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Event-related potentials during an emotional stroop task

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Keywords

Emotional Stroop, Event-related potential, Threat words, N1, P2, N2, P3, Attention, Emotion, Attentional bias

Disciplines

Arts and Humanities | Life Sciences | Medicine and Health Sciences | Social and Behavioral Sciences

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EVENT-RELATED POTENTIALS DURING AN EMOTIONAL STROOP TASK

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Abstract

Emotional Stroop tasks have gained wide interest in scientific literature in the last two decades. Although no direct measure of attention is employed, these studies infer the presence of preferential processing of threatening information based on reaction time (RT) impairment in a competing task. Because event-related potential (ERP) measures are sensitive to both the extent (amplitude) and speed (latency) of cerebral processing, they are valuable tools with which to examine more directly the claim that threatening stimuli are associated with enhanced attention. Twenty-two students rated a pool of words to identify those that were personally disturbing. Two word types (threat and neutral) were then compared in two tasks (colour relevant, in which the colour ink of words was identified, and word relevant in which words were classified as threatening or not). No emotional Stroop effect was observed in terms of longer RTs to identify the colours of threat words. ERP results provided valuable information about threat processing which was not observed with behavioural measures. Threat content was associated with larger P2 amplitude in the right than left hemisphere and larger P3 amplitude across tasks. The results indicate strong evidence for enhanced processing of threat-related stimuli in healthy individuals. It is concluded that ERPs are a sensitive measure of processes underlying emotional Stroop performance, which can be used to elucidate attentional biases in healthy and clinical populations.

Introduction

Emotional Stroop tasks are the principal research tool for demonstrating attentional biases (Wells & Matthews, 1996). Interpretations of emotional Stroop studies, however, usually infer the presence of attentional biases towards threatening words based on impaired reaction time (RT) performance in a competing (colour naming) task, without direct measures of attention towards threatening material. Emotional Stroop RT studies can therefore only equivocally establish the presence of an attention bias or determine whether such a bias takes the form of more elaborate, or faster, processing of threat stimuli. Event-related potentials (ERPs) provide more direct measures of attention-related cerebral processing (Mangun & Hillyard, 1995), and are therefore an excellent means of directly examining attention to stimuli during emotional Stroop tasks. Amplitudes of ERP components are generally assumed to signify the degree or intensity of the engagement of cognitive processes, and latencies are thought to measure the time course of stages of processing (Luck, Woodman, & Vogel, 2000).

ERPs allow a finer examination than RTs of the amount of time and resources allocated to stimulus evaluation during sensory and cognitive stages of information processing, in order to examine the stage and precise temporal loci of experimental phenomena (Hillyard & Kutas, 1983). Also, several studies have shown that ERPs are sensitive to emotional aspects of stimuli, with larger amplitude ERP components to emotional relative to neutral stimuli and emotionally negative relative to emotionally positive stimuli interpreted as indicating enhanced attention towards more salient stimuli (Bernat, 2001; Carretié et al., 2001; Ito et al., 1998; Johnston, Miller, & Burleson, 1986; Lang, Nelson, & Collins, 1990). ERPs also allow the study of attentional biases that are not accompanied by reliable impairments in task performance at a behavioural level (Pérez-Edgar & Fox, 2003; Weinstein, 1995).

Emotional versus traditional Stroop tasks

Traditionally, Stroop tasks investigated interference caused when naming the ink colour of incongruent compound stimuli (e.g., the word red printed in green ink), relative to the time taken to colour name congruent or neutral stimuli (Stroop, 1935). Emotionally modified Stroop tasks emerged in the 1980s, investigating the effect of emotional words, rather than colour words, as embedded distracters during information processing. Individuals are typically asked to name the colour ink of words varying in emotional value (e.g., neutral versus anxiety-related words), and RTs between word types are compared. Emotional Stroop tasks have been applied to the study of information processing in a wide range of clinical and subclinical psychological conditions, particularly anxiety (see Williams et al., 1996 for a review). Individuals with psychological disorders often show longer RTs during emotional Stroop tasks when colour-naming words related to their clinical concerns, compared to neutral words. It is assumed these effects are due to attentional biases which lead to facilitated detection of threatening stimuli, which “captures” attentional resources at the expense of processing neutral material, hence interfering with the competing colour-naming task (Williams et al., 1996). Despite two decades of research using emotional Stroop tasks in clinical and non-clinical populations, however, fundamental questions about the locus and nature of emotional Stroop effects remain inadequately examined. The current study addresses aspects of these questions by employing ERP methodologies.

ERPs during Stroop tasks

There is a well-established literature examining ERPs in traditional colour-word Stroop tasks (Duncan-Johnson & Kopell, 1981; Ilan & Polich, 1999; Liotti, Woldorff, PerezIII, & Mayberg, 2000; Rebai, Bernard, & Lannou, 1996; West, 2003; West & Alain, 1999, 2000), however very few ERP studies of emotional Stroop tasks (Metzger, Orr, Lasko, S.J. Thomas et al. / *International Journal of Psychophysiology* 63 (2007) 221–231

McNally, & Pittman, 1997; Pérez-Edgar & Fox, 2003) have been reported. In a study in the clinical domain, Metzger and colleagues (1997) used ERPs to investigate the emotional Stroop effect in individuals with post-traumatic stress disorder (PTSD). They found slower RTs for those with PTSD to name word colours, especially for traumatic words, suggesting a processing bias towards trauma-related information in PTSD. This was accompanied, however, by significantly reduced and delayed P3 components across all word types, suggesting that Stroop interference was not related to discernable differences in attention-related cerebral processing of trauma versus non trauma related words. These results were unexpected and seem contrary to cognitive models of anxiety (e.g. Williams et al., 1997). Metzger and colleagues, however, did not report on ERP components other than the P3, raising the possibility that relevant, earlier, attentional effects were overlooked. Another possibility is that emotional Stroop interference was due to effort taken to avoid processing emotional information, rather than enhanced processing, interfering with the ongoing colour naming task (de Ruiter & Brosschot, 1994; Kyrios & Iob, 1998a). Traditional Stroop studies often include a word relevant comparison condition where task requirements maintain the association between the words and their meanings (Duncan-Johnson & Kopell, 1981; Stroop, 1935), in anticipation that participants may develop strategies (such as blurring the focus of their eyes) to avoid processing interfering word content during the colour task (see MacLeod, 1991 for a discussion). Emotional Stroop studies, however, have yet to address this issue. As it may be possible for participants to avoid attending to unpleasant word meaning during the colour categorisation task, it is important to compare implicit attention to threatening words during the typical emotional Stroop colour naming task with explicit, task relevant attention to threat words in order to avoid the above interpretive difficulties, and to fully explore attention towards threatening stimuli.

In a non-clinical study, Perez-Edgar and Fox (2003) investigated ERPs in an S.J. Thomas et al. / *International Journal of Psychophysiology* 63 (2007) 221–231

emotional Stroop task with normal children. They found smaller N1 and N2 components to emotionally negative words (e.g., afraid, alone) relative to positive and control words, indicating differential processing during both sensory and cognitive stages. Slow waves were more pronounced for negative words, indicating the likely involvement of additional processing resources, even though there were no discernable differences between words at the RT level, supporting the utility of using ERPs to examine the subtleties of attentional biases in healthy individuals.

ERPs and emotion

There are suggestions in the literature that ERPs are a more sensitive measure of attentional biases than RT measures. RT studies of emotional Stroop tasks (Becker, Rinck, Margraf, & Roth, 2001; Cox, Hogan, Kristian, & Race, 2002; Kampman, Keijsers, Verbraak, Naring, & Hoogduin, 2002; Lavy et al., 1994; MacLeod & Dunbar, 1988; Mathews & MacLeod, 1985; McNally et al., 1994; Mogg, Mathews, & Weinman, 1989; Yovel & Mineka, 2004) have generally found no delayed latencies to colour name general threat words for non-clinical participants (although there are some exceptions: McKenna & Sharma, 1995; Pratto & John, 1991). A number of ERP studies of healthy individuals, however, have found larger amplitude ERPs in response to emotional relative to neutral stimuli, and in emotionally negative relative to emotionally positive stimuli, suggesting that preferential processing is apparent when examining ERP rather than RT measures. One study (Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001), for example, measured ERPs in normal participants to arousing positive, arousing negative, relaxing and neutral pictorial stimuli in a cue/target paradigm. The P200 and P340 post target components had their highest amplitudes to negative stimuli. Ito and colleagues (1998) found larger late positive potentials (LPPs) for positive and negative relative to neutral pictures, and for negative relative to positive pictures, S.J. Thomas et al. / International Journal of Psychophysiology 63 (2007) 221–231

during tasks in which undergraduates pressed computer keys to evaluate stimuli as positive, neutral or negative. Bernat, Bunce, and Shevrin (2001) had undergraduates merely watch words that appeared on a computer screen, and found that unpleasant words elicited more positive amplitudes than pleasant words across all components (P1, N1, P2, P3 and LPP) in both supraliminal and subliminal conditions. Weinstein (1995) found no RT differences between high and low anxious normals' performance in deciding whether visually presented words (positive, neutral or threat) matched semantically with priming sentences (threat or positive). ERPs, however, showed larger amplitude N100 and P400 in the high anxious group in the threat priming condition. Larger amplitude ERPs to negative emotional stimuli have therefore been demonstrated in sensory and cognitive components, using both pictorial and word stimuli and in the absence of any observed differences at the behavioural level. Such patterns have been interpreted as indicating an adaptive (affective) negativity bias, that is an attentional bias prioritising processing of negative over mundane stimuli occurring in the general population (e.g. Carretié et al., 2001).

Additional methodological issues

Inconsistencies in results of emotional Stroop RT studies of normal participants, as noted above, may be partly due to methodological issues such as individual participant characteristics (e.g., age, gender) or threat word selection. Few emotional Stroop studies involving normal participants, for example, obtain personal ratings by participants of the threat value of words used in experiments, thus they fail to control for the idiosyncratic nature of threat appraisal. Previous emotional Stroop studies (Foa et al., 1993; Kyrios & Iob, 1998a) have demonstrated the difficulty in predetermining groups of words that will be uniformly threatening to particular types of research participants, leading to recommendations for the use of ideographically tailored stimuli (Muller & Roberts, 2005).

Aims and hypotheses

The current study used direct evidence from brain activity in order to determine whether threat stimuli received preferential processing by normal individuals during an emotional Stroop task. Given the few studies in this area, an investigation of a non-clinical group was warranted in order to build understanding of normal functioning in emotional Stroop tasks, and evaluate this paradigm for future use with clinical samples. It was hypothesised that threat words would receive greater attention than neutral words, as indexed by larger ERP amplitudes. In addition, attention to threatening compared to neutral stimuli was explored during both sensory and cognitive stages of information processing. Larger amplitudes of sensory components (N1, P2) to threat words were hypothesised to indicate the likelihood of increased attention-related cerebral processing during relatively early, perceptual stages of information-processing (Bernat, 2001; Hillyard, Teder-Sälejärvi, & Münte, 1998; Junghöfer, Bradley, Elbert, & Lang, 2001; Mangun & Hillyard, 1995; Näätänen, Simpson, & Loveless, 1982), whereas increased amplitudes for the N2 and P3 components more elaborate processing of threatening stimuli during later, higher level, cognitive stages (Duncan-Johnson & Donchin, 1982; Picton, 1992). The current study also examined latencies of ERP components in order to assess the speed of processing threatening versus neutral stimuli. Additionally it examined whether processing of threat content was affected by tasks that manipulated the attentional focus of participants. In one task (the colour identification task) participants were required to ignore word meaning and respond to the colour of stimuli (the usual form of emotional Stroop tasks). In a comparison task (the word classification task) participants were required to read words and classify them according to their perceived threat value. In addition to ERP measures RTs were examined to determine whether preferential processing of threat resulted in interference at the behavioural level. Furthermore, because of

the idiosyncratic nature of threat appraisal, the threat value of stimuli was determined separately for each participant.

Materials and methods

Participants

Twenty-two undergraduate psychology students (5 males) from the University of Wollongong participated in the study in return for partial course credit. The mean age of participants was 19 (range: 18-24, SD: 1.7). Eighteen participants were right handed, and five were left-handed, according to their accounts. Participants gave written informed consent and the University of Wollongong Ethics Committee approved the research protocol. Participants were screened with the Brief Symptom Inventory (Derogatis & Melisaratos, 1983) and reported to be free from neuropsychiatric history, drug or alcohol abuse or dependence.

Stimuli

A pool of 60 potentially threatening words was compiled (see Appendix A), largely from previous emotional Stroop studies (Foa et al., 1993; Lavy et al., 1994; McNally et al., 1994; Sauteraud, Cottraux, Michel, Henaff, & Bouvard, 1995; Tata et al., 1996). A broad range of different types of threat words was used in the pool, including general threat words (e.g., *war*, *coffin*, *abuse*), obsessional words (e.g., *unclean*, *blasphemy*, *punishment*), and physical threat words (e.g., *palpitation*, *suffocate*, *faint*). Words ranged in length from 3-11 letters (mean word length was 7 letters). A pool of neutral words was matched for word length and frequency of usage (Kucera & Francis, 1967). Individual ratings were obtained from participants as to the threat value of the words by asking them to indicate “How disturbing is this word to you (including associations with unpleasant thoughts, feelings or anxiety)?” on a five point Likert type scale ranging from 0 (*not at all disturbing*) to 4 (*severely disturbing*).

The 10 words rated as most disturbing by each participant were then used as the threat word stimuli for that participant (McNally et al., 1994; Novara & Sanavio, 2001). Threat stimuli used in the experiment were rated at least 2 (*moderately disturbing*) by the relevant participant.

Each block consisted of a random presentation of 50 neutral and 50 personally threatening stimuli. Each word within each category was presented five times in each block, with the constraint that the same word did not appear in immediate succession. All stimuli were presented in the centre of a computer screen against a white background in upper-case letters using a 7 mm size serif font. Half the stimuli were coloured blue, and half green, with random appearance of colours. Stimulus duration was 200msec and ISI varied randomly between 2.5-3.5 seconds.

Procedure

Participants rated the pool of words approximately 1 hour prior to the experiment, following which they completed a battery of psychometric questionnaires, for use in future studies, and were fitted with the electrode cap. During the experiment participants were comfortably seated in a dimly lit sound-attenuated room, one meter from the computer screen, with a two-button-press device fixed to a chair arm next to their dominant hand. Participants made responses using the index and middle fingers of their dominant hand. Threat and neutral stimuli were compared in a colour-identification (*colour relevant*) task in which participants were instructed to ignore word meaning and to indicate as quickly and accurately as possible whether each word appeared in blue or green colour. In another (*word relevant*) task, participants responded to the same stimuli with instructions to classify whether or not each word was threatening. The word relevant task was included as in other Stroop studies (Duncan-Johnson & Kopell, 1981; MacLeod, 1991; Stroop, 1935), as a comparison condition

where task requirements maintain the association between the words and their meanings, in order to compare implicit attention to threatening words during a typical emotional Stroop colour naming task with explicit, task relevant attention to threat words. Rather than have participants merely read words, a button press response was required, indicating a semantic classification (*threat* or *non-threat*) of words in order to ensure that participants attended to word meaning, and to have comparative RT measures between tasks. In the word relevant task, the instructions to participants were “I would like you to push a button to classify as quickly and accurately as you can whether you consider the word to be a *threat* word, or a *non-threat* word. By *threat* word, I mean any word that is disturbing or has negative, anxiety-related, or stressful connotations in any shape or form (e.g., *worried*, *terrorist*, *hurt*). By *non-threat* word, I mean any word that is completely neutral (e.g., *table*, *sky*, *clerk*).” Participants received 10 practice trials before each task to ensure they fully understood task requirements. Task sequences and assignment of buttons to response codes were counterbalanced between participants.

Electrophysiological Recording

ERP data were collected and stored using AMLAB II (Associative Measurement) digital signal processing hardware and software. The EEG was recorded from 19 scalp electrodes (F1, F2, Fz, F3, F4, F7, F8, Cz, C3, C4, T3, T4, T5, T6, Pz, P3, P4, O1, O2), referenced to linked ears according to the international 10 - 20 system (Jasper, 1958) using tin electrodes in an electrode cap (Electro-cap International). The participant was grounded by a cap electrode located midway between Fpz and Fz. Vertical EOG was recorded from tin electrodes placed 1cm above and below the left eye, and electrodes placed beyond the outer canthus of each eye recorded horizontal EOG. Electrode impedances were kept below 5 Ω .

Data analysis

Mean response times for correct responses to each stimulus type were calculated for each participant in each task. Incorrect responses were excluded from the overall RT analysis, and extreme scores (over two standard deviations from the participant's condition mean) were excluded from the analysis (Ratcliff, 1993). The mean RT scores were analysed using a 2 (task: colour relevant, word relevant) x 2 (word type: neutral, threat) repeated measures analysis of variance (ANOVA).

The ERP epoch was defined as –100 ms to 1200 ms post stimulus. ERP data were amplified with EEG and EOG gains of 20 000 and 5 000 respectively, digitised at a sampling rate of 512 Hz with a bandpass down 3 dB at 0.01 and 35 Hz and filtered offline with a low pass filter at 30 Hz. Electrophysiological data were corrected for excessive eye movement using the Semlitsch (1986) procedure. Peak quantification involved the automatic identification of the maximum voltage within defined latency ranges, with manual confirmation.

Four components were quantified from the individual participants' waveforms, with peak amplitudes determined relative to the 100 millisecond pre-stimulus baseline. Peaks were detected in specified channels and time-locked to the onset of the stimulus, and amplitude measures were taken at all sites at the same post-stimulus latency (Picton, Bentin, Berg, Donchin, Hillyard, Johnson, Miller, Ritter, Ruchkin, Rugg et al., 2000): The N1 was time-locked to electrode Cz and the search window was 110-160 ms, P2 to electrode Pz from 150-210 ms, N2 to electrode Fz from 260-500 ms, and P3 to electrode Pz from 340-600 ms. Search windows were based on visual inspection of the grand mean waveforms. ERP component data were analysed at 9 of the 17 sites recorded (Fz, Cz, Pz, F3, C3, P3, F4, C4, P4). Initially, separate one-way ANOVAs were conducted to determine at which sagittal

plane (frontal, central or parietal) each component was maximal. Once this was determined, planned contrasts of each component were focussed on the sagittal plane at which each was maximal: This was the central region for the N1, ($F(1, 21) = 4.05, p = .06$), the parietal region for P2, ($F(1, 21) = 15.89, p = .00$), the frontal region for N2, ($F(1, 21) = 43.77, p = .00$), and the parietal region for the P3, ($F(1, 21) = 85.36, p = .00$). ERP measures at the relevant sagittal plane were subjected to separate 3-way ANOVAs with task (word relevant, colour relevant), threat level (neutral, threat), lateral plane (left, midline, right) as within subject factors. Within the lateral plane, two planned contrasts were computed: left versus right hemispheres, and the midline region versus the mean of the left and right hemispheres. As the contrasts were planned and there were no more of them than the degrees of freedom for an effect, no Bonferroni-type adjustment was necessary (Tabachnick et al., 2001). Also, single degree of freedom contrasts are not affected by violations of symmetry assumptions common in repeated measures analyses, and thus do not require Greenhouse-Geisser type corrections. ERP data were normalised using the vector scaling procedure (McCarthy and Wood, 1985), and interactions involving topography are reported only if they remained significant after normalisation.

Results

Word ratings

Means and standard deviations of overall subjective disturbance ratings for words, frequency of each word's use as a threat stimulus, and mean and range of ratings of words where they were used as threat stimuli are shown in Appendix A.

Reaction time to personally threatening versus neutral words

Mean RTs as a function of task and stimulus type are shown in Table 4.1. For RTs,

there were no significant effects or interactions involving word type. Thus RT measures did not differentiate between responses to threat versus neutral words, and no emotional Stroop effect was discernable at the behavioural level. RTs were significantly longer in the word classification than colour classification task, ($F(1, 21) = 75.52, p = .00$).

1.1.1 ERP amplitude and threat processing

Results are organised to address key hypotheses. For clarity, and as a large body of literature has been devoted to descriptions of the topography of the various ERP components, only effects or interactions involving word type or task are reported.

Grand average ERP waveforms for the colour and word tasks are shown in Figure 4.1. Visual inspection of the waveforms indicates larger amplitude to threat than neutral words in the period approximately 350 ms to 700 ms post stimulus, particularly in the word relevant task. Mean amplitudes of ERP components as a function of task and stimulus type are shown in Table 4.1.

Table 0.1. Mean reaction times (ms), amplitude (μV) and latency (ms) of N1, P2, N2 and P3, as a function of task and stimulus type. Standard deviations are in parentheses.

		Word relevant task		Colour relevant task	
		Neutral words	Threat words	Neutral words	Threat words
Reaction time		593 (99)	592 (75)	478 (67)	474 (73)
N1 amplitude	C3	– 1.5 (1.7)	– 1.4 (2.4)	– 1.4 (1.8)	– 1.3 (1.9)
	Cz	– 1.5 (2)	– 1.4 (2.7)	– 1.8 (1.9)	– 1.1 (1.8)
	C4	– .6 (1.7)	– 1 (2.1)	– 1.4 (1.6)	– .5 (1.39)
N1 latency	Cz	122.7 (21.4)	129.5 (21)	132 (21.6)	137.4 (23)
P2 amplitude	P3	3.6 (3.5)	2.7 (4.4)	3.8 (3.9)	3.6 (4)
	Pz	6.8 (3.4)	6 (3.3)	6.6 (3.8)	8.2 (5.5)
	P4	4.1 (3.7)	4.1 (2.9)	4.7 (4.4)	6 (3.6)
P2 latency	Pz	180.3 (14.3)	180.4 (18.9)	188.8 (14.8)	188.2 (21.9)
N2 amplitude	F3	– 2.1 (5)	– .8 (6.5)	– .6 (4.7)	– .4 (3.9)
	Fz	– 3 (5.3)	– 3.3 (5.5)	– 1.8 (4.3)	– .8 (4.6)
	F4	– 2.1 (5)	– 2.5 (5.2)	– .6 (4.3)	.3 (4.2)
N2 latency	Fz	351.3 (63.7)	327.2 (42.7)	316.9 (39.7)	330.9 (49)
P3 amplitude	P3	12.3 (6)	17.1 (6.4)	13.4 (7.7)	14.4 (7.4)
	Pz	15.8 (7.1)	21.3 (8.4)	16.8 (10.7)	20.3 (11.6)
	P4	11.6 (5.8)	16.7 (7.2)	14.7 (8.6)	15.3 (7.6)
P3 latency	Pz	484.4 (88.2)	504.8 (78.9)	431 (86.2)	435.9 (62.6)

Sensory components

N1 amplitude showed no significant effects or interactions involving threat. P2 amplitude showed an interaction between threat and laterality (left vs. right) ($F(1, 21) = 4.6$, $p = .04$). Simple effects analyses showed that P2 amplitude to threat words was significantly

larger in the right than left hemisphere across conditions ($t(21) = 3.45, p = .01$). Also, in the colour condition, P2 amplitude in the right hemisphere was significantly larger to threat than neutral words ($t(21) = 2.69, p = .01$). No other simple effects for P2 amplitude were significant ($p > .05$ in all cases). In summary of the sensory ERP amplitude results, P2 amplitudes showed right > left hemisphere to threat words across conditions, and threat > neutral words in the right hemisphere in the colour task.

Figure 0.1. Grand average ERP waveforms to threat and neutral words, in the word relevant and colour relevant tasks. Note: tickmarks on the x-axis equal 100 ms; stimulus onset is indicated by the vertical bar on the Cz plot.

Cognitive components

N2 amplitude showed no significant effects or interactions involving threat, however there was an effect of task, which is detailed below in 3.5. P3 amplitude was larger to threat than neutral words, ($F(1, 21) = 8.90, p = .01$). The main effect of threat was qualified by a marginally significant interaction between threat and task, $F(1, 21) = 4.09, p = .06$. Analyses of simple effects showed that P3 amplitude was larger to threat than neutral words in the word relevant condition, ($t(21) = 3.08, p = .01$). Thus the P3 component of the ERP differentiated between threat and neutral words, with larger amplitudes to threat words, particularly in the word relevant task.

ERP latency and threat processing

Mean latencies of ERP components as a function of task and stimulus type are shown in Table 4.1. No significant threat-related differences were observed for N1, P2, N2 or P3 component latencies.

Effects of task

N1 amplitudes showed no significant effects or interactions involving task. As detailed above in 4.3.3.1, in the colour task, P2 amplitudes in the right hemisphere were significantly higher to threat than neutral words. N2 amplitudes showed a significant effect of task, ($F(1, 21) = 6.18, p = .02$), with larger N2 amplitudes in the word relevant than colour relevant task. There was a trend towards larger P3 amplitudes to threat words in the word relevant than colour relevant conditions (detailed above in 4.3.3.2). P3 amplitude also showed a task by laterality (left vs. right) interaction, ($F(1, 21) = 33.82, p = .02$), with larger amplitudes in the left than right hemisphere in the word relevant task, and the opposite pattern in the colour relevant task. Simple effects analyses showed a tendency towards right>left hemisphere P3 amplitude differences in the colour task across word types, ($t(21) = 2.01, p = .06$). There was a main effect of task, ($F(1, 21) = 26.74, p = .00$) upon P3 latency, with longer latency in the

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word relevant than colour relevant task. In summary, directing participants' attention to word meaning was associated with larger N2 amplitude and longer P3 latency across word types, along with a trend towards further augmented P3 amplitudes to threat words, whereas the colour classification task was associated with larger P2 amplitude to threat than neutral words in the right hemisphere, and a tendency towards larger P3 amplitude in the right than left hemisphere.

Discussion

The current study used ERPs to clarify and extend current understanding of information processing in emotional Stroop tasks, hitherto derived primarily from RT measures. In particular, ERPs and RTs were used to address the following questions:

Do healthy individuals show more intensive processing of personally threatening words in an emotional Stroop task?

The colour relevant task, in which participants identified the colour of words while ignoring their meaning, was analogous to usual emotional Stroop tasks. Behavioural data in this task were consistent with other emotional Stroop studies (Becker et al., 2001; Cox et al., 2002; Kampman, Keijsers, Verbraak, Naring et al., 2002; Lavy et al., 1994; MacLeod & Dunbar, 1988; Martin, Williams, & Clark, 1991; Mathews & MacLeod, 1985; McNally et al., 1994; Mogg et al., 1989; Yovel & Mineka, 2004) in that non-clinical participants did not show an emotional Stroop effect in terms of longer RTs to threat words. This indicates that the non-patient group was able to respond to threat words, even when rated as personally disturbing, with equivalent efficiency as neutral words. RT measures did not differentiate between threat and neutral words either when word meaning was task irrelevant (in the colour classification task), or when it was relevant to the task (the word classification task).

The current ERP data, however, provide strong evidence to indicate that threat

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information was indeed processed differently from neutral information. In particular, threat words were associated with larger P3 amplitudes across tasks. This result is consistent with those of a number of previous studies indicating larger amplitude late positive potentials (LPPs) in healthy individuals to emotionally negative relative to emotionally positive or neutral stimuli (Bernat, 2001; Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001; Huang & Luo, 2006; Ito et al., 1998; Johnston et al., 1986; Lang et al., 1990; McNeely, Dywan, & Segalowitz, 2004; Palomba, Angrilli, & Mini, 1997). The current study apparently extends the above ERP findings for the first time to an emotional Stroop experimental approach, and also to an experimental design using idiosyncratically selected threat stimuli.

There are a number of possible reasons for enhanced P3 amplitudes to threat words. P3 amplitude is affected by the probability and meaning or value of a stimulus, with larger amplitudes occurring to rarer or more meaningful stimuli (Johnson, 1993). As probability levels in this study did not differ between threat and neutral words, larger amplitudes to threat words are likely to be due to enhanced salience of threat stimuli, possibly due to their evolutionary importance (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Cacioppo & Gardner, 1999; Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001; Mogg & Bradley, 1998). As all the emotional stimuli used in this study were negative or threat related, it may be that effects were due to emotional content per se, rather than the negative valence, of the stimuli. A number of studies comparing ERPs to positive, negative and neutral stimuli, however, have found that negative stimuli are associated with larger amplitude ERPs relative to positive and neutral stimuli (Bernat, 2001; Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001; Ito et al., 1998; Junghöfer et al., 2001; Lang et al., 1990) indicating enhanced processing of (or an attentional bias towards) negative information rather than merely emotional: neutral differences. The possibility that larger amplitude P3s were due to the self-relevance of words rated by participants as disturbing, rather than their threat value alone was

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also considered. Gray (2004) found larger amplitude P3s to self-relevant information, however the information used by Gray was over-learned and autobiographical (e.g., participants' own names, mother's name), and therefore likely to be of far greater self relevance and experiential history than words rated as disturbing by a non-clinical group. Also, threat words used in the current study were derived from previous studies in which they had been categorised as threat words by experts and experimental participants using rigorous empirical methods (Foa et al., 1993; Lavy et al., 1994; McNally et al., 1994; Sauteraud et al., 1995; Tata et al., 1996). This raises the likelihood that larger amplitudes were due more to the threat value of the words than their self-relevance. Additionally, the possibility was considered that the method of obtaining idiosyncratically relevant threat stimuli (asking participants to rate words one hour prior to the experiment to indicate whether or not they found them personally disturbing), might have primed participants to think of stimuli as disturbing, thereby partially increasing attention to threat words. Bernat and colleagues (2001) had participants rate mood adjectives daily for 28 days on a Likert-type scale prior to recording ERPs to the stimuli. When the same mood adjectives were presented on a computer screen while participants watched passively, the resultant ERPs showed similar results to the current study, with higher amplitude P3s to unpleasant than pleasant words. A number of studies in which participants have had no prior contact with experimental stimuli have also found similar results, that is larger P3s or LPPs, to negative versus neutral or positive stimuli (Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001; Huang & Luo, 2006; Ito et al., 1998; Johnston et al., 1986; Lang et al., 1990; McNeely et al., 2004; Palomba et al., 1997). Given the consistent results across studies, both where participants have previously rated stimuli and where they have not had prior exposure to stimuli, it is concluded that priming effects are not sufficient to explain the current results. The use of idiographically tailored stimuli is an important consideration in emotional Stroop tasks, particularly when studying clinical groups

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(Muller & Roberts, 2005), and further investigation of the magnitude of any priming effects resulting from various methods of stimulus selection may be warranted in future studies. It would also be of interest to explore ERPs to a wider range of emotional stimuli, and to have individuals make judgements about semantic attributes of threatening stimuli other than their relation to threat, in order to test the parameters of these effects.

The current study's findings of differential processing of emotional information in the ERP data despite a lack of RT differences in the emotional Stroop task provide further evidence (Pérez-Edgar & Fox, 2003; Weinstein, 1995) that ERPs are a sensitive measure with which to explore attentional biases. The results are important as they indicate that although emotional Stroop RT tasks are the principal research tool for investigating attentional biases (Wells & Matthews, 1996), they apparently may be less sensitive than other (i.e., ERP) measures of attentional biases occurring in non-clinical participants.

On a methodological note, the emotional Stroop task was adapted for the current study by replacing verbal colour naming with button pressing (to avoid contamination of EEG data with muscle artefacts associated with verbalisations), and by using only two stimulus colours. It is unlikely that the failure to find an emotional Stroop effect in the current study was due to these changes, because in traditional Stroop tasks increasing hue numbers from two to five has been found to increase overall response time but not interference (MacLeod, 1991), and robust Stroop interference effects have been found using two stimulus colours in both standard (Duncan-Johnson & Kopell, 1981) and emotional (Metzger et al., 1997) Stroop tasks. Robust Stroop interference is also found using button press responses (Ilan & Polich, 1999; Liotti et al., 2000; West & Alain, 1999), although the magnitude of the effect is reduced compared to oral responses. Also, highly significant emotional Stroop interference using the current experimental approach has been found with a clinical (panic disordered) group (Study 4, Chapter 5). The lack of emotional Stroop effect in the current experiment with healthy

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participants is therefore not likely to be due to reduction in magnitude of effect due to use of button press rather than spoken responses.

Are sensory ERPs sensitive to effects of threat processing?

Attentional biases underlying emotional Stroop interference are predominantly assumed to operate at relatively early, largely automatic stages of information processing (Williams, Watts, MacLeod, & Mathews, 1988; Williams et al., 1997). There is clinical and experimental evidence to support this (Mogg, Bradley, Williams, & Mathews, 1993). A number of studies, however, suggest that strategic processes also play a role in emotional Stroop interference (e.g., see George et al., 1993; Kyrios & Iob, 1998; MacLeod & Rutherford, 1992; Thorpe & Salkovskis, 1997). Generally speaking, sensory ERP components (e.g., N1-P2) indicate more automatic, exogenous activity (Näätänen et al., 1982) and later components (e.g., N2, P3) more controlled, effortful and conscious stages of information processing (Hunter, Turner, & Fulham, 2001; Mangun & Hillyard, 1995; Picton, 1992).

In the current results, threat-neutral differences were evident from around 180 ms post stimulus, with larger P2 amplitudes to threat words in the right than left hemisphere across conditions, and larger P2 amplitudes to threat than neutral words in the right hemisphere during the colour classification condition. The P2 has been associated with low level processing such as stimulus classification (Crowley & Corain, 2004) and phonological processing of words (Rugg, Cox, Doyle, & Wells, 1995). The ERP results thus suggest that differences between emotional Stroop word categories may be discriminated at relatively early stages of attention during low level processing of stimuli. This is consistent with other ERP studies showing that emotion discrimination begins at early stages of word processing (Bernat, 2001; Junghöfer et al., 2001). Findings of higher right hemisphere amplitude for sensory (P2) ERPs to threat words may indicate that words with particular emotional value

attract more intense processing during a relatively early, more sensory, stage by specialised brain networks that are unevenly distributed between the cerebral hemispheres (Ortigue et al., 2004). The right-sided results for threat words may also be consistent with findings that the right hemisphere is more involved than the left in processing emotional information, and particularly negative emotional information (see Heller, Nitschke, & Miller, 1998 for a review).

It is worth noting that the small amplitude (mean $-1.2 \mu\text{V}$) of the N1 peaks in the current results raises an issue of the reliability of the measurement of this component. Bernat and colleagues (2001), however, in their supraliminal condition where participants watched mood adjectives while ERPs were recorded, found similarly small N1 amplitude using comparable word stimuli (font size and type of words) to those in the current experiment. Despite the small amplitude, N1 component peaks in the current experiment were reliably discerned at similar latencies and with similar morphology in individual participants' ERP waveforms. It is therefore concluded that the small N1 amplitudes in both Bernat et al. (2001) and the current study are likely to be associated with the nature of the word stimuli.

Overall, an integration of sensory and cognitive ERP data yields results that are consistent with information processing models of threat stimuli in the general population (e.g. Beck & Clark, 1997; Mathews & Mackintosh, 1998). These theories propose rapid, automatic assessment of the valence of stimuli (supported by the current P2 amplitude data), followed by progressive recruitment of slower, elaborative, semantic processing, under more voluntary control (supported by the current P3 amplitude data).

Is there ERP evidence of faster processing of threat words?

Preferential processing of threat words (at least in individuals high in anxiety) is assumed by some emotional Stroop theorists to take the form of faster capture of attention by S.J. Thomas et al. / International Journal of Psychophysiology 63 (2007) 221–231

those stimuli (Mathews & Mackintosh, 1998), however the speed of attentional capture can only be indirectly inferred from RTs to emotional Stroop stimuli. More rapid detection and/or processing of threat material should be associated with decreased latencies of ERP components. In the current experiment, ERP component latencies were not sensitive to threat content. Very few studies have reported latencies of ERP components to threatening information, and consistent results have yet to emerge. Some studies have reported shorter latencies of ERP components to threatening relative to positive or neutral stimuli (Carretié, Martín-Loeches, Hinojosa, & Mercado, 2001; Pérez-Edgar & Fox, 2003). Other studies have found no latency effects as a result of emotional category of stimuli (Ito et al., 1998; Weinstein, 1995). Because of the small number, and differing results, of studies reporting on ERP latencies to emotional stimuli, further research is warranted in this area.

How is threat processing affected by tasks requiring attention to different aspects of emotional Stroop stimuli?

The inclusion of a word relevant condition (Stroop, 1935) not typically seen in emotional Stroop tasks, allowed comparison of incidental attention towards threatening stimuli (in the colour classification condition) with direct attention towards threatening stimuli. This was important because the nature of the emotional Stroop task allows the possibility for participants to avoid attending to unpleasant word meaning during the colour categorisation task. In order to fully investigate effects of threat processing on ERPs, therefore, a comparison task requiring attention to word meaning is necessary.

RTs and P3 latencies were longer, and N2 amplitudes were larger overall in the word relevant than colour relevant task. N2 amplitude is proposed to reflect the activity of aspects of automatic attention based on stimulus features, but is also affected by task difficulty and response characteristics (Hunter et al., 2001; Mangun & Hillyard, 1995). Larger N2

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amplitudes, along with longer RTs and P3 latencies overall in the word classification task indicate that it was a more difficult task involving more time and attentional resources than the colour task.

The pattern of ERP results also indicates that word meaning was processed in both tasks. In the colour relevant task, right hemisphere P2 amplitude was larger to threat than neutral content. This leads to the suggestion that although participants' attention was directed away from the meaning and towards the colour of words, word meaning was nonetheless assessed and threat words received differential processing in the right hemisphere at a relatively early, automatic stage. Threat content was also associated with significantly larger P3 amplitude across tasks. Requiring participants to explicitly attend to word meaning, however, was associated with a strong trend towards further augmented amplitude of P3 to threat words, indicating apparently more intense involvement of top-down cognitive processes later in the information processing chain (Duncan-Johnson & Donchin, 1982; Picton, 1992). It is predicted that the comparison condition in which participants are forced to attend to word meaning will be of particular interest in future ERP studies of the emotional Stroop in clinical participants who show RT impairment to threatening stimuli in the colour naming task. Such comparisons would assist in differentiation between enhanced processing versus cognitive avoidance theories of Stroop interference (de Ruiter & Brosschot, 1994; Kyrios & Iob, 1998).

Conclusions

The current study was one of the first to use ERPs to explore attention during a popular research task, the emotional Stroop. Behavioural RT measures showed no evidence of attentional bias towards words rated as personally disturbing by healthy participants. ERP measures, however, showed that these "threat" words were differentially attended to. The results indicate that in this healthy group of participants, enhanced attention to threat stimuli

primarily took the form of more thorough or intense processing during higher level, controlled stages of cognition (indicated by P3 amplitude). During early (P2) processing, threat words were also associated with larger right than left hemisphere amplitude across conditions and threat > neutral amplitude differences in the right hemisphere during the colour task. Threat content was not associated with differential speed of processing (ERP latency). ERP results indicate that threat content was processed to some extent even when participants were instructed to ignore word meaning and attend to the colour of the stimuli only (the usual emotional Stroop task). When participants were instructed to attend to word meaning, effects of threat during more controlled stages of processing (P3 amplitude) were further intensified.

Results suggest that ERPs are a sensitive tool with which to explore performance in emotional Stroop tasks. Additionally they suggest that cognitive models of information processing in emotional Stroop tasks need to accommodate both relatively early, automatic and later, strategic, aspects of information processing, and to consider threat-related biases in healthy individuals. Because there is evidence that clinical groups suffer RT impairment in emotional Stroop tasks, it is reasonable to hypothesise that ERP changes associated with threat would be amplified in clinical samples. We are currently conducting a study of obsessive-compulsive and panic disordered individuals in order to investigate this hypothesis.

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Appendix A

The pool of potential threat words from which emotional Stroop threat stimuli for study 3 (Chapter 4) were drawn, mean and standard deviation (SD) of overall subjective disturbance ratings for words, frequency of use of each word as a threat stimulus, and mean and range of ratings of words where they were used as threat stimuli (where 0 is not at all disturbing, and 4 is severely disturbing).

Word	Mean overall word rating (SD)	Frequency of use as a threat stimulus	Mean rating (range) where word used as a threat stimulus
Abuse	2.5 (1.06)	16	2.76 (2)
Accident	1.18 (1.1)	6	2.50 (2)
AIDS	2 (1.27)	12	2.92 (2)
Arrest	0.82 (1.01)	1	4.00 (0)
Blasphemy	0.48 (.68)	2	2.00 (0)
Bully	1.59 (1.01)	6	2.50 (2)
Cancer	2.5 (1.34)	16	3.12 (2)
Choke	1.41 (1.3)	7	2.71 (2)
Coffin	1.5 (1.41)	9	2.67 (2)
Contaminate	1.05 (1.13)	3	2.33 (1)
Corpse	1.27 (1.52)	5	2.80 (2)
Crazy	0.59 (.85)	1	2.00 (0)
Dandruff	0.32 (.57)	1	2.00 (0)
Dangerous	0.86 (1.08)	1	4.00 (0)
Death	2.09 (1.31)	13	2.92 (2)
Debt	0.86 (.89)	3	2.00 (0)
Decayed	0.59 (.96)	0	
Defecate	0.90 (1.04)	5	2.20 (1)
Dirty	0.36 (.79)	1	3.00 (0)
Dizzy	0.27 (.55)	1	2.00 (0)
Disease	1.18 (1.01)	3	2.00 (0)
Erection	0.45 (.74)	3	2.00 (0)
Excrement	0.81 (.8)	3	2.00 (0)
Faint	0.36 (.79)	2	2.50 (1)
Festering	0.77 (.87)	1	2.00 (0)
Filthy	0.64 (.73)	0	
Funeral	1.23 (1.54)	6	3.17 (2)
Garbage	0.32 (.95)	0	

Word	Mean overall word rating (SD)	Frequency of use as a threat stimulus	Mean rating (range) where word used as a threat stimulus
Germ	0.41 (.73)	0	
Harm	0.82 (.91)	0	
Hate	1.32 (.89)	4	2.50 (2)
Hazard	0.5 (.86)	0	
Impulsive	0.09 (.29)	0	
Impurity	0.41 (.73)	0	
Insane	0.64 (.90)	2	2.00 (0)
Lethal	1.05 (1.29)	4	3.00 (2)
Lonely	1.19 (1.17)	5	2.80 (2)
Muggers	1 (1.02)	4	2.50 (2)
Murder	1.91 (1.48)	15	2.73 (2)
Painful	1.14 (1.04)	2	3.00 (2)
Palpitation	0.73 (1.08)	0	
Panic	1.09 (.92)	2	2.00 (0)
Poison	0.86 (1.21)	1	2.00 (0)
Prostitute	0.27 (.55)	1	2.00 (0)
Punishment	0.27 (.46)	1	2.00 (0)
Rejected	0.82 (1.05)	1	4 (0)
Secretion	0.36 (.49)	0	
Sewage	0.41 (.73)	0	
Sex	0.18 (.59)	1	2 (0)
Sick	0.41 (.59)	0	
Sperm	0.27 (.55)	1	2 (0)
Stress	0.72 (1.16)	3	3 (2)
Suffocate	1.5 (1.14)	3	2.33 (1)
Threaten	1 (1.07)	1	2 (0)
Torture	2.18 (1.53)	12	3.25 (2)
Tumour	1.45 (1.34)	7	2.86 (2)
Unclean	0.23 (.53)	0	
Urine	0.36 (.66)	1	2 (0)
Violence	1.5 (1.22)	6	2.17 (1)
War	2.32 (1.39)	16	2.63 (2)

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