Neural correlates of intrusion of emotion words in a modified Stroop task

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Abstract

Behavioural studies have demonstrated that the emotional Stroop task is a valuable tool for investigating emotion–attention interactions in a variety of healthy and clinical populations, showing that participants are typically more distracted by negative stimuli as compared to neutral or positive stimuli. The main aim of this study was to find and examine the neural correlates of this greater intrusion from negative emotional stimuli. Reliable reaction time (RT) and event-related potential (ERP) data were collected from 23 participants who performed a manual emotional Stroop task with short (40 ms) and long (500 ms) inter-trial intervals. In the short interval condition, participants were found to produce longer RTs for negative than neutral words, suggesting that these stimuli were more difficult to ignore. This RT effect disappeared in the long interval condition, although larger P1 amplitudes were found for the negative words. This suggests that differences in early attention allocation may be unrelated to the degree of intrusion at the behavioural level. In addition, a larger negative slow wave around 300–700 ms post-stimulus was observed in the long interval condition, but only for those negative words that produced prolonged RTs as compared to their matched controls. This late and broadly distributed effect is believed to reflect suppression of meaning representations.
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Behavioural studies have consistently shown that people more readily pay attention to emotionally negative stimuli than to neutral or positive ones, regardless of whether these stimuli are task relevant or not. For example, visual search has been found to be facilitated for snakes and spiders as compared to flowers and mushrooms (Öhman et al., 2001). Similarly, negative words have been found to produce more interference than neutral or positive words on a modified (emotional) Stroop task (McKenna and Sharma, 1995; Pratto and John, 1991). In this task, participants are instructed to respond as quickly and accurately as possible to the ink colour of the presented words, while ignoring their meaning. Typically, prolonged reaction times (RTs) are found for negative words as compared to neutral words, suggesting that participants are more distracted by the meaning of these words. Although not totally undisputed (e.g.,

Algom et al., 2004; McKenna and Sharma, 2004), many have argued that these effects are primarily the result of an automatic attention bias towards negative stimuli (e.g., Williams et al., 1996), serving the need to quickly detect information that is important for survival (Öhman et al., 2001; Pratto and John, 1991). Conversely, it is also recognised that certain stimuli may trigger attention systems due to specific psychopathologies or individual learning histories (for a review see, Williams et al., 1996). For example, the word 'hairy' may be particularly distracting for spider phobics, as may be the word 'spirit' for alcoholics. In agreement with this, the largest Stroop interference effects of negative stimuli in non-clinical populations are usually observed for those stimuli that relate to the participants' current concerns and that are congruent with their present mood state (e.g., Gilboa-Schechtman et al., 2000; Smith et al., 2006). These findings support the notion that not all negative stimuli may generate the same effects across individuals and across time. Thus, although a bottom-up, automatic process may be at the basis of emotion intrusion effects, it cannot be presumed to operate independently from top-down regulatory mechanisms that may operate in a more idiosyncratic way. Indeed, there is

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growing evidence to suggest that the enhanced processing of emotional stimuli is due to a range of perceptual and attentional brain processes which interact at multiple levels and which include both stimulus-driven and goal-driven mechanisms (Vuilleumier, 2005).

Evidence from PET and fMRI studies confirm that emotional stimuli receive more attention than neutral stimuli, showing higher activation levels at several areas of extrastriate cortex, indicative of increased visual processing (e.g., Lang et al., 1998). In addition, high levels of activation have been found at rostral–ventral portions of the anterior cingulate cortex (ACC) during the emotional Stroop task, implying a central role for this brain area in attention allocation and emotion regulation (Bush et al., 2000; Whalen et al., 1998). These studies, however, do not provide information about the time course of these activations and thus do not offer a detailed insight into the dynamic pattern of attention, perception, and selection processes that take place between stimulus presentation and response production. Event-related brain potentials (ERPs) do not have this limitation due to their excellent time resolution (Luck, 2005). In addition, off-line averaging procedures allow selection of EEG trials not only on the basis of particular stimulus characteristics (e.g., neutral vs negative) but also on the basis of specific behavioural response attributes (e.g., whether or not response interference is observed). The main aim of the present study was to find and examine ERP correlates of attention bias and intrusion from negative words during an emotional Stroop task. To date, only very few studies have recorded ERPs in participants performing an emotional Stroop task (Pérez-Edgar and Fox, 2003; Thomas et al., 2007) and the present study is therefore essentially exploratory in nature.

ERP studies have reported enhanced responses to emotional stimuli, but these studies have used comparatively simple paradigms (i.e., viewing/rating a set of pleasant, unpleasant, and neutral stimuli) and have varied widely in methodological detail. For example, the vast majority of ERP studies have used pictorial stimuli (e.g., Carretié et al., 2001; Cuthbert et al., 2000; Delplanque et al., 2004; Huang and Luo, 2006; Keil et al., 2002; Moser et al., 2006; Palomba et al., 1997; Smith et al., 2003), including emotional facial expressions (e.g., Eimer and Holmes, 2002; Holmes et al., 2006), while only a few have used linguistic material (e.g., Bernat et al., 2001; Herbert et al., 2006; Schapkin et al., 2000; Thomas et al., 2007). Also, some tasks required participants to pay attention to the emotional meaning of the items (e.g., Herbert et al., 2006; Huang and Luo, 2006, Schapkin et al., 2000) while others involved no explicit valence evaluation (e.g., Delplanque et al., 2004; Carretié et al., 2004). In general, these ERP viewing/rating studies reported larger positive amplitudes around and subsequent to the P3 time window for emotional items, which has been explained in terms of more elaborate processing of these stimuli (Palomba et al., 1997; Ito and Cacioppo, 2000). Interestingly, Moser et al. (2006) showed that the amplitude of this late positivity can be reduced by asking participants to suppress their emotional response. Similarly, Thomas et al. (2007) reported that P3 amplitude differences between threat and neutral words were considerably smaller when word meaning was not relevant for task performance. These latter findings suggest that late positive ERP deflections can be intentionally down-regulated, suggesting that it may be diminished or possibly absent in an emotional Stroop paradigm, where the task is to ignore word meaning and respond to printed colour.

Emotion effects on earlier ERP components have also been described, particularly in more recent studies. For example, Smith et al. (2003) found that P1 amplitudes to negative pictures were larger than P1 amplitudes to positive pictures. A similar effect has been reported by Delplanque et al. (2004) and Bernat et al. (2001), of which the latter used emotional adjectives instead of pictures. The P1 typically reaches its maximum amplitude at around 80–130 ms post-stimulus and is maximal over the occipital areas. The P1 is presumed to reflect early visual processing and is typically larger for attended than unattended stimuli (Hillyard et al., 1998). These findings therefore suggest the existence of an extremely rapid differentiation of pleasant and unpleasant stimuli, which possibly serves the function of a stimulus-driven call for processing resources or a 'tagging' of critical stimuli for priority processing (cf., Öhman et al., 2001). Another possible candidate for this 'alerting' function is the P2 component (maximum amplitude around 200–250 ms), which, in a few studies, has also been found to be affected by stimulus valence. P2 results, however, are inconsistent as to whether enlarged amplitudes can be observed for positive stimuli only (Schapkin et al., 2000), negative stimuli only (Huang and Luo, 2006), or both positive and negative stimuli (Herbert et al., 2006; Carretié et al., 2004). With regards to the current study, these early ERP attention effects seem to occur more automatically than the P3-type effects described above, and may thus be more robust against ignore instructions, such as in the emotional Stroop task. Indeed, Pérez-Edgar and Fox (2003) observed smaller N1 and N2 amplitudes for negative as compared to positive and neutral words, while Thomas et al. (2007) reported larger P2 amplitudes for threat vs neutral words at right parietal locations. Both groups of researchers interpreted the presence of these effects as evidence for an early attention bias towards negative or threat-related items. Interestingly, these early ERP effects were observed in the absence of behavioural interference effects, which led Thomas et al. (2007) to suggest that ERPs may be more sensitive measures than RT for examining attentional biases in healthy individuals.

Studies that have analysed ERPs during the traditional Stroop task (e.g., Liotti et al., 2000; Markela-Lerenc et al., 2004; Rebaï et al., 1997; West, 2003; West and Alain, 1999, 2000) have primarily focussed on ERP modulations that occurred around 400 ms post-stimulus. They all reported an increased, fronto-central or broadly distributed negativity (350–500 ms) for the incongruent trials, which was linked to increased activation of the anterior cingulate cortex (Liotti et al., 2000), possibly associated with conflict detection (West, 2003; West et al., 2004) or selection of competing responses (West and Alain, 1999). West and Alain (2000) suggested that this negative slow wave (which they labelled N450) may reflect "the activity of a neural system involved in the suppression of a conceptual level processing system on incongruent trials" and

which may index "the efficiency of an inhibitory mechanism" (p. 109). According to this interpretation, an N450-like ERP deflection might also be present in an emotional Stroop task, showing larger amplitudes for negative as compared to neutral words, reflecting stronger efforts to suppress meaningful and personally relevant conceptual representations. ERP emotional Stroop studies (Pérez-Edgar and Fox, 2003; Thomas et al., 2007) however, did not observe such effects, suggesting that the presence and characteristics of this negative slow wave may be specific to the traditional Stroop task. Indeed, it could be argued that the negative slow wave reflects processes associated with response conflict rather than conceptual interference (cf., Cohen et al., 1990; Wyble et al., 2005). Alternatively, the absence of a negative slow wave effect in these emotional Stroop studies may have been due to the fact that no behavioural interference effects were observed. That is, neither Pérez-Edgar and Fox (2003) nor Thomas et al. (2007) found any notable differences between negative and neutral words at the RT level. In the current study, we investigated this alternative explanation by comparing ERP effects for negative words that did produce RT interference (on an individual level) with those for negative words that did not.

In the present study, ERPs were recorded during an emotional Stroop task in which participants had to respond manually, by means of button presses, to the colour of the ink of centrally presented neutral or negative words. The two sets of words (negative, neutral) were presented in blocked format because blocking has been found to generate larger overall RT interference than mixing stimuli (Holle et al., 1997; Richards et al., 1992). Two inter-trial intervals (ITIs) were used, one short (40 ms) and one long (500 ms). Relatively long ITIs have been used in all previous ERP and fMRI Stroop studies (traditional and emotional) because they ensure proper pre-stimulus baselines. Sharma and McKenna (2001), however, have demonstrated that behavioural effects in an emotional Stroop task are larger when shorter ITIs are used and that RT effects may even disappear with ITIs longer than 240 ms. Indeed, this could explain the failure to observe any behavioural interference effects in previous ERP emotional Stroop studies that used ITIs of 1000 ms (Pérez-Edgar and Fox, 2003) and 2500–3500 ms (Thomas et al., 2007) respectively. We therefore included a short 40 ms ITI to enable replication of earlier behavioural results and to validate stimulus materials, and a long 500 ms ITI to record ERPs that are comparable with previous ERP Stroop studies and that are not contaminated by overlapping response activations.

To examine ERP correlates for actual intrusion by emotion stimuli in the long ITI condition, we divided ERPs into two separate sets on the basis of individual-specific behavioural outcomes. That is, for each individual participant, we calculated which negative words caused RT interference and which RT facilitation (relative to their matched neutral words) and compared their corresponding ERP effects. Analogue to emotional Stroop studies with clinical populations (Williams et al., 1996), the negative words that generated the greatest RT interference were assumed to be those that related most to individual-specific concerns. In line with traditional Stroop studies, we expected that negative words that produced RT interference would elicit a larger

negative slow wave around 400–500 ms than their neutral counterparts. In contrast, this negative slow wave effect was expected to be smaller or absent for those words that did not produce RT interference. Finally, in agreement with previous viewing and rating studies, early ERP attention effects were expected to be present, showing relatively larger P1 and/or P2 amplitudes for the negative words. In line with the ERP emotional Stroop studies, these early attention effects were expected to be independent from the ultimate behavioural effect.

1. Method

1.1. Participants

Twenty-eight participants were recruited and paid £6 for their participation. They all had English as their first language and reported unimpaired colour vision. Data from five participants were excluded because of technical difficulties with the behavioural analysis software ($n=2$), high electrode impedance ($n=1$), or an insufficient number of artefact free EEG trials for ERP averaging ($n=2$). The remaining 23 participants (11 females) ranged in age from 17 to 42, with a mean age of 23.8 years (SD 5.70). Participants' state anxiety scores varied between 22 and 47 (mean 35.7, SD 6.6) and trait anxiety scores varied between 22 and 56 (mean 41.6, SD 8.9).[1] Ethics approval for this study was obtained from the Psychology Department Research Ethics Committee.

1.2. Stimulus materials and test design

Sixty negative emotion and neutral words were selected from the Affective Norms for English Words (ANEW) (Bradley and Lang, 1999) (see Appendix A). The negative words had a mean valence rating of 2.39 (SD 0.40, range 1.66–2.98) while the neutral words had a mean valence rating of 5.24 (SD 0.68, range 3.43–5.98). In addition, the negative words were characterised by higher arousal values (mean 5.75, SD 0.96) than the neutral words (mean 4.19, SD 0.58) ($t(58)=19.81$, $p<.001$). Word lengths were equivalent for the two word categories. Occurrence frequencies for the neutral and negative words were matched as closely as possible, using the Celex database (Baayen et al., 1995). This resulted in a mean frequency value of 260 for the negative words (SD 407, range 13–2012) and of 275 for the neutral words (SD 454, range 29–2372). Celex frequency values did not differ significantly between the two word categories ($t(58)=0.14$, $p=0.889$). There were also no significant differences between these categories with respect to the number of orthographic neighbours ($t(58)=1.29$, $p=0.202$), the Hyperspace Analogue to Language (HAL) frequency norms ($t(58)=0.403$, $p=0.689$), and mean lexical decision time ($t(58)=2.50$, $p=0.119$), as derived from the online database

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[1] On the basis of these scores, participants were divided into low and high state anxious groups (median-split), however, adding state-anxiety group status as a between subjects factor in our analyses did not produce any main or interaction effects for any of the dependent variables. These results are therefore not reported.

from the English Lexicon Project (ELP) (http://elexicon.wustl.edu) (Balota et al., 2002).

Stimulus presentation, randomisations, timing, and recording of the manual responses were controlled by e-Prime software. Negative and neutral words were presented in separate test series, each consisting of 6 test blocks. Two example test series are depicted in Fig. 1. Within each test block, five different words from the same category were presented randomly in four different colours (red, green, blue, yellow), with the restriction that the same word or colour did not repeat itself on consecutive trials. Each word was thus repeated 4 times, creating a total number of 20 stimulus presentations per test block. The stimuli were presented at the centre of the computer screen until a response was made. Within each test series, three of the six blocks presented the
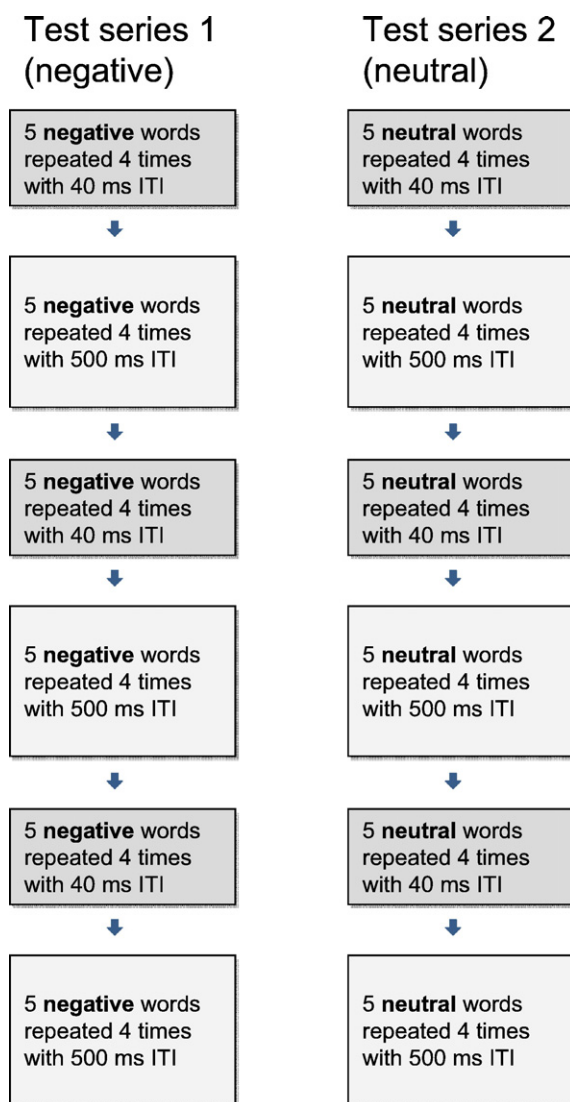

Fig. 1. Schematic representation of two separate test series. Test series 1 presents *negative* words in 6 different test blocks with alternating short (40 ms) and long (500 ms) inter-trail intervals. Test series 2 follows the same format but presents *neutral* words. Each test block consists of five different words presented four times in four different colours (red, green, blue, yellow) respectively (i.e., 20 stimulus presentations in total). The order of test series (negative, neutral) and the order of the starting interval (short, long) were counterbalanced between participants.

stimuli 40 ms after a response was given (short ITI) and the other three presented the stimuli 500 ms after a response was given (long ITI). Test blocks with these two different ITIs were presented in an alternating fashion (see Fig. 1) and test series could start with either a short or long ITI. Presentation order of the two test series (negative, neutral) and the starting test block (short vs long ITI) were counterbalanced between participants. Before the beginning of the experiment, two practice sessions were presented modelled after the test series (i.e., 6 test blocks of 20 trials each with alternating short and long ITIs). In these practice blocks, 4 to 8 same-letter strings (e.g., ffff, bbbbbb) in four different colours were presented to familiarise the participants with the response format.

Responses had to be given with the index and middle-finger of each hand, using the e-Prime response box. This response box had five response buttons of which the middle one was not used. The buttons were colour-coded so that 'red', 'blue', 'green', 'yellow' responses corresponded to left-hand middle-finger, left-hand index-finger, right-hand index-finger, and right-hand middle-finger button presses respectively. During the experiment, participants kept their fingers rested on the corresponding response buttons. By the end of the practice sessions, participants were required to make responses without looking at the response buttons. In the current experiment, all participants were able to do so and thus no further practice was needed.

1.3. EEG recording and analysis

EEG data were recorded (average reference) from 19 Ag–AgCl electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2) mounted in an elastic cap (Easy Cap QA40). In addition, two ear-clip electrodes were used to record activity from the earlobes (A1 and A2) for later off-line re-referencing. Two Ag–AgCl electrodes were placed above and below the participants' left eye to record vertical eye movements and blinks. All electrode locations were first cleaned with isopropyl-alcohol (70%) before an abrasive electrolyte gel (Abralyt 2000) was used to gently remove any dead skin cells and to conduct the electrical activity. Inter-electrode impedance was typically below 3 kΩ and never exceeded 8 kΩ.

EEG and EOG signals were amplified using a Quickamp 72 amplifier and Brain Vision Recording software (version 1.02). The data were continuously recorded with a sample rate of 250 Hz and a bandpass filter of 0.1 and 35 Hz (24 dB). EEG data were corrected for vertical eye movements and blinks using the Gratton and Coles (1989) method as implemented in the BrainVision analysis software. Recordings were then re-referenced to a mathematically simulated linked ears reference and a lowpass filter of 25 Hz (24 dB roll-off) was applied. Subsequently, EEG recordings were automatically screened for artefacts and remaining eye movements using the following criteria (a) maximum allowed voltage step of 50 μV between two sample points, (b) maximum allowed absolute difference of 80 μV over a 200 ms interval, and (c) lowest allowed activity of 0.5 μV over a 100 ms interval. Epochs containing artefacts in any of the EEG channels were rejected from further analyses. EEG epochs were created starting 200 ms prior to stimulus onset to 1500 ms following stimulus

onset. These epochs were baseline corrected to a pre-stimulus baseline of −200 to 0 ms. They were averaged time-locked to the onset of the stimuli.

Separate ERPs were calculated for those negative words that fell in the top and bottom half of the individual's RT facilitation/interference continuum. For each individual and for each of the 15 negative words that were presented in the 500 ms ITI con-

dition, an RT difference score was calculated. This was done by subtracting the mean RT for the matched neutral word (see Appendix A) from that of the negative word (both averaged across 4 repetitions), producing either a positive value (RT interference) or a negative value (RT facilitation). These words were then placed on a continuum from the lowest negative value to the highest positive value. A median-split method (leaving

a

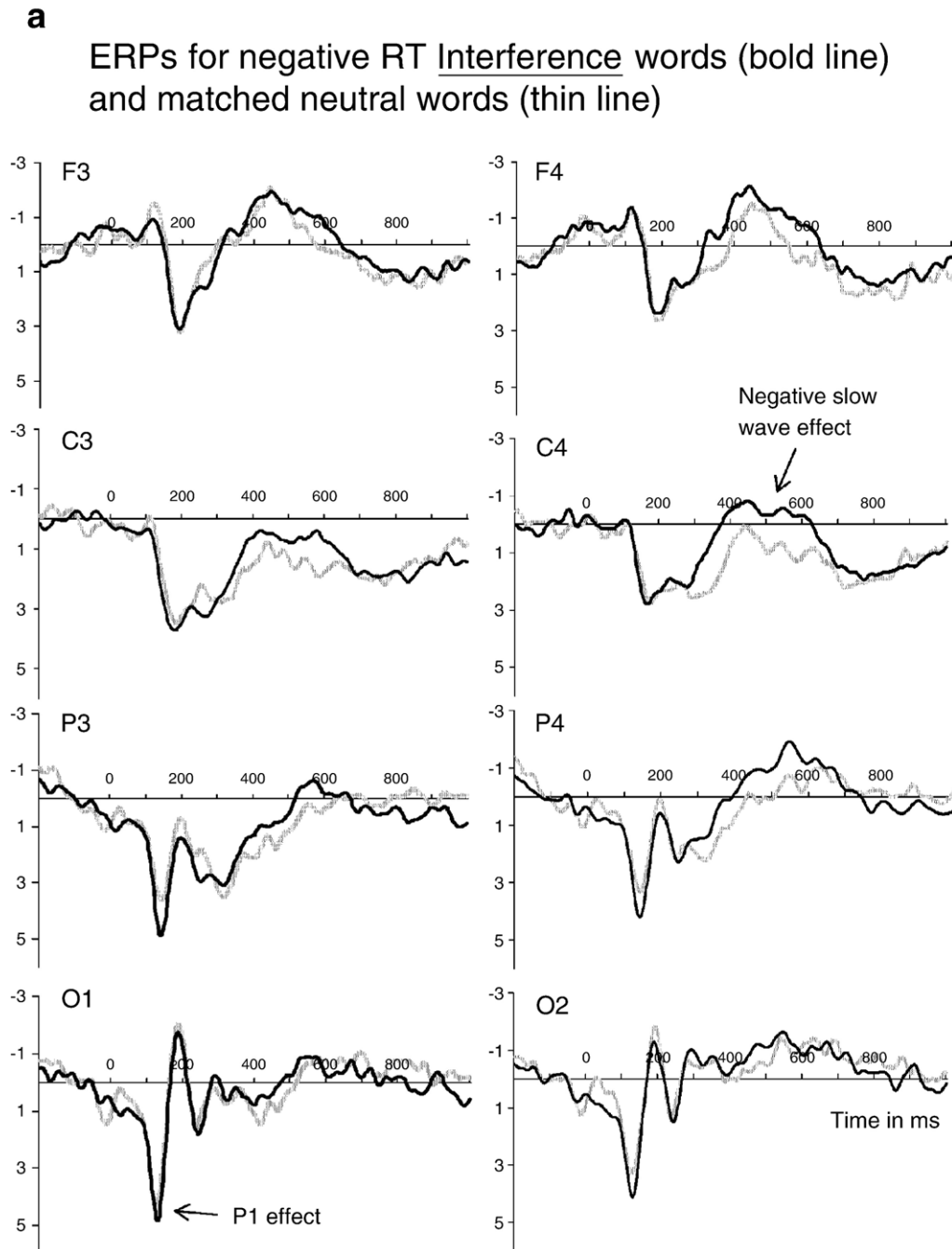## ERPs for negative RT <u>Interference</u> words (bold line) and matched neutral words (thin line)

Fig. 2. a: Grand average ERPs for selected frontal (F3, F4), central (C3, C4), parietal (P3, P4), and occipital (O1, O2) electrode positions for negative words that produced *RT interference* (bold line) and matched neutral words (thin line). Note that relative to ERPs for neutral words, those for the negative words were characterised by a larger P1 and a more pronounced negative slow wave 300–700 ms post-stimulus. b: Grand average ERPs for selected frontal (F3, F4), central (C3, C4), parietal (P3, P4), and occipital (O1, O2) electrode positions for negative words that produced *RT facilitation* (bold line) and matched neutral words (thin line). Note that relative to ERPs for neutral words, those for the negative words were characterised by a larger P1. The slow wave effect observed for the negative RT interference words (a) was not present.
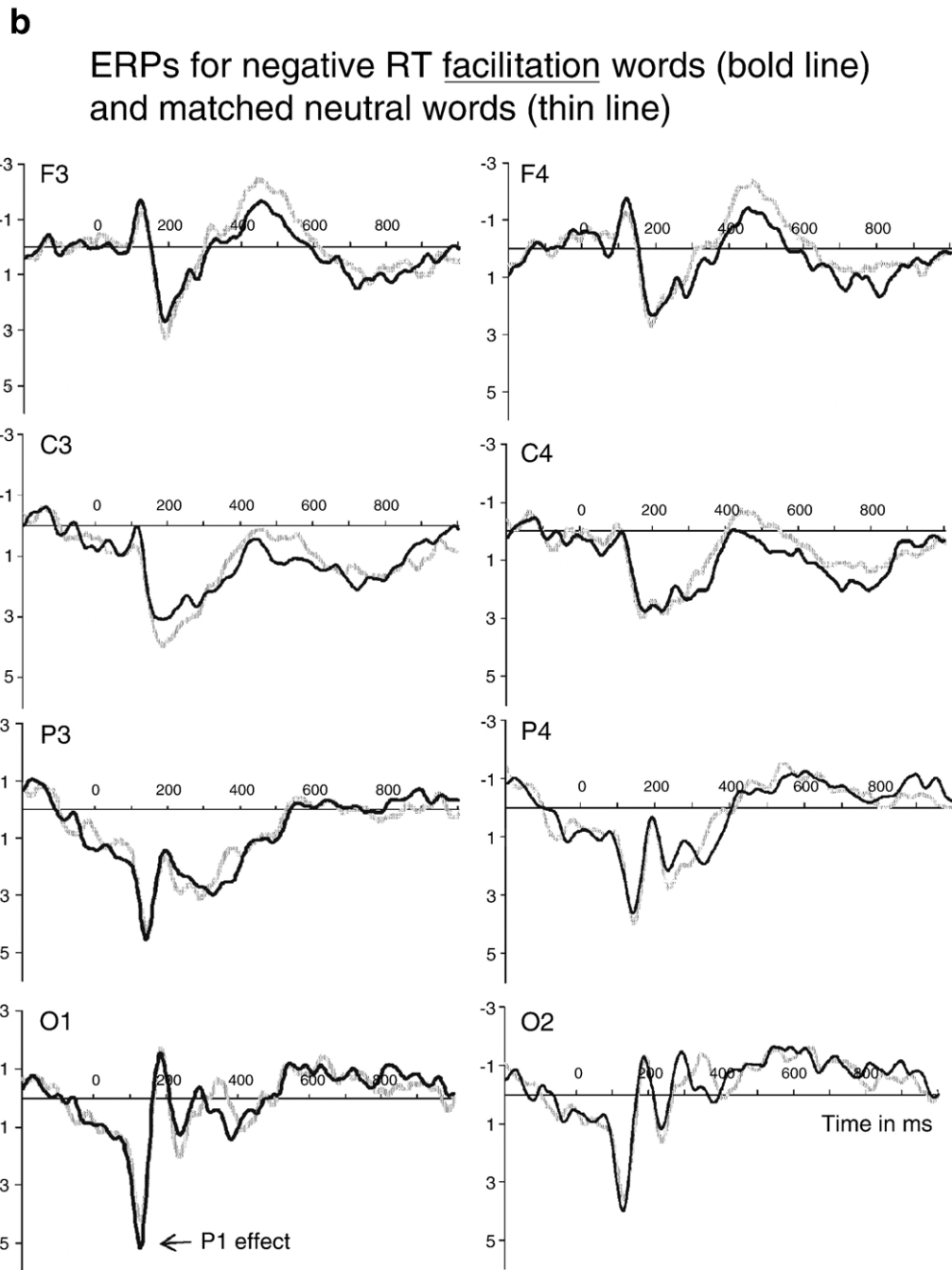
b

ERPs for negative RT <u>facilitation</u> words (bold line) and matched neutral words (thin line)

Fig. 2 (*continued*).

out the median) was subsequently used to obtain two distinct ERPs for the seven words on either side of this continuum. The RT effects were significantly different for both individual-specific sets of seven words ($t(22)=13.65$, $p<.001$), with the RT facilitation words (bottom half) producing an average facilitation of 154 ms (SD 110) and the RT interference words (top half) producing an average slowing of 155 ms (SD 104). All ERPs that were obtained this way were based on more than 20 individual EEG trials.

Visual inspection of the grand average waveforms (Fig. 2a and b) indicated two potential effects: (i) enhanced P1 amplitudes for negative words producing RT interference and

for those producing RT facilitation (both compared to their matched neutral words), and (ii) more negative amplitudes for negative words that produced RT interference in the period 300–700 ms post-stimulus (negative slow wave) relative to their matched neutral words. To quantify the P1 effect, the maximum local peak in the 80–180 ms post-stimulus interval was determined for the pooled O1 and O2 electrode positions. Mean amplitudes in the period 8 ms (2 sample points) before and after the latency of this peak were determined for T5, T6, P3, P4, O1, and O2. A $2\times2\times2\times3$ repeated measures ANOVA was performed on these P1 amplitude values with valence (negative, neutral), behavioural effect (RT interference, RT facilitation),

hemisphere (left, right) and region (Temporal, Parietal, Occipital) as within subjects factors. To quantify the negative slow wave, mean amplitudes were calculated for the total 400 ms epoch (300–700 ms) and for 4 consecutive 100 ms time windows starting 300 ms post-stimulus. To estimate the scalp distribution of this broadly distributed effect, mean amplitudes of 3 frontal (F3, Fz, F4), 3 central (C3, Cz, C4) and 3 parietal (P3, Pz, P4) electrode positions were entered into the statistical analyses. Repeated measures ANOVAs were conducted on these mean amplitudes with valence (neutral, negative), behavioural effect (RT interference, RT facilitation), coronal position (frontal, central, parietal), and laterality (left, middle, right) as within subjects factors. For all ANOVAs, the Greenhouse–Geisser method was used to correct for violation of the Sphericity assumption and all post-hoc pairwise comparisons were made with Bonferroni correction. Uncorrected degrees of freedom are reported for ease of notification and epsilon values are mentioned when different from 1. Significance levels were derived from the corrected degrees of freedom.

1.4. Procedure

Upon arrival at the laboratory, participants were thoroughly informed about the EEG and experimental procedure before being asked to sign the informed consent form. They were not informed about the nature of the stimulus words, although examples of both word categories were given in the instructions. They were seated in a comfortable, adjustable chair in a sound-attenuated room. After fitting the electrode cap, EOG- and ear-clip electrodes, they positioned themselves behind a table at a distance of approximately 60 cm facing the PC monitor. After ascertaining that participants could name the colours of the response buttons correctly, they were read the instructions for the practice trials. They were asked to ignore the letter strings and respond to the ink colours as quickly and accurately as possible by pressing the appropriate response buttons. Participants were then asked to place their index and middle-fingers of each hand on the 4 response buttons for the duration of the task. Two practice sessions were given before the start of the experiment. Participants could decide with a button press when to start each separate practice block (six per each practice session) once the experimenter had left the participant room and had indicated that recording had started. The test series followed the same procedure but now the letter strings were replaced with negative or neural words, depending on the specific test series. After the experiment, participants filled in the State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1970) and rated the valence of all presented words using an 11-point rating scale ranging form −5 extremely negative to +5 extremely positive.

2. Results

2.1. Valence ratings

Participants rated the emotion words (mean −2.97, SD 0.77) as being more negative than the neutral words (mean rating 0.63, SD 0.97) ($t(28)=15.94, p<.001$). The valence ratings obtained in the

Table 1
Mean error rates (%) and reaction times (in ms) (SD in parentheses) for the negative and neutral words in both the short and long inter-trial interval (ITI) conditions

	Short (40 ms) ITI		Long (500 ms) ITI	
	Neutral	Negative	Neutral	Negative
Error rate	0.031 (0.05)	0.030 (0.04)	0.028 (0.03)	0.035 (0.05)
Reaction time	839 (140)	871 (172)	802 (175)	803 (152)

experiment correlated almost perfectly ($r=0.935, p<.001$) with those of the existing norms (Bradley and Lang, 1999).

2.2. Behavioural data

A summary of the behavioural results is given in Table 1. Participants made very few errors and error rates did not differ between negative and neutral words, or between short and long ITI conditions. Mean RTs were calculated for correct responses only. They were generally slower for the short — as compared to the long interval condition ($F(1,22)=37.56, p<.001$). As hypothesised, RTs were slower for the negative than neutral words, but *only* in the 40 ms ITI condition ($t(22)=2.44, p<.05$). In the 500 ms ITI condition there were no RT differences between negative and neutral words.

Averaging of the RT difference scores for each word in the 500 ms ITI condition[2] revealed that some of the negative words produced, on average, a slowing down of the response (e.g., infection, lice, crushed) while others primarily produced a facilitation of response (e.g., morbid, brutal, deserter) or little interference at all (e.g., assault, foul, abuse). Surprisingly, no correlations were found between the mean RT effects for the individual words and absolute ($r=-0.018, p=0.925$) and relative ($r=0.044, p=0.817$) valence ratings. Furthermore, RT effects did not correlate with word occurrence frequency (Celex: $r=-0.013, p=0.947$, HAL: $r=0.055, p=0.773$), word length ($r=-0.123, p=0.517$), mean lexical decision time (Balota et al., 2002) ($r=-0.011, p=0.952$), or with arousal values (Bradley and Lang, 1999) ($r=0.126, p=0.506$).

2.3. Electrophysiological data

Fig. 2a and b show the grand average ERP waveforms for selected frontal (F3, F4), central (C3,C4), parietal (P3, P4), and occipital (O1, O2) electrode positions for the neutral and negative words, split according to their behavioural effect (RT interference, RT facilitation). Note that ERPs for the negative words seem to evoke a larger P1 at occipital (O1, O2) and left parietal (P3) electrode positions. This early effect seemed to be present for both the RT interference (Fig. 2a) and RT facilitation (Fig. 2b) conditions. In addition, ERPs for negative words that produced RT interference (Fig. 2a) also seem to be more negative going

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[2] Please note that for each individual participant, half of the words were presented in the 40 ms ITI interval condition and the other half in the 500 ms ITI interval condition. The mean interference scores for each word were calculated for the 500 ms ITI condition only and thus were based on averages of 11 or 12 participants.

between 300–700 ms post-stimulus, particularly at right-central (C4) and parietal (P3, P4) electrode positions. In contrast, ERPs for negative words that produced RT facilitation (Fig. 2b) seemed to produce no such effect or possibly the opposite.

2.3.1. P1 amplitude

A significant effect of Valence ($F(1,22)=3.18$, one-tailed $p<.05$) was found confirming that P1 amplitudes were larger for negative than neutral words. There was a marginally significant effect of region ($F(2,44)=3.26$, $p=0.054$, $\varepsilon=0.896$) revealing that P1 amplitudes were generally larger for occipital than parietal electrode positions (Bonferroni pairwise comparison, $p<.05$). There was also a near to significant effect of Valence × Hemisphere interaction ($F(1,22)=3.78$, $p=0.065$) revealing that the greatest P1 amplitude differences between negative and neutral words were obtained from left hemisphere electrode positions. There were no significant interactions with Behavioural effect, indicating that P1 amplitude is larger for negative as compared to neutral stimuli, regardless of whether these negative stimuli produced RT interference or RT facilitation.

2.3.2. Negative slow wave (300–700 ms)

A significant Behavioural effect × Valence interaction was found for the 300–700 ms mean amplitude ($F(1,22)=7.83$, $p=0.01$) supporting the observation that the negative slow wave effect is different for negative stimuli that produced RT interference as compared to those that produced RT facilitation.

More specifically, negative words that produced RT interference showed a larger negative slow wave than their neutral counterparts ($F(1,22)=3.301$, $p=0.083$), while those that led to RT facilitation showed a smaller negative slow wave than their matched neutrals, although this did not reach significance ($F(1,22)=1.357$, $p=0.256$). The Behavioural effect × Valence interaction was significant for the mean amplitudes of the first three 100 ms time epochs (300–400 ms $F(1,22)=5.01$, $p<.05$; 400–500 ms $F(1,22)=6.25$, $p<.05$; 500–600 ms $F(1,22)=11.34$, $p<.01$) but not for the last one (600–700 ms $F(1,22)=1.15$, $p=0.30$). Separate analyses for the RT interference and RT facilitation word categories plus their matched controls, revealed that the mean amplitude for the 500–600 ms epoch was significantly more negative for the negative words that produced an RT interference effect ($F(1,22)=5.39$, $p<.05$). Patterns in the remaining 100 ms epochs showed trends in the same direction but these did not reach significance.

There were significant main effects of coronal position ($F(2,44)=9.54$, $p=.002$, $\varepsilon=0.681$) and laterality ($F(2,44)=7.31$, $p=.003$, $\varepsilon=0.897$). Observation of the mean values and subsequent pairwise comparisons (Bonferroni corrected) revealed that the mean 300–700 ms amplitude was more negative over the frontal electrode positions than over both the central ($p<.001$) and parietal ($p<.05$) electrode positions. In addition, mean amplitudes over the right hemisphere were more negative than over the left hemisphere ($p<.05$) and midline electrode positions ($p<.001$). A significant Coronal position × Laterality interaction ($F(4,88)=$
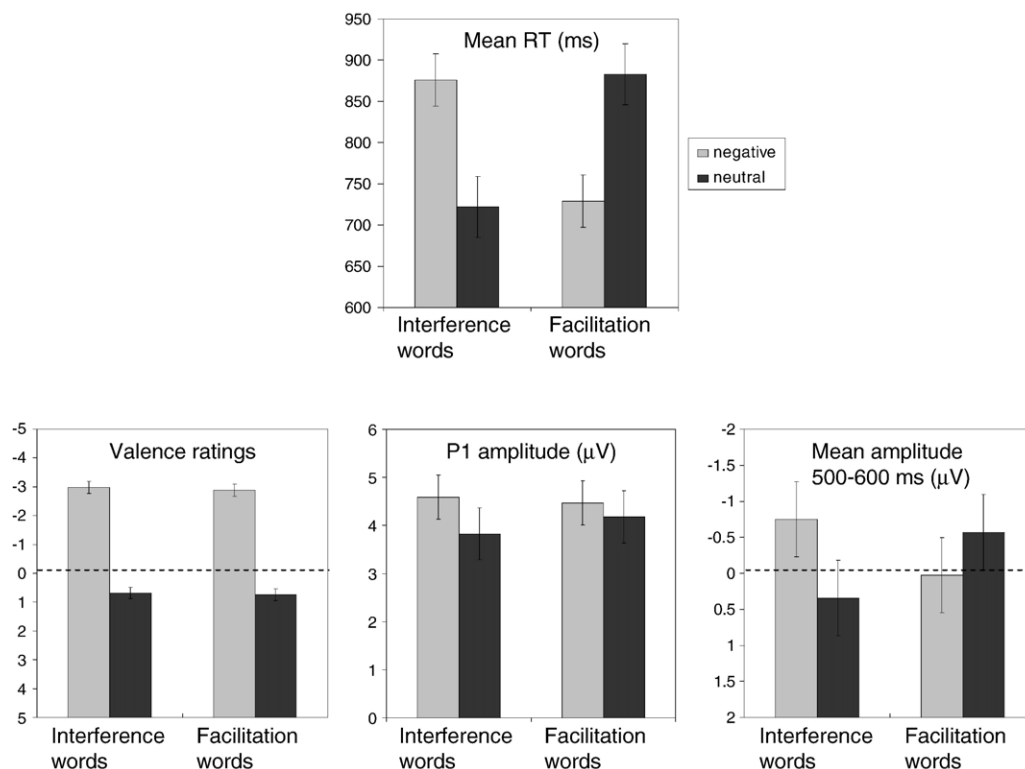

Fig. 3. Mean RTs, subjective valence ratings, P1 peak amplitude, and mean amplitude in the 500–600 ms epoch for the negative words that produced RT interference effect (left panels) and those that produced RT facilitation (right panels), both compared to their matched neutral words. Individual RT scores were taken as the basis for the distinction between RT interference and RT facilitation words (see text).

17.37, $p<.001$, $\varepsilon=0.653$) revealed that for the left hemisphere and midline electrode positions, the frontal electrodes clearly had the most negative mean amplitude, while for the right hemisphere, negative mean amplitudes were obtained for both frontal and parietal electrodes but not for central ones (see also Fig. 2a and b).

2.4. In summary

The main results are summarised in Fig. 3. From this figure it becomes clear that the negative slow wave amplitude (500–600 ms mean amplitude in particular) followed the same pattern as the RT results, with relatively larger amplitudes for the interference words and smaller amplitudes for the facilitation words. Valence ratings and P1 amplitude did not follow the same pattern. That is, the negative words were judged to be more negative than their neutral counterparts and they were found to have larger P1 amplitudes, *irrespective* of the behavioural effect observed (i.e., RT interference or RT facilitation). Statistical analyses support these observations (for ERP measures see above). There was a significant effect of valence for the valence ratings ($F(1,22)=185.24$, $p<.001$) and no interaction with behavioural effect. In contrast, there was no valence effect for the mean RTs but there was a significant Behavioural effect × Valence interaction ($F(1,22)=186.39$, $p<.001$).

3. Discussion

The main aim of the present study was to examine ERP correlates of attention bias towards and intrusion from negative words during the emotional Stroop task. The behavioural results in the 40 ms ITI condition were largely in agreement with those from previous studies (e.g., McKenna and Sharma, 1995; Pratto and John, 1991) and confirm the existence of greater intrusion from negative stimuli in healthy volunteers. In the 500 ms ITI condition, however, RTs for neutral and negative stimuli were highly similar, suggesting that under these circumstances negative words were *not* more difficult to ignore than neutral words. Two ERP effects were observed in the 500 ms ITI condition: (i) larger P1 amplitudes for negative as compared to neutral words, and (ii) more negative amplitudes in the 300–700 ms time window (negative slow wave) for those negative words that produced RT interference. Enhanced P1 amplitudes for negative stimuli have been reported before in passive viewing and rating studies (e.g., Bernat et al., 2001; Delplanque et al., 2004; Smith et al., 2003), suggesting that effects of early attention allocation are task independent. In addition, because participants in the current study were asked to ignore the word stimuli, this P1 effect seems to occur automatically and outside the participants' control. The broadly distributed negative slow wave effect showed parallels with the N450 effect reported for incongruent trials in traditional Stroop studies (Liotti et al., 2000; Rebaï et al., 1997; West and Alain, 1999, 2000), which could mean that it reflects a generic process underlying interference or conflict regulation. Most interestingly, the two ERP effects observed in this study appeared to be dissociated, i.e., stimulus valence modulated P1 but not negative slow wave amplitude, while

behavioural outcome (RT interference vs RT facilitation) modulated the negative slow wave but not P1 amplitude.

In accordance with earlier emotional Stroop studies in healthy participants (e.g., McKenna and Sharma, 1995; Pratto and John, 1991), prolonged RTs for negative as compared to neutral words were found in the short ITI condition. The stimuli were carefully controlled by matching length and occurrence frequency, and thus this behavioural effect supports the notion that negative words produce more interference in the emotional Stroop task, presumably because participants pay more attention to, and are more distracted by the meaning of these words. In the 500 ms ITI condition, this effect completely disappeared, which confirms the observation by Sharma and McKenna (2001) that time pressure plays a crucial role in obtaining behavioural interference effects in an emotional Stroop task.[3] This finding has important consequences for ERP and fMRI research which generally favour longer ITIs and which thus may risk loosing the behavioural effect of interest. Indeed, Pérez-Edgar and Fox (2003) and Thomas et al. (2007) did not report significant RT differences between emotion and neutral word categories in their ERP emotional Stroop studies while using ITIs of 1000 ms and 2500–3500 ms respectively. Similarly, using an ITI of 1500 ms, Whalen et al. (1998) did not obtain significant behavioural interference effects in an emotional counting Stroop task adapted for fMRI recording. Nevertheless, in the current study, a subset of the words was found to produce RT slowing in the 500 ms ITI condition, both on an average level (i.e., some of the negative words produced RT slowing in most participants) and on an individual level (i.e., each individual responded slower to some of the negative words). The practical implication of this finding is that ERPs can be calculated for these subsets of words to study the neural mechanisms underlying actual intrusion from emotional stimuli (see below), but what this means theoretically needs further investigation. In particular, it would be interesting to determine the specific stimulus characteristics that make them more "resilient" to the lack of time pressure. In our experiment, the RT effects did not correlate with occurrence frequency, word length, or mean lexical decision time, which rules out explanations that link slower responses for negative words to their specific stimulus characteristics (cf., Larsen et al., 2006). Surprisingly, they also did not correlate with the subjective valence ratings or with normative arousal values. This implies that these two dimensions (valence and arousal) are not sufficient to explain all levels of emotion–attention interactions and/or that some of these interactions may not be accessible for subjective scrutiny.

The negative words were found to evoke larger P1 amplitudes than the neutral words, regardless of ultimate behavioural outcome (RT interference vs RT facilitation). Since the P1 is generally believed to index early attention allocation in the extrastriate cortex (Hillyard et al., 1998), this result suggests that the negative stimuli

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[3] Please note, that in the current study the specific stimulus set cannot be blamed for the absence of behavioural effects, since they *did* produce RT interference in the short ITI condition.

received more attention than the neutral stimuli at a very early stage of visual information processing (<180 ms). Enlarged P1 amplitudes have been observed before for negative pictures (Carretié et al., 2004; Delplanque et al., 2004; Smith et al., 2003), but only Bernat et al. (2001) reported a similar effect for words. In addition, in all these studies participants were instructed to simply view the stimuli or to rate them for emotionality, whereas in the current study participants were required to ignore the meaning of the presented words. Pictorial and facial stimuli, especially those related to fear, can be considered "biologically prepared" (Lang et al., 2000). The most prevailing explanation of the P1 valence effect is therefore that primitive affective systems, including the amygdala, influence the early processing stages of those stimuli, presumably to aid their rapid processing (Smith et al., 2003; Vuilleumier, 2005). For words, however, this seems a less likely explanation since they cannot be considered biologically prepared in the same way as pictures and faces. In addition, lexical access is commonly believed not to start before 200 ms (Osterhout and Holcomb, 1995) which is evidently later than the P1 deflection. Nevertheless, Bernat et al. (2001) argued that their participants could have reacted towards the well-learned iconic representations of the highly familiar negative and neutral words. In addition, they also did not want to exclude the possibility that some very early, low-level semantic processing may have contributed to the observed effect. Yet, in our experiment, the most plausible explanation for the enlarged P1 for negative words might come from the fact that we used a blocked design, making it possible for participants to "anticipate" the nature of the forthcoming stimulus and to potentially recruit more attentional resources when a negative stimulus was expected. This means that the P1 effect, as observed in this study, might have been the result of a top-down rather than a bottom-up process. It is important to note here, however, that participants were instructed to ignore the meaning of the words and therefore this seems to concern an involuntary (automatic) mechanism.

We did not observe any subsequent ERP valence effects, suggesting that negative and neutral words were similarly processed through further stages. This result parallels the observed overall RT pattern in the 500 ms ITI condition, showing that participants were equally able to ignore the meaning of the negative and neutral words. Holmes et al. (2006) reported comparable findings using a task in which participants were presented with faces that could be either fearful or neutral, and that were either task relevant or task irrelevant. When the centrally presented faces were task irrelevant, performance and RT on a concurrent two-choice judgement task were not affected by their emotional expression, while ERP effects were restricted to the 160–220 ms post-stimulus time window. In contrast, when the faces were made task relevant, additional ERP emotionality effects were found in the 220–300 and 300–700 ms time windows. Similarly, Thomas et al. (2007) reported larger P2 amplitudes for threat words at right parietal positions but strongly reduced P3 amplitudes for these negative stimuli when they were not task relevant (i.e., the emotional Stroop condition). In addition, as mentioned before, Thomas and colleagues did not find any significant RT differences between threat and neutral words when these were supposed to be ignored. Combined, these results suggest that negative stimuli automatically attract more attention at very early stages of information processing (either as a result of bottom-up or top-down mechanisms), but that despite this early attention bias, impact on subsequent stages can be suppressed in accord with task instruction, to such an extent that equal response times are produced. It should be noted though, that this may only hold for tasks in which relatively long ITIs are used.

For each individual participant, a subset of the negative words produced RT slowing while another subset produced RT facilitation. These subsets contained different words for each participant, suggesting individual-specific reactions towards the words, possibly related to their personal concern. ERPs to these two subsets of words were compared to their matched controls and were found to display different patterns in the 300–700 ms time window. That is, words that primarily produced RT slowing in respect to their matched controls (i.e., the 'classic' intrusion effect) showed increased negative amplitudes over this time period (500–600 ms epoch in particular), while words that primarily produced RT facilitation showed decreased negative amplitudes, albeit to a lesser extent.[4] We referred to these ERP effects as negative slow wave effects. Because the negative slow wave amplitude differences co-varied with the RT effects (see Fig. 3), they presumably reflect the activity of a neural system that is associated with response interference. One likely interpretation could be that the negative slow wave is a manifestation of the brain's attempt to suppress conceptual representations, which needs to be more pronounced for those words that are most difficult to ignore. This reasoning would fit with interpretations given for the N450 (West and Alain, 1999; 2000) or early negativity (Liotti et al., 2000), which are observed in traditional Stroop tasks for the incongruent stimuli. West and Alain (1999, 2000) suggested that the N450 reflects a mechanism involved in conflict resolution, inhibiting meaning representations of the words when they are incongruent with their ink colour. Likewise, Liotti et al. (2000) proposed that the early negativity (350–500 ms) may be associated with increased efforts to suppress or over-ride the processing of incongruent word meaning. Finally, West and Alain (2000) reported that the N450 effect co-varied with their behavioural data, being more prominent in those experimental conditions for which the RT interference effect was largest. Clearly, this observation parallels the results observed in the current study.

The negative slow wave was characterised by a broad scalp distribution, comparable to those observed for the N450 effect in traditional Stroop studies by Rebaï et al. (1997) and Liotti et al. (2000), and to a lesser extent by Markela-Lerenc et al. (2004) and West and Alain (1999, 2000), who reported the effect to be more fronto-central. The broad distribution of this negative wave makes it likely that the effect has its source(s) in a deeper brain structure. Liotti et al. (2000) and Markela-Lerenc et al. (2004) both employed dipole source modelling and concluded that the source of the

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[4] Please note, although we used a between block design these opposite ERP patterns refer to within block effects, ruling out explanations in terms of negative mood induction or contextual effects.

increased activity for the incongruent trials around 400–450 ms post-stimulus is likely to be in the ACC. The ACC has been identified as an important component of both attentional and emotional networks (Bush et al., 2000), and, in the context of the traditional Stroop task, it has been argued to play a major part in conflict detection and conflict resolution (Carter et al., 1998). In the emotional Stroop task, ACC activation is believed to reflect emotional processing and regulation of emotional responses (rostral–ventral affective division) and modulation of attention and executive functions (dorsal cognitive division) (Bush et al., 2000; Whalen et al., 1998). It could thus reasonably be suggested that the negative slow wave may be the scalp manifestation of such activations.

In conclusion, as one of the first studies examining ERP correlates of attention bias towards and intrusion from emotional stimuli, we feel that valuable lessons can be learned from the current findings. First, it was demonstrated that the ITIs commonly used in ERP and fMRI research (≥ 500 ms) may run the risk of losing the behavioural effect of interest, as suggested by an earlier study by Sharma and McKenna (2001). In future studies, it is therefore important to include conditions with shorter intervals to verify behavioural effects and to validate the materials used. Second, we found that stimulus selection on the basis of valence and arousal ratings may be too crude or too two-dimensional to reflect all levels of emotion–attention interaction. Moreover, RT facilitation/interference effects, as observed for the negative words in the 500 ms ITI condition, could not be explained by such ratings. This was an unexpected finding and more research is needed to substantiate this claim. Third, comparable to previous passive viewing/rating studies, the P1 was found to be larger for negative as compared to neutral stimuli. Because we used linguistic instead of pictorial stimulus materials, this effect seems to be too early to be the result of a bottom-up process. Instead, we suggest that the P1 was larger for the negative words due to a top-down process, reflecting a strategic shift in attentional control. Fourth, despite apparent differences in early attention allocation, no valence effects were observed in ERP deflections later than 180 ms, suggesting that emotional influences on subsequent stages of verbal processing can be voluntarily suppressed. Finally, our unique approach of calculating separate ERPs for words which, on an individual basis, produced either RT interference or RT facilitation, was successful in obtaining a possible neural correlate for processes underlying interference. This correlate, the negative slow wave, showed similarities, both in terms of timing and scalp distribution, with an ERP effect observed for incongruent trials in traditional Stroop studies (Liotti et al., 2000; West and Alain, 1999, 2000). In agreement with those studies, it was suggested that the negative slow wave may reflect a process involved in the suppression of meaning representations, possibly located in the ACC.

Acknowledgements

Appendix A. Word stimuli

Negative	Neutral	Negative	Neutral
Lice	Hawk	Trauma	Rattle
Scum	Cork	Sinful	Violin
Hurt	Knot	Morbid	Locker
Foul	Cane	Brutal	Runner
Rude	Fork	Afraid	Window
Tomb	Lamb	Obesity	Glacier
Ugly	Lawn	Crushed	Bandage
Annoy	Slush	Traitor	Trumpet
Germs	Wagon	Garbage	Whistle
Abuse	Cliff	Assault	Nursery
Crime	Tower	Illness	Passage
Anger	Coast	Deserter	Overcast
Putrid	Cannon	Insecure	Mushroom
Rabies	Crutch	Terrified	Sheltered
Maggot	Golfer	Infection	Sentiment

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