answer, in the remaining half, the answer was incorrect. Incorrect answers deviated only slightly from correct answers, such that participants could not rely on making rough estimates.

Participants’ responses and response times to the gender-naming task and the math task were unobtrusively recorded by the computer. At the end of the experimental trials, participants were thanked for their efforts, debriefed, and paid by the experimenter

Results

Math performance

Participants solved 89% (*SD* = 17) of the math equations correctly and had an average response time of 1,269 ms (*SD* = 281). A one-way analysis of variance (ANOVA) yielded no effect of target expression on correct responses; $F(1, 40) = 1.25$, *ns.,* or on response times to the math task, $F(1, 40) < 1$, *ns*. Accordingly, negative expressions did not interfere with math performance.

Gender-naming task

Incorrect responses to the gender-naming task represented only 4% of the trials, such that separate analyses of these responses would not be informative. We excluded the incorrect responses from subsequent analyses.

To analyze participants’ performance on the gender-naming task, we conducted a 2 (target expression) x 2 (math task) ANOVA of participants’ response times. This analysis revealed a main effect of math task, $F(1, 40) = 6.53$, $p < .05$. Participants responded more slowly to faces when a concurrent math task was present (*M* = 923, *SD* = 144) rather than absent (*M* = 891, *SD* = 136). More importantly, the analysis yielded an interaction effect of math task and target expression, $F(1, 40) = 4.74$, $p < .05$.

More focused comparisons yielded a main effect of target expression only in the trials without a math task; $F(1, 40) = 5.59$, $p < .05$. In these trials, participants responded more slowly when the expression was angry (M = 912, *SD* = 150) rather than happy (*M* = 869, *SD* = 121). In the trials with a math task, we found no effects of target expression, $F < 1$. In these trials, participants responded equally quickly to angry and happy faces (*M* = 927, *SD* = 140 and *M* = 918, *SD* = 148, respectively).

Removing the trials with an incorrect response to the math task from the analyses did not alter any of the above-described effects on gender naming.

Discussion

As expected, performing a math task eliminated the greater attentional interference of angry relative to happy faces in a gender-naming task. Importantly, the math task had this effect even though the task was not visually

present during gender naming and even though the emotional expression of the stimuli was in the focus of the visual field. The results of Study 1 thus provide the strongest evidence to date that
working memory load moderates attentional interference of negative information. Notably, high working memory load also resulted in a general slow-down of responses to the gender-naming task. This slow-down was likely due to the increased attentional demands of the high load task (Barrouillet, 2007).

Study 2

We designed Study 2 to replicate and extend the findings of Study 1. Rather than manipulating the presence or absence of a working memory load, Study 2 varied the level of working memory load. To this end, participants retained either a one-digit number or an eight-digit number during the gender-naming task. Varying digit span is a well established way to manipulate working memory load (Sternberg, 1966). If the effects of performing a math task in Study 1 were due to their differential demands on working memory capacity, as our analysis suggests, then attentional interference of negative information should be greater while retaining one-digit rather than eight-digit numbers. On the other hand, if the results of Study 1 were simply due to the presence of an additional task, then retaining one-digit and eight-digit numbers should both suppress attentional interference of negative information.

Method

Participants and Design

Thirty-six paid volunteers at the VU University Amsterdam (20 women, 16 men, average age 21) took part in the experiment. The experimental design was 2 (digit span: one-digit versus eight-digit; within participants) x 2 (target expression: positive versus negative; within participants). The main dependent variable consisted of participants' response times to the gender-naming task.

Procedure and Equipment

The experimental design was similar to that of Study 1. Participants again performed the gender-naming task consisting of 56 trials. This time, participants were presented with a number at the beginning of each trial, which they had to retain during the gender-naming task. We varied the working memory load of the number task by manipulating the digit span of the number. In half of the trials (28 trials), this was a one-digit number between zero and ten, such as ‘9’. In the remaining 28 trials, this was an eight-digit number, such as ‘25371906’. Trials containing a one-digit or an eight-digit number were presented in a random order.

In each trial, following the gender-naming task, a number again appeared on screen and participants had to judge whether it was the same number as they had retained during the gender decision task. In half of the trials, this was the same number as they had seen previously, whereas in the remaining half this was a different number. In the trials in which participants retained an eight-digit number one of the eight digits could vary, such that participants had to retain all eight digits in order to perform the number-task effectively.

Results

Digit span performance

A 2 (digit span) x 2 (target expression) ANOVA yielded a main effect for digit span on participants’ correct responses; $F(1, 35) = 110.93$, $p < .001$ and on participants’ response times; $F(1, 35) = 806.00$, $p < .001$. Participants gave more correct responses to the one-digit numbers ($M = 94\%$, $SD = 10$) than to the eight-digit numbers ($M = 77\%$, $SD = 11$) and participants responded faster to the one-digit numbers ($M = 1126$, $SD = 216$) than to the eight-digit numbers ($M = 2095$, $SD = 290$). As in Study 1, there were no effects for target expression on either correct responses, $F(1, 35) < 1$, *ns,* or response times, $F(1, 35) < 1$, *ns*.

Gender-naming task

To analyze participants’ performance on the gender-naming task, we conducted a 2 (digit span) x 2 (target expression) ANOVA of participants’ response times. As in Study 1, incorrect responses (4% of all responses) were excluded from the data. The analysis yielded a main effect of digit span, $F(1, 35) = 5.66$, $p < .05$. Participants were slower to respond to the faces when they had to retain an eight-digit number ($M = 937$, $SD = 131$) than when they had to retain a one-digit number ($M = 874$, $SD = 157$). More importantly, the analysis yielded the predicted interaction of digit span and target expression, $F(1, 35) = 4.38$, $p < .05$.

Focused comparisons only revealed a significant effect of target expression in the one-digit trials, $F(1, 35) = 4.05$, $p < .05$. When participants retained a one-digit number, that is, when working memory load was low, participants responded slower to angry faces ($M = 892$, $SD = 161$) than to happy faces ($M = 855$, $SD = 152$). When participants retained an eight-digit number, that is, when working memory load was high, participants responded equally fast to angry faces ($M = 946$, $SD = 140$) and happy faces ($M = 927$, $SD = 122$), $F(1, 35) = 1.79$, *ns*.

As in Study 1, removing the trials with an incorrect response to the digit span task from the analyses did not alter any of the above-described effects on gender naming.

Discussion

The results of Study 2 thus confirmed that working memory load moderates the greater attentional interference of negative relative to positive information. Moreover, Study 2 demonstrates that attentional interference is not merely determined by the absence or presence of a concurrent task but rather by the degree to which working memory is taxed.

General Discussion

Negative information has the power to grab people's attention readily and involuntarily (Eastwood, Smilek, & Merikle, 2003; Öhman, Flykt, & Esteves, 2001; Pratto & John, 1991). However, this power is not without limitations. Specifically, the present research hypothesized that top-down processes that are involved in working memory may modulate preferential allocation of attention to negative emotional information. When working memory load is low, top-down control of attention is relatively weak, and negative information may capture attention even when it is irrelevant to the focal task. By contrast, when working memory load is high, top-down control of attention is strengthened, so that task-irrelevant negative information may no longer assume priority in attention. This reasoning was confirmed in two experiments, which demonstrated that working memory load can eliminate the greater attentional interference of negative relative to positive information.

The present findings provide the most direct demonstration to date that working memory resources regulate attention to negative information. Prior work has documented how visual distracters can reduce attentional interference of negative information (Erthal et al., 2005; Pessoa et al., 2002). The present work goes beyond these findings, by showing that even non-visual, purely mental forms of task load can reduce attentional interference of negative information, presumably because such task load taxes working memory. Moreover, task load can moderate interference of negative stimulus features, even when the stimulus is in the focus of visual attention. An important implication of these findings is that working memory exerts a much more pervasive influence on attention to negative information than was previously assumed.

At a more general level, the present research contributes to the theoretical integration between the literatures on working memory and emotion. Whereas traditional conceptions portrayed working memory as a "cold" cognitive system, a growing amount of evidence highlights the relevance of working memory for "hot" emotional processing (Erk et al., 2007; Van Dillen & Koole, 2007). The present work adds to these findings by proposing a key role for working memory resources in determining whether "hot" information about potential threats in the environment gets prioritized over "cool" information that is relevant to people's ongoing cognitive tasks. As such, working memory functions seem vital to understanding the interface between cognition and emotion.

Our findings that attention to negative information depends on working memory resources could be considered surprising, given that the attention-grabbing power of negative information is widely assumed to be automatic (e.g. Öhman, Flykt, & Esteves, 2001; Pratto & John, 1991). However, these previous accounts can be reconciled with the present findings. Under conditions of low working memory load, negative information was found to interfere with ongoing attentional processing. The present findings thus confirm that automatic processes play an important role in quickly guiding attention towards negative information. However, as the present findings also show, negative information may cease to receive preferential attention when working memory is more fully engaged by a focal task. Attention to negative information is thus fast and unintentional, but contingent upon the availability of sufficient working memory capacity. Consequently, attention to negative information appears to be driven by a combination of top-down and bottom-up control processes.

The relative importance of top-down and bottom-up processes in attending to negative information may vary between different persons and situations. As the present findings indicate, conditions such as greater working memory load may increase the contribution of top-down attentional control. Other conditions, such as a higher intensity of negative information, may result in a greater contribution of bottom-up processes (Yantis, 2000), and accordingly result in a stronger negativity bias. In line with this, attentional interference of negative information is stronger for intensely negative stimuli than for mildly negative stimuli (Schimmack, 2005). A reduced capacity for top-down control may similarly result in a more pronounced negativity bias (see Eysenck et al., 2007; Williams et al., 1996). Future research is needed to gain more insight into the dynamic interplay between bottom-up versus top-down processes in attention to negative information.

So far, we have interpreted response time differences between positive and negative emotional stimuli as an index of interference of negative information (as is conventional, see Smith et al., 2006). Because this is a relative index, it remains possible that the effects of working memory load have been driven by an increase in attention to positive information. Nevertheless, we prefer to interpret our findings in terms of changes in attention to negative information. First, research that incorporated neutral control conditions has similarly shown load-induced reductions in attentional interference of negative information (Erthal et al., 2005; Okon-singer, 2007). Second, neuro-imaging work indicates that increased working memory load decreases, rather than increases, neural responsiveness to positive emotional stimuli (Erk, Klezcar & Walter, 2007). The broader literature thus supports our interpretation that working memory load reduces interference of negative information rather than boosting interference of positive information.

The present findings mesh well with recent neuropsychological evidence for a role of corticofrontal working memory areas in attentional control of processing of negative emotional stimuli (Blair et al., 2007; Hariri, Bookheimer, & Mazziotta, 2000). For example, using functional magnetic resonance imaging (fMRI), a recent study found that high working memory load compared to low working memory load resulted in decreased responsivity to negative stimuli in the bilateral amygdalae (Van Dillen et al., 2008). The amygdalae enhance perception of emotionally salient events (Anderson & Phelps, 2001) and may as such facilitate bottom-up control of attention. In accord with the present findings, bottom-up facilitation of attention to negative information in the brain can be modulated by taxing working memory.

At a more general level, the present research attests to a considerable amount of flexibility in human information processing. Evolutionary forces from a distant past may have shaped the mind to prioritize negative over other types of information. Nevertheless, this prioritization seems open to reprogramming in the present, by people’s current goals and interests. Perhaps it is this capacity to flexibly reprioritize information that allows people to move beyond the perception of imminent risks and dangers to explore the promises and opportunities that the future may hold.

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Samenvatting

Omgaan met negatieve gevoelens: De rol van het werkgeheugen in emotieregulatie.

Hoewel negatieve gevoelens vaak hun nut hebben, kunnen ze ook ongewild iemands gedachten in beslag nemen en zodoende zijn of haar psychisch en fysiek welbevinden ondermijnen. Het is daarom belangrijk om na te gaan of er manieren bestaan waarop mensen zich kunnen beschermen tegen de verstorende werking van negatieve gevoelens. De hardnekkigheid van negatieve gevoelens is in ieder geval gedeeltelijk verklaarbaar door de onevenredige invloed die negatieve informatie heeft op het menselijke aandachtssysteem. Een bruikbare manier om negatieve gevoelens te reguleren is daarom wellicht om de hoeveelheid aandacht die aan negatieve informatie besteed wordt te controleren.

De huidige dissertatie veronderstelt dat het werkgeheugen een centrale rol speelt in het reguleren van de aandacht voor negatieve informatie. Het werkgeheugen is een systeem waarin informatie tijdelijk opgeslagen en bewerkt kan worden. Het speelt een belangrijke rol in informatieverwerkingsprocessen, zoals probleem oplossen, plannen en communiceren. Omdat het werkgeheugen een beperkte capaciteit heeft, betekent dit dat mensen geen ongelimiteerde hoeveelheid informatie tegelijk kunnen vasthouden. De huidige dissertatie onderzoekt hoe de verwerking van negatieve informatie beïnvloed wordt door deze beperking van de werkgeheugencapaciteit. Hoofdstuk 1 geeft een theoretisch overzicht van de literatuur terwijl hoofdstuk 2 tot 4 empirisch onderzoek beslaan naar de rol van het werkgeheugen in het omgaan met negatieve informatie.

Hoofdstuk 1 introduceert de belangrijkste theoretische begrippen, bestaande uit aandacht, het werkgeheugen, negatieve emotie, en hun onderlinge samenhang. Het hoofdstuk geeft een overzicht van alle empirische bevindingen met betrekking tot de rol van het werkgeheugen in het omgaan met negatieve gevoelens. In het hoofdstuk wordt een werkgeheugen model van afleiding van negatieve gevoelens geïntroduceerd (Van Dillen & Koole, 2007) waarin de theoretische verbanden tussen deze concepten zijn georganiseerd. Het centrale idee van dit model is dat afleiding het gebruik van beperkte werkgeheugencapaciteit behelst. Hoe meer werkgeheugen wordt benut voor een afleidende activiteit, hoe minder ruimte over blijft voor het voortduren van een emotionele reactie. In het vervolg van Hoofdstuk 1 wordt besproken in hoeverre het werkgeheugen model steun heeft van empirische bevindingen, waaronder het onderzoek waarvan verslag wordt gedaan in Hoofdstuk 2 tot 4. Tenslotte worden de beperkingen en implicaties van het model besproken, als wel mogelijkheden voor toekomstig onderzoek.

Hoofdstuk 2 beschrijft drie experimenten waarin onderzocht werd hoe werkgeheugenbelasting negatieve stemming kan afzwakken. Deelnemers werd neutrale, zwak negatieve, en sterk negatieve afbeeldingen getoond, waarna zij een taak uitvoerden en vervolgens aangaven hoe onprettig ze zich voelden op dat moment. Werkgeheugenbelasting werd gemanipuleerd door de aanwezigheid van de taak (Studie 1), taakcomplexiteit (Studie 2), of taakvoorspelbaarheid (Studie 3) te variëren. Deelnemers in alle drie de experimenten rapporteerden minder negatieve stemming in reactie op negatieve afbeeldingen als zij vervolgens een hoog belastende taak uitvoerden dan wanneer zij een laag belastende taak, of geen taak uitvoerden. Werkgeheugenbelasting had geen effect op de gerapporteerde stemming in reactie op neutrale afbeeldingen. Wanneer werkgeheugenbelasting hoog was, rapporteerden deelnemers niet langer meer negatieve stemming in reactie op sterk negatieve afbeeldingen dan in reactie op zwak negatieve afbeeldingen. Deze bevindingen suggereren dat het belasten van het werkgeheugen de emotionele verwerking tegengaat, en zodoende afleiding van negatieve stemming bevordert.

Hoofdstuk 3 beschrijft een experimentele studie waarin gekeken werd of werkgeheugenbelasting niet alleen zelf gerapporteerde stemming afzwakt, maar ook emotionele verwerking in het brein. Met behulp van functionele magnetische resonantie technieken (functional magnetic resonance imaging; fMRI) werd aangetoond dat taakbelasting tot een toename in neurale activteit leidde in werkgeheugengebieden (rechter dorsolaterale frontale cortex, rechter superiere parietale cortex), maar tot een afname in neurale activiteit in gebieden die reageerden op negatieve emotionele afbeeldingen (de bilaterale amygdalae en de rechter anterieure insula). In overeenstemming met de bevindingen van Hoofdstuk 2, resulteerde een hoge werkgeheugenbelasting opnieuw in een reductie in zelf gerapporteerde negatieve stemming in reactie op negatieve afbeeldingen. Samen ondersteunen deze bevindingen een model waarin emotionele en niet-emotionele informatie concurreren om beperkte werkgeheugencapaciteit.

Hoofdstuk 4 rapporteert twee experimenten die het effect onderzochten van werkgeheugenbelasting op onwilleurige aandacht voor negatieve informatie. Hoewel eerder werk veronderstelt dat aandacht voor negatieve informatie automatisch en onvermijdelijk is (Pratto & John, 1991), wordt in Hoofdstuk 4 de hypothese getoetst dat aandacht voor negatieve informatie afhangt van de beschikbaarheid van werkgeheugencapaciteit. In twee experimenten benoemden deelnemers de sekse van boze versus blije gezichten. Werkgeheugenbelasting werd gemanipuleerd door de aan- of afwezigheid van een rekentaak (Studie 1), of het onthouden van een één versus acht cijfes (Studie 2). Uit de resultaten bleek dat boze gezichten meer interfereerden met het benoemen van de sekse van de gezichten dan blije gezichten, maar alleen wanneer werkgeheugenbelasting laag was. De interferentie van negatieve informatie op aandacht wordt dus mede bepaald door de werkgeheugenbelasting van een additionele taak.

Samengevat veronderstelt de huidige dissertatie dat het werkgeheugen een essentiële rol speelt in het omgaan met negatieve emotie. Werkgeheugenbelasting bleek de invloed van negatieve afbeeldingen op stemming af te zwakken (**Hoofdtuk 2 en 3**), alsmede emotionele responsen in het brein (**Hoofdstuk 3**). Bovendien onderdrukte werkgeheugenbelasting de interferentie van negatieve informatie op aandacht (**Hoofdstuk 4**). Ondanks de soms overweldigende indruk van negatieve informatie, blijken mensen in staat te zijn om hun negatieve emotionele reacties te reguleren door zich te richten op de taken en doelen die hen op dat moment bezig houden.

Summary

Dealing with negative feelings: The role of working memory in emotion regulation.

Though negative emotions are often adaptive, they can occupy people's thoughts unwantedly and thereby undermine psychological and physical well-being. It is therefore important to look for ways in which people can shield themselves against the disruptive power of negative emotion. The pervasiveness of negative emotions is partly due to the strong impact of negative information on the human attention system. Consequently, one potentially effective way to deal with negative emotions may be to control the amount of attention that is to negative information. The present dissertation examines how processing of negative emotional information is influenced by the availability of working memory resources. Chapter 1 provides a theoretical overview and Chapters 2 to 4 report empirical tests of the role of working memory in dealing with negatively charged information.

Chapter 1 introduces the key concepts of the present dissertation, which consist of attention, working memory, negative emotion, and their interplay, and provides an overview of relevant empirical findings on the role of working memory in dealing with negative emotions. The theoretical relations between these concepts are organized by a working memory model of distraction from negative emotion (Van Dillen & Koole, 2007). The central idea of the model is that distraction involves the use of limited processing capacity in working memory. The more working memory is being used by a distracting activity, the less room will remain for negative emotions to persist. The remainder of Chapter 1 considers how the working memory model fits with the empirical literature, including the research that is presented in Chapters 2-4. Moreover, the model's limitations and implications are discussed, along with directions for future work.

Chapter 2 describes three experiments that examined whether and how loading working memory can attenuate negative mood. Participants were exposed to neutral, weakly negative or strongly negative pictures followed by a task and a mood scale. Working memory demands were varied by manipulating task presence (Study 1), complexity (Study 2), and predictability (Study 3). Participants in all three experiments reported less negative moods in negative trials with high compared to low working memory demand. Working memory demands did not affect mood in the neutral trials. When working memory demands were high, participants no longer reported more negative moods in response to strongly negative pictures than to weakly negative pictures. These findings suggest that loading working memory prevents mood-congruent processing, and thereby promotes distraction from negative moods.

Chapter 3 describes an experimental study which examined whether loading working memory not only modulates subjective experience of negative emotion, but also the unfolding of emotional brain responses. Using functional magnetic resonance imaging (fMRI), task load was found to result in increased activation in working memory regions (right dorsolateral frontal cortex, right superior parietal cortex), but in decreased responsivity to negative scenes in emotional regions (the bilateral amygdalae and the right inferior insula). In line with previous research, task load also reduced subjectively experienced negative emotion in response to negative scenes. Together, these findings support a model in which emotional and non-emotional information compete for the limited capacity of working memory.

Chapter 4 reports two experiments that examined the effect of working memory load on unintentional intrusions of negative information on attentional processing. Whereas attentional interference of negative information has been assumed to be automatic and unavoidable (Pratto & John, 1991), Chapter 4 advances the hypothesis that this effect may depend on the availability of working memory resources. In two experiments, participants judged the gender of angry versus happy faces. Working memory load was manipulated by the presence or absence of a math task (Study 1) or mental rehearsal of a one- versus eight-digit number (Study 2). The results showed that angry faces interfered more with gender naming than happy faces, but only when working memory load was low.

These results indicate that attentional interference of negative information can be modulated by top-down attentional control processes.

Taken together, the present dissertation suggests that working memory plays a vital role in dealing with negative emotion. Indeed, taxing working memory was found to moderate the impact of negative emotional stimuli on negative feelings (**Chapter 2 and 3**), circuits within the emotional brain (**Chapter 3**) and attentional interference of negative information (**Chapter 4**). As such, the present dissertation demonstrates how, despite the pervasive impact of negative emotional information, people may be capable of regulating negative emotional responses in accord with ongoing task demands and goal-directed activities.

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Onder het juk van plichtsbesef
Ga ik elke morgen weer op weg
Fietsend langs paal en perk
Met aan den einder: Het Werk
Elke dag weer een déja-VU
Terwijl ik denk: Is dit het nu?

- Lotte van Dillen, Amsterdam, Juni 2004

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