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Working Memory Load Reduces Facilitated Processing of Threatening Faces: An ERP Study

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The present study tested the hypothesis that facilitated processing of threatening faces depends on working memory load. Participants judged the gender of angry versus happy faces while event-related brain potentials were recorded. Working memory load was manipulated within subjects by the mental rehearsal of one- versus eight-digit numbers. Behavioral results showed that the relative slow-down to angry compared to happy faces in the gender-naming task (i.e., the negativity bias) was eliminated under high working memory load. Under low (but not high) load, N2 amplitudes were smaller to angry compared to happy faces. Moreover, high load reduced LPP amplitude and eliminated the enhanced LPP to angry compared to happy faces that were present under low load. These results suggest that working memory load improves attentional control, and reduces sustained attention for distracting negative expressions. Taken together, these findings demonstrate that facilitated processing of threatening cues may be contingent on cognitive resources.

Keywords: cognitive resources, attentional selectivity, facial expression, LPP, N2

In emotion research, it has often been argued that, because of their high social and biological relevance, the attentional processing of emotional facial expressions is prioritized over more neutral information (Anderson & Phelps, 2001; Bradley, 2009; Öhman, 2007; Schupp et al., 2004). People for example more easily detect an angry face among distractors than a happy or neutral face (Öhman, Lundqvist, & Esteves, 2001), whereas they are at the same time slower to disengage attention from angry faces than of neutral or happy faces (Belopolsky, Devue, & Theeuwes, 2011; Fox, Russo, & Dutton, 2002; Yiend & Mathews, 2001). From an evolutionary viewpoint, facilitated attentional processing of threatening social cues is functional and automatic (Fox et al., 2002). However, in the current article we propose that, rather than an ever-present processing advantage for angry faces, the attention-grabbing power of angry (relative to neutral or positive) faces depends upon working memory capacity. We suggest that attention to threat cues such as angry faces is dependent upon people's ongoing plans and activities: When working memory resources are used for engaging in a focal task, people's attention is less likely to be diverted by negative but task-irrelevant angry facial expressions.

In support of the idea that enhanced attention to negative relative to neutral or positive cues is resource-dependent, a number of recent behavioral and neuroimaging findings suggest that the detection of negative distracters in the visual field, such as emotional scenes or faces, is modulated by the perceptual load of a target cue (Bishop, Jenkins, & Lawrence, 2007; Doallo, Holguín, & Cadaveira, 2006; Erthal et al., 2005; Huang, 2011; Pessoa, McKenna, Gutierrez, & Ungerleider, 2002). Moreover, there is research to suggest that even mentally rehearsed, rather than visually present information, may compete with attentional processing of emotional cues (Erk, Klezcar, & Walter, 2007; Van Dillen, Heslenfeld, & Koole, 2009; Van Dillen & Koole, 2009). For example, Erk, Klezcar, and Walter (2007) demonstrated how amygdala activity in response to negative scenes was effectively reduced when people simultaneously performed a visuospatial working memory task. These findings thus suggest that the modulation by working memory load is not simply a consequence of visual competition but rather a consequence of available cognitive resources.

Although the above-described findings provide support for the notion that working memory load attenuates preferential processing of negative cues such as angry faces, it is unclear how exactly working memory load has its effects. We propose that working memory load interferes with the typically facilitated processing of threatening faces. An important function of working memory is to control 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). High working memory load may thus disrupt attentional interference of task-irrelevant negative features, such as angry facial expressions, even when the target face is in the focus of visual attention.

To test this idea, we examined modulations by working memory load of facilitated processing of angry faces during a gender-

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naming task using angry and happy faces. Previous research has shown that people are slower in categorizing the gender of angry as compared to happy or neutral faces, indicating that their attention is involuntarily drawn to the angry expression of the faces, at the cost of task-relevant features (Van Dillen & Koole, 2009; Van Dillen, Lakens, & Van den Bos, 2011; Van Honk, Tuiten, De Haan, Van Den Hout, & Stam, 2001). Importantly for our current analysis, Van Dillen and Koole (2009) recently demonstrated that this relative slowing of gender categorizations for angry faces does not occur when working memory load is high. In two studies, these authors showed that participants responded as fast to angry faces as to happy faces when they concurrently had to solve moderately complex math equations (Study 1) or maintain a series of eight digits (Study 2).

Van Dillen and Koole have interpreted response time differences between happy and angry target faces as an index of interference of negative facial cues (as is conventional; see Smith et al., 2006). Because this is a relative index, it remains possible that the effects of working memory load are driven by an increase in attention to positive information under high load. Reaction times represent the outcome of a set of cognitive (and other) processes performed on stimuli of interest, but are not, themselves, direct measures of those processes. This issue is circumvented when using event-related potential (ERP) measures, which allow for more direct measurement of neural responses that reflect cognitive and motivational processes of interest (Bartholow, 2010). To find more conclusive evidence for the notion that working memory load reduces facilitated attention to threatening faces, we examined the effect of working memory load on responses to angry versus happy target faces combining behavioral measures (RTs) with ERP methodology. Another important advantage of ERP methodology over behavioral or, for example fMRI methodology, is the high temporal resolution (in ms) of ERP measures. Accordingly, ERP recordings can be used to investigate the time course of facilitated emotion processing, hereby providing an effective tool for examining when working memory load has its effects on the various stages of face processing.

Many ERP components have been studied in relation to emotional processing, and researchers commonly differentiate between early (0−250ms) processing that reflects obligatory initial attention capture driven by stimulus characteristics, and later processing (beyond 250 ms) that is driven more by contextual factors (Carretié, Hinojosa, Martin-Loeches, Mercado, & Tapia, 2004; Foti, Hajcak, & Dien, 2009). Although we will examine both early and later components of the ERP signal, we expect the effects of working memory load to arise in the later components, more specifically the N2 and the Late Positive Potential (LPP).

The N2 is a negative amplitude deflection over fronto-central scalp sites at around 200 to 300 ms. It is typically conceived of as an index of attentional control (Dennis & Chen, 2009; Folstein & Van Petten, 2008; Schupp et al., 2004) and N2 amplitude increases have been interpreted as recruitment of cognitive control. Several studies have shown that the amplitude of the N2 is attenuated in response to negative compared to positive stimuli (Olofsson, Nordin, Sequeira, & Polich, 2008; Schupp et al., 2004), an effect that has been localized to the anterior cingulate cortex (Carretié et al., 2004). Following our prediction that angry faces distract from focal tasks under low but not high concurrent load, we predicted N2 amplitude to be modulated by facial expression on low load trials, with angry expressions reducing cognitive control relative to happy expressions. On high load trials, however, we expected similar N2 amplitudes, regardless of facial expression.

As an indicator of sustained attention, we also measured the LPP, a positive deflection starting at around 400 ms poststimulus that is maximal at centro-parietal scalp sites. The LPP has been shown to be modulated by facial expressions of emotions, such that amplitude is more positive in response to angry than in response to happy or neutral faces (Frühholz, Jellinghaus, & Herrmann, 2011; Schupp et al., 2004; Schutter, De Haan, & Van Honk, 2004). Moreover, previous work revealed that cognitive strategies such as reappraisal and distraction reduce LPP amplitude to negative pictures (Foti & Hajcak, 2008; Hajcak & Nieuwenhuis, 2006; MacNamara, Foti, & Hajcak, 2009). Finally, recent findings suggest a relation between working memory and the LPP. For instance, Hajcak and colleagues demonstrated how direct stimulation via epidural cortical stimulation (EpCS) of the dorsolateral prefrontal cortex (the DLPFC), a brain region implicated in working memory processes, resulted in smaller LPP deflections in response to aversive pictures (Hajcak et al., 2010). Similarly, MacNamara, Ferri, and Hajcak (2011) observed smaller LPP responses to negative and neutral complex scenes during a passive viewing task under high compared to low working memory load. Based on these findings, we expected the moderating impact of working memory load on the attentional interference produced by task-irrelevant angry compared to happy faces to be reflected in the amplitude of this component.

Different from earlier neuropsychological studies on the attentional modulation of affective processing (Doallo et al., 2006; Erthal et al., 2005; Holmes, Vuillemier, & Eimer, 2003), in the current experiment the emotional faces were always in the focus of participants' visual attention, as the faces were the object of the gender-naming task. In addition, no visual distracter stimuli were present. Accordingly, any effects of working memory load on affective processing cannot be attributed to emotion-avoidant gaze patterns (Dunning & Hajcak, 2009; MacNamara, Ferry, & Hajcak, 2011; van Reekum et al., 2007), or differences in task parameters (Erthal et al., 2005), but instead have to be the result of variations in the availability of working memory resources.

Method

Participants and Design

Fifteen paid volunteers from Leiden University (all women,[1] mean age 20, age range 19–25) gave their written informed consent and took part in the experiment in exchange for payment (€10,-) or two course credits. Participants were right-handed, had normal or corrected to normal vision and no neurological or psychiatric history. The experiment had a 2

[1] We selected only female participants to prevent any confounds of perceiver gender, such as greater responsiveness of men to (attractive) female faces (van Hooff, Crawford, & Van Vugt, 2010).

(working memory load: low vs. high) × 2 (target expression: happy vs. angry) within-participants design. The main dependent variables consisted of participants' neural responses to the target expressions, as well as their digit-span performance (both correct responses and response times), and their response times to the gender-naming task. The study met all criteria for approval by the Psychology Ethics Committee at Leiden University.

Procedure

Participants performed a gender-naming task in which they had to indicate the gender of pictures of male and female faces displaying happy or angry expressions. The faces were drawn from the The Karolinska Directed Emotional Faces (KDEF) database (Lundqvist, Flykt, & Öhman, 1998). We selected pictures of 30 individuals (15 men and 15 women) facing the camera directly and displaying either a happy or an angry expression. Accordingly, the total set consisted of 60 pictures. Another four neutral faces (two male, two female) were selected for the practice trials. Pilot testing confirmed that there were no differences in self-reported arousal, on a scale from 1 (*not at all arousing*) to 7 (*very arousing*), in response to angry faces (M = 4.06 SD = .55) and happy faces (M = 3.97 SD = .54; $t(32)$ = .586, p = .542).

Each of the pictures was displayed twice; once with a high concurrent working memory load, and once with a low concurrent working memory load. Trials with high and low concurrent load were presented in a random order and the order of stimulus presentation was balanced between the two digit span conditions. Each trial was announced by a row of four asterisks (****), which remained in the center of the screen for one second (see Figure 1). Next, participants were presented with a number of either one or eight digits for four seconds, which they were asked to retain during the gender-naming task that followed immediately afterward. After the number disappeared from the screen, a picture of either an angry or a happy male or female face appeared on screen for one second, during which participants were to indicate as quickly as possible, by making a left or right button response, the gender of the face (male/female). These category labels appeared in the lower right and left of the screen during picture display; left/right response options were counterbalanced across participants. After participants pressed a button, their chosen response changed into bold font type for the remaining duration of the picture display. Following picture offset, a number again appeared on screen for four seconds and participants were asked to judge whether it was the same number as the one they were shown at the beginning of the trial by pressing one of two buttons (same/different). In half of the trials, the number was the same one they had seen previously, whereas in the remaining half the number was different. The two trial types (same/different) were randomized throughout the task.

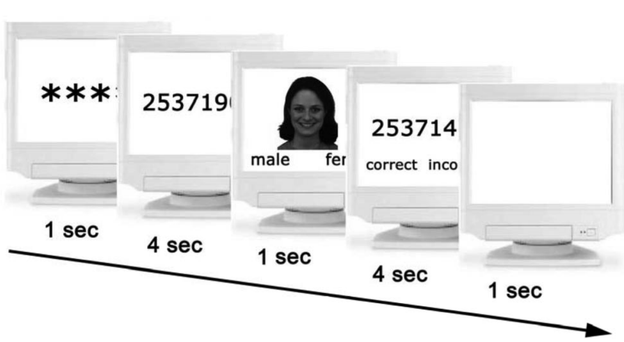

Figure 1. Procedure used in the current experiment, showing the sequence of events within a trial.

We varied working memory load of the digit span task by manipulating the digit span of the number (Sternberg, 1966). In half of the trials (60 trials), this was a one-digit number between zero and nine (e.g.,7); in the remaining 60 trials, this was an eight-digit number (e.g., 25371906). In the trials in which participants retained an eight-digit number only one of the eight digits could vary, such that participants had to retain all eight digits in order to perform the digit span task effectively. Before the experimental trials, participants performed four practice trials in order to become familiar with the experimental procedure.

During the experiment, participants were seated in a dimly lit, soundproofed room in a comfortable chair, approximately 75 cm from a computer monitor. The computer unobtrusively recorded participants' responses and response times to the gender-naming task and the digit-span task. At the end of the experimental trials, participants were thanked for their efforts, debriefed, and paid by the experimenter.

EEG Recordings and Signal Processing

Continuous EEG was recorded from 12 scalp sites (Fz, F3, F4, Cz, C3, C4, Pz, P3, P4, Oz, O1, O2), as well as two electrodes placed on the left and right mastoids, using an ECI Electrocap and the ActiveTwo BioSemi system (BioSemi, Amsterdam, Netherlands). Vertical and horizontal eye movements were recorded with electrodes placed supra- and infraorbitally at the left eye and on the left versus right orbital rim. The Common Mode Sense (CMS) active electrode and the Driven Right Leg (DRL) passive electrode formed the amplifier reference during acquisition.

EEG and EOG activity were sampled at 256 Hz and digitized on a laboratory computer using ActiView software (BioSemi). The EEG data was processed and analyzed using Brain Vision Analyzer software (Brain Products). Off-line, the data was rereferenced to the average activity of the mastoids electrodes, band-pass filtered with cutoffs of 0.1 and 30 Hz, and corrected for ocular artifact using the Gratton, Coles, and Donchin (1983) method. The EEG-data were segmented into epochs from 200 ms before stimulus onset to 1,000 ms after stimulus onset. Separate ERP averages were computed for the four different trial types (working memory load x target expression). Epochs exceeding a 100 μV amplitude difference, a voltage step difference of 50 μV between sample points or with activity less than 0.5 μV were excluded from these averages. The resulting averages were baseline corrected for the 200 ms prior to stimulus onset.

Early and midlatency components were scored by locating the highest peak within predetermined timeframes: P1 (50–150 ms), N1 (50–150 ms), P2 (150–250ms), and N2 (150–350 ms). LPP amplitude was scored by computing the average amplitude from 400 to 1,000 milliseconds (MacNamara et al., 2011; Van Strien, DeSonneville, & Franken, 2010). We first visually inspected the grand averages to determine whether this epoch effectively captured the LPP. Although research suggests that the LPP can be affected by stimulus valence for well over 1,000 ms (Foti et al., 2009, etc.), we did not examine the LPP component beyond stimulus offset (1,000 ms), as we were primarily interested in the effects of expression valence of the target faces during the gender categorization task.

Analyses

All components were first investigated in a global cluster to detect the caudality (frontal, central, or posterior) showing maximum amplitude.[2] Next, for the electrodes on which amplitude was maximum, a repeated measures GLM analysis was conducted with the within-subject factors target expression (two levels: angry, happy), working memory load (two levels: low vs. high) and electrode (three levels: left, midline, right). Significant interactions were followed by planned comparisons of the simple effect of target expression within each working memory load condition. If applicable, Greenhouse-Geisser corrections were performed.

Results

Behavioral Data

Digit recognition. First we removed outlier data points (more than three standard deviations from each individual's mean; 1.9% of the data). We then computed the average percentage of correct responses on both the long and short digit-span trials. A 2 (working memory load) × 2 (target expression) ANOVA yielded a main effect for digit span on participants' correct responses, $F(1, 14) = 131.93$, $p < .001$, $\eta_p^2 = .910$, and on participants' response times; $F(1, 14) = 448.63$, $p < .001$, $\eta_p^2 = .972$. As expected, participants were faster and gave more correct responses in the one-digit trials ($M_{rt} = 988$ ms, $SD = 126$; $M_{correct} = 0.97$, $SD = 0.03$) than in the eight-digit trials ($M_{rt} = 2165$ ms, $SD = 140$; $M_{correct} = 0.79$, $SD = 0.06$). There were no effects of target expression on digit recognition performance. We included trials of incorrect responses to the digit span task in subsequent analyses of response times to the gender-naming task. However, when we controlled for digit span performance by means of a covariance analysis, this did not affect any of the findings reported below.

Gender categorization. We removed incorrect responses to the gender-naming task (4% of all responses) from the analyses. There were no outliers. Because we did not find any effects of target gender, we collapsed responses to male and female faces. A 2 (working memory load) × 2 (target expression) ANOVA of participants' response times yielded the predicted interaction of working memory load and target expression, $F(1, 14) = 5.07$, $p = .042$, $\eta_p^2 = .280$. Pairwise comparisons revealed a significant effect of target expression only in the low-load trials, $F(1, 14) = 8.08$, $p = .010$, $\eta_p^2 = .383$. When participants retained a one-digit number (i.e., low load), they were slower to name the gender of angry faces ($M = 749$, $SD = 168$) than of happy faces ($M = 690$, $SD = 165$). When participants retained an eight-digit number, (i.e., high load) they responded equally slowly to happy faces ($M = 747$, $SD = 167$) as to angry faces ($M = 734$, $SD = 167$); $F(1, 14) = 1.01$, $p = .359$, $\eta_p^2 = .060$. Additionally, while responses to happy faces were slower under high than low load, $F(1, 14) = 8.01$, $p = .014$, $\eta_p^2 = .381$, high load did not further slow-down response times to angry faces $F(1, 14) = 1.25$, $p = .283$, $\eta_p^2 = .088$.

ERP Data

Early components. P1 amplitude was largest over parietal and occipital electrodes, and was affected by working memory load only, $F(1, 14) = 6.55$, $p = .021$, $\eta_p^2 = .356$. P1 amplitude was higher for the eight-digit trials than for the one-digit trials across all parietal and occipital electrodes ($M_{high} = 6.65$, $SE_{\mathrm{hifg}} = .83$; $M_{low} = 4.06$, $SE_{\mathrm{low}} = .93$). No significant interactions with target expression were found. N1 amplitude was largest over frontal and central electrodes, and P2 amplitude was largest over parietal electrodes. Analysis of the N1 and P2 amplitude did not reveal any effects of target expression or working memory load.

N2 amplitude. N2 was largest over fronto-central electrodes (see Figure 2). Thus, we focused our analyses of the effects of working memory load and target expression on N2 deflections on these electrodes (Fz, F3, F4, and Cz, C3, C4), using a 2 (working memory load) × 2 (target expression) × 3 (electrode) × 2 (caudality) repeated measures ANOVA. Apart from a main effect of caudality, $F(1, 14) = 5.39$, $p = .037$, $\eta_p^2 = .293$, indicating larger N2 amplitudes over frontal than central electrodes, the analysis yielded a significant two-way interaction between target expression and working memory load, $F(1, 14) = 9.84$, $p = .021$, $\eta_p^2 = .431$. In support of our hypothesis, analyses per electrode revealed significant interactions on all frontal electrodes, and marginally significant interactions on the central electrodes. Moreover, planned comparisons per working memory load condition revealed a significant effect of target expression in the one digit-trials at all electrode sites, such that under low load N2 amplitude was less negative in response to angry faces compared to happy faces (see Table 1). In the eight-digit trials, however, N2 amplitudes in response to angry faces and happy faces did not differ at any of the electrode sites (all Fs < 1).

LPP amplitude. Amplitudes were largest over central and parietal electrodes (see Figure 2). Thus, analyses of the effects of working memory load and target expression on LPP amplitude were focused on these electrodes (Cz, C3, C4, and Pz, P3, P4), using a 2 (working memory load) × 2 (target expression) × 3 (electrode) × 2 (caudality) repeated measures ANOVA.[3] First of

[2] Missing values at five electrode sites; Fz (N=2), F4 (N=2), P3 (N=2), O1 (N=1), O2 (N=2) were replaced with the average amplitude across the remaining participants for the specific trial type.

[3] Separate analyses of the early (400-700 ms) and late LPP time window (700-1,000 ms; see for example Langeslag & Van Strien, 2009) or analysis of the maximal LPP amplitude (see for example Herring, Taylor, White, & Crites, 2011) all revealed similar patterns of findings as currently reported. Moreover, we also scored the P3 (or P300) component separately (by locating the highest peak between 250–500 ms). Amplitude deflections of the P3 were largest over parietal electrodes. The functional significance of both the P3 and LPP are thought to be very similar, In most studies addressing the visual processing of emotional stimuli the P3 and LPP gradually blend into each other and are difficult to discern and a systematic account of similarities and possible differences between P3 and slow wave for affective stimulus parameters has not yet emerged (Olofsson, Nordin, Sequeira, & Polich, 2008). Indeed, analyses of the P3 revealed an identical pattern of findings as our LPP analyses.

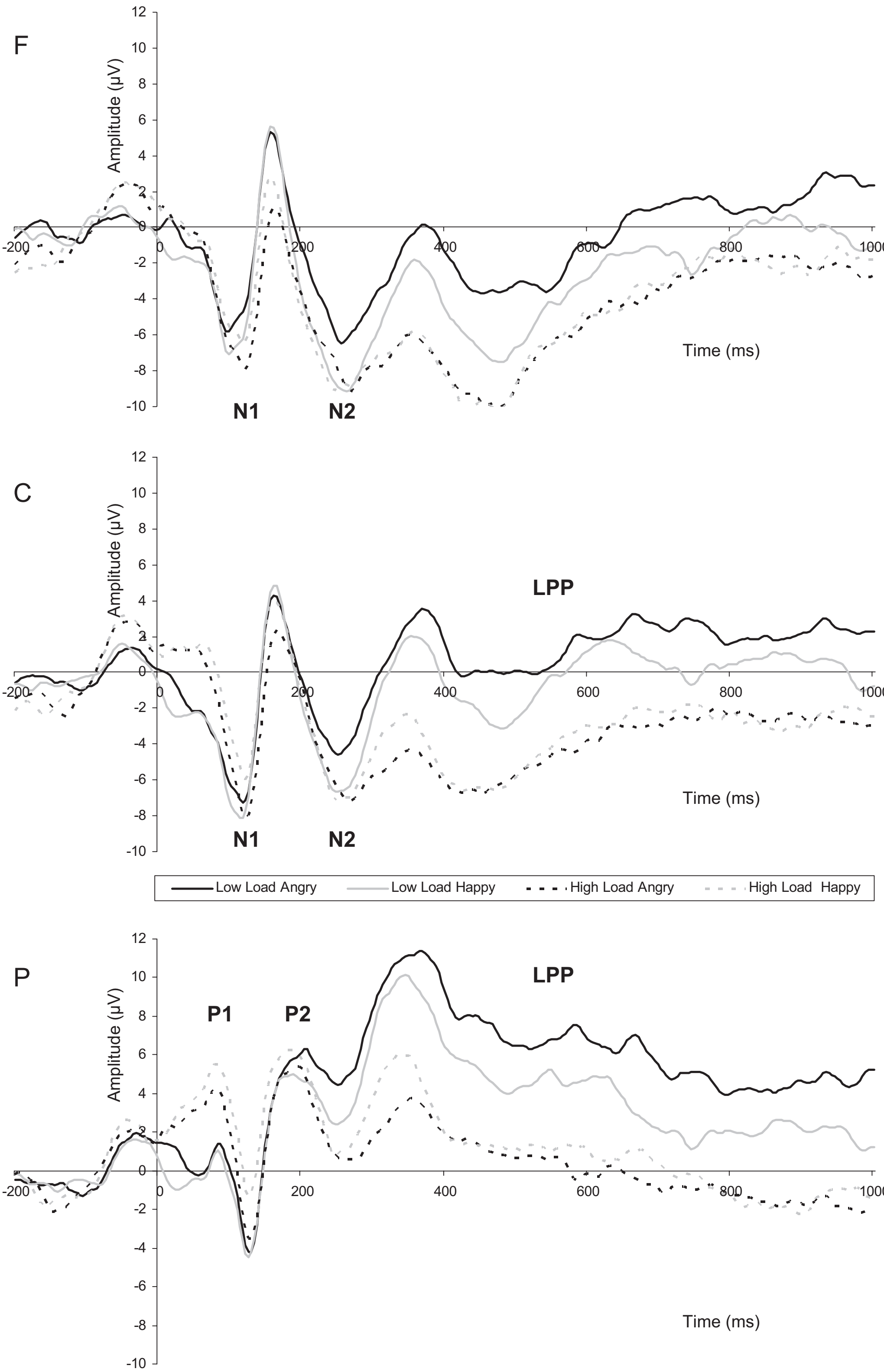

Figure 2. Grand-average event-related potentials (ERPs) over pooled frontal electrodes (F3, Fz, F4; upper row) central electrodes (C3, Cz, C4; middle row) and parietal electrodes (P3, Pz, P4; lower row) as a function of cognitive load (low/high) and target expression (happy/angry).

Table 1

Interaction Effect of Target Expression and Load Condition and Effect of Target Expression (Angry, Happy) Within Each Load Condition (Low, High) on Mean N2 Amplitude and Standard Deviations (Between Brackets) Across Frontal Electrodes (F3, Fz, F4) and Central Electrodes (C3, Cz, C4)

	Low load			High load			Load × Expression
	Angry	Happy	F_{exp}	Angry	Happy	F_{exp}	F_{int}
F3	−8.86 (5.44)	−11.68 (4.86)	14.61**	−10.01 (5.02)	−9.65 (5.39)	<1	6.96*
Fz	−11.74 (6.07)	−14.03 (4.33)	10.97**	−11.73 (5.58)	−12.06 (5.55)	<1	9.32**
F4	−10.03 (5.15)	−11.18 (5.05)	4.39*	−9.85 (5.41)	−10.13 (6.93)	<1	9.84**
C3	−6.99 (4.48)	−8.73 (3.28)	5.83*	−8.09 (4.05)	−8.02 (5.28)	<1	4.00†
Cz	−9.19 (5.37)	−11.18 (3.91)	6.25*	−10.45 (4.72)	−10.91 (5.60)	<1	3.38†
C4	−6.52 (4.54)	−7.22 (3.07)	6.21*	−7.22 (4.62)	−7.31 (5.54)	<1	4.15†

Note. Amplitudes are in microvolts; F_{exp} = F value of target expression. F_{int} = F value of target expression × working memory load interaction. Degrees of freedom are 1 and 14.
† $p < .1$. * $p < .05$. ** $p < .01$.

all, this analysis revealed a main effect of caudality, $F(1, 14) = 44.37$, $p < .001$, $\eta_p^2 = .760$. Similar to previous work (e.g., Cacioppo, Crites, Berntson, & Coles, 1993) LPP amplitude was generally larger over parietal than over central electrodes. In addition, the main effect of working memory load was significant, $F(1, 14) = 22.29$, $p < .001$, $\eta_p^2 = .614$, such that across electrodes, participants' LPP amplitude to the faces was smaller on the high-load trials. This is in line with previous findings demonstrating that increases in working memory load may reduce LPP amplitude, regardless of stimulus valence (MacNamara et al., 2011). In line with our hypothesis, we also observed the predicted interaction between target expression and working memory load, $F(1, 14) = 9.36$, $p = .008$, $\eta_p^2 = .401$. No other main effects or interactions were observed.

We next conducted separate repeated measure ANOVAs per electrode, in which effects of working memory load, target expression and their interaction were tested (see Table 2). We observed significant interactions of working memory load and target expressions for all central and parietal electrodes, except for the Cz electrode, which was marginally significant. Subsequent planned comparisons per digit span condition revealed a significant effect of target expression during the low-load trials at all central and parietal electrodes, such that amplitude of the LPP component was greater in response to angry compared to happy faces (i.e., the negativity bias). As predicted, no effects of target expression were observed in the high-load trials for any of the electrodes (all Fs > 1).

General Discussion

Because negative social cues, such as angry faces, communicate crucial information for adaptive behavior, people prioritize processing of such cues from their environment (Anderson & Phelps, 2001; Bradley, 2009; Öhman, 2007). The present research shows that this negativity bias is subject to contextual constraints. Using behavioral measures (response times) and electrophysiological measures (ERPs), it was demonstrated that cognitively engaging tasks modulate the cognitive control (N2) and selective allocation of attention (LPP) to angry versus happy facial expressions. That is, when people need the bulk of their working memory resources to perform a task, task-irrelevant angry facial expressions no longer reduce cognitive control and draw preferential attention over happy facial expressions, even if these expressions are in the focus of people's visual attention.

In line with previous results (Van Dillen & Koole, 2009), the behavioral results revealed an attentional prioritization effect of

Table 2

Interaction Effect of Target Expression and Load Condition and Effect of Target Expression (Angry, Happy) Within Each Load Condition (Low, High) on Mean LPP Amplitude and Standard Deviations (Between Brackets) Across Central Electrodes (C3, Cz, C4) and Parietal Electrodes (P3, Pz, P4)

	Low load			High load			Load × Expression
	Angry	Happy	F_{exp}	Angry	Happy	F_{exp}	F_{int}
C3	2.72 (6.24)	.94 (5.18)	6.79*	−3.07 (7.18)	−2.61 (6.28)	<1	7.17*
Cz	1.89 (6.81)	−.24 (6.93)	5.99*	−3.92 (7.23)	−3.81 (6.85)	<1	3.83†
C4	3.54 (5.53)	2.39 (5.95)	2.43	−2.45 (6.19)	−1.68 (6.47)	<1	5.49*
P3	8.07(6.62)	4.23 (8.39)	9.35**	.95 (6.41)	2.18 (5.86)	<1	6.19*
Pz	6.37 (7.19)	5.26 (6.40)	6.18*	.12 (6.65)	.07 (8.15)	<1	8.17*
P4	7.69 (6.16)	5.77 (5.53)	9.32**	1.81 (8.39)	1.87 (6.39)	<1	6.01*

Note. Amplitudes are in microvolts. F_{exp} = F value of target expression; F_{int} = F value of target expression × working memory load interaction. Degrees of freedom are 1 and 14.
† $p < .1$. * $p < .05$. ** $p < .01$.

angry compared to happy faces on low load trials (when participants concurrently maintained one digit in memory), such that participants were slower to categorize the gender of angry compared to happy faces. High load (when participants concurrently maintained eight digits in memory) increased response latencies for happy but not angry faces, resulting in a reduced interference effect of angry relative to happy faces. The ERP-results provided insight into why this happened. N2 amplitude, which has been interpreted as indicating cognitive control, was especially low for angry faces under low cognitive load. Under high load, N2 was high regardless of target expression. Moreover, results for the LPP, which has been interpreted as sustained attention, showed that high working memory load reduced LPP amplitude more strongly to angry than to happy faces. In low load trials, we observed a differentiation in LPP amplitude in response to angry versus happy faces, in line with previous studies (Frühholz et al., 2011; Schupp et al., 2004; Schutter et al., 2004), reflecting a negativity bias. These results suggest that the effect of increased working memory load in reducing the attentional negativity bias could be due to an increase in cognitive control and a reduction in sustained attention that people display when they are confronted with negative compared to positive cues.

Although the LPP results showed that working memory load reduced sustained attention to both happy and angry faces, in contrast to previous research (Van Dillen & Koole, 2009), the response latency data in the current study did not show this general slow-down in response times as a result of cognitive load. Instead, it was found that load reduced the response latencies for happy faces, but not for angry faces. We have taken response time differences between happy and angry target faces as an index of interference of negative compared to positive facial cues. Because this is a relative index, alternatively one could argue that the effects of working memory load might have been driven by an increase in attention to positive information under high working memory load.

We think, however, that an interpretation in terms of changes in relative attention to negative versus positive information is more plausible. First, the absence of a load effect on the angry face trials could be due to the fact that response times reflect the sum of various cognitive processes, which could have opposing effects. Hence, the increase in response times due to additional task load and the decrease in response times due to reduced attention to the angry faces may have canceled each other out, leaving only a slowing of response times to the happy faces to be observed. Second, although the current study did not include neutral faces, research that incorporated neutral face stimuli has shown similar load-induced reductions in attentional interference of negative relative to neutral stimuli (Erthal et al., 2005; Okon-Singer, Tzelgov, & Henik 2007; Van Dillen et al., 2011). Finally, and most importantly, the alternative interpretation that reduced interference under high load could be due to increased attention for happy faces is in contrast with the N2 and LPP-results found in the current study. According to these results working memory load eliminated the reduced cognitive control for angry faces that was found on low-load trials (as evidenced by an increased N2). Moreover, in line with previous behavioral and neuroimaging studies (Erk et al., 2007; Kron, Schul, Cohen, & Hassin, 2010; Weinberg & Hajcak, 2011) working memory load decreased, rather than increased sustained processing of positive emotional stimuli (as evidenced by a reduced LPP on high-load trials). This supports our interpretation that working memory load boosts attentional control over negative information and reduces selective attention to negative over positive information, rather than that it increases attention to positive information.

It is important to note that a recent LPP study by MacNamara et al. (2011) also examined the effects of cognitive load on affective processing. The authors varied working memory load via the mental rehearsal of a series of letters, while they presented participants with complex negative or neutral pictures. Whereas they also found an overall reduction of LPP activity in the high-load trials compared to the low-load trials, they observed a negativity bias, as evidenced by larger LPP deflections in response to negative compared to neutral pictures, regardless of working memory load. In MacNamara et al.'s study, participants viewed the pictures without any additional task instructions, which could have facilitated the negativity bias, especially since the pictures depicted complex scenes that may have triggered interpretational processes. In support of this, and contrary to our findings, they found aversive pictures to interfere with working memory performance. In our study, the face stimuli were the target stimuli of a gender categorization task, in which task-relevant gender-related facial features and task-irrelevant affective facial features competed directly for attention. As inducing additional working memory load results in more selective processing in accord with ones current task goals (Liu et al., 2003) participants in our study might have focused their attention more at gender-related features at the cost of expression-related features. Clearly, more research is needed to answer the question when and how working memory controls attention in accord with specific task parameters.

We also examined the early components of the ERP, such as the P1, the N1, and the P2, as a negativity bias has been reported for these components (Carretié et al., 2004; Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004). We did not observe any modulations by target valence for any of the early components. Although methodological differences among studies preclude strong inferences, this is in line with our prediction that working memory would especially modulate later components that are more susceptible to contextual variations and motivational processes, such as the N2 and the LPP.

Our findings are in line with theories that suggest that attentional control operates flexibly depending on current task requirements (Folk, Remington, & Johnston, 1992; Knudsen, 2007). When working memory load of a focal task is high, attention is more stringently directed at task-relevant stimulus properties. When working memory load is low, however, attention is more diverted, and accordingly more susceptible to the captivating powers of salient features such as angry expressions. Naturally, whether this task shielding is adaptive depends on the importance of both the focal task and the nature of the negative social cue.

As the present findings indicate, conditions such as increased working memory load may involve higher attentional control over salient but task-irrelevant features such as emotional expressions. Other conditions, such as a higher intensity of emotional expressions, may result in a stronger attention bias to these stimuli (Bradley, 2009; Delplanque et al., 2004; Yantis, 2000). In line with this, attentional interference of negative information is stronger for intensely negative stimuli than for mildly negative stimuli (Schimmack, 2005). An important question is how these influences interact: When does task-induced attentional control prevail over stimulus-driven attention, and vice versa? Using emotional expressions of varying intensity may help answer this question.

The current research focused on the role of working memory load in basic categorizations of emotional faces. It is conceivable that working memory load may similarly moderate the impact of emotional cues on more complex interpersonal situations. For example, people may be guided more by emotional facial cues in their decisions when they have ample cognitive resources available. Given that the unfolding of an emotional response begins with selective attention to emotional cues (Pessoa, 2008), working memory load of a focal task may function as a gatekeeper for the impact of emotional cues on people's thoughts and behavior.

Our current findings moreover fit well with research on emotion regulation, such as reappraisal, which has demonstrated similar effects on the late positive potential. Indeed, it has been suggested that working memory plays a crucial role in effective reappraisal, as these strategies involve a conscious, deliberate search for, and maintenance of information that changes the way an emotional stimulus is interpreted (Gross, 2002; Kalisch, 2009). Working memory processes may also play a role in the effectiveness of a commonly used therapeutic intervention for PTSD, namely Eye Movement Desensitization and Reprocessing (EMDR; Shapiro & Maxfield, 2002). During EMDR, trauma clients are instructed to move their eyes rapidly horizontally while they retrieve traumatic memories. Whereas the intervention proves to be very successful in reducing the vividness and emotional intensity of traumatic memories (for a meta-analysis, see Davidson & Parker, 2001), its actual workings are still being debated. In a recent series of experiments (Gunter & Bodner, 2008), performing horizontal or vertical eye movements, an auditory shadowing task, or a drawing task while holding an unpleasant autobiographical memory in mind *all* decreased the vividness, emotionality, and completeness of those memories relative to an eyes stationary control condition. In addition, other research demonstrated that tapping (Andrade, Kavanagh & Baddeley, 1997), or holding digits in mind (Isaacs, 2004) rather than making eye movements proved to be as effective as EMDR. Gunter and Bodner (2008) therefore proposed that the beneficial effects of EMDR and similar treatments on memory intrusions may be due to reduced attention to trauma-related material. By dividing working memory resources between a task and the traumatizing memories, they argue, clients are enabled to experience these memories from a more "detached" perspective.

Conclusion

In sum, both behavioral and neurophysiological findings replicate the well-documented observation that, by default, people prioritize attention to socially relevant angry faces. Angry faces cease to receive preferential attention, however, when our cognitive resources are more fully engaged by a focal task. Thus, the present work provides further evidence for the growing notion that attention to negative social cues is fast and unintentional, but contingent upon the availability of sufficient working memory resources.

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