7 GENERAL DISCUSSION

The primary purpose of this thesis was to investigate the scalp topography of attention and working memory for visual words in PTSD. This is the first work to demonstrate abnormal scalp activity related to visual linguistic information in PTSD. It is a clear extension of previous work on auditory ERPs (e.g., McFarlane et al., 1993), with more precise investigation of the component processes of selective attention, stimulus evaluation, working memory updating and target detection.

7.1 SUMMARY OF FINDINGS

7.1.1 Behavior

The behavioral data indicated slower and less accurate responses in PTSD, for both tasks, although the PTSD patients had greater difficulty with the demands of the variable target task. The behavioral data alone do not clearly identify components of executive functions; they simply implicate deficits at some stage of the stimulus-response processing stream. The greater difficulty with the variable target task suggests deficits in working memory processes. The ERPs provide greater insight into several components of executive functions: selective attention, working memory, and target detection.

7.1.2 Selective Attention: Early Color Discrimination

The early visual discrimination of relevant information from a variety of distracting features can be defined by elementary visual features, such as color, orientation, shape, location and motion. In this study, selective attention was required for colored words.

Early attention effects are indicated by enhanced ERP activity in an occipital N150, a superior frontal P150 and a posterior temporal N180. This enhanced activity indicates early visual discrimination of the attended stimuli, which is consistent with previous visual attention studies (Hillyard & Munt, 1984; Wijers et al., 1989a, 1989b, 1989c; Anllo-Vento et al., 1998; Hillyard & Anllo-Vento, 1998; van der Stelt et al., 1998; Valdes-Sosa et al., 1998; Smid et al., 1999). The findings of neuroimaging studies indicate activity in the primary visual cortex within 60-120 ms and color processing in the inferior occipital fusiform area (V4) within 100-150 ms (Buchner et al., 1994; see also Di Russo et al., 2001; Foxe & Simpson, 2002; Damasio et al., 1980; Lueck et al., 1989; Zeki et al., 1991; Allison et al., 1994; Vaina, 1994; Clarke et al., 1995; Sakai et al., 1995; Komatsu, 1998; Lamme et al., 1998; Mesulam, 1998; Chao & Martin, 1999; Martinez et al., 1999). Given that attention effects are identified in both posterior visual areas and frontal areas, this study lends some support to the theory that frontal attention systems are engaged in early modulation of visual processing (e.g., Foxe & Simpson, 2002; Giesbrecht et al., 2003).

Furthermore, this early visual processing was greater during demanding working memory processing, indicated by larger activity in posterior temporal P90, occipital N150 and a superior prefrontal P150 for attended common words in the variable target task. Similarly, there is enhanced target activity in the occipital, posterior temporal and prefrontal regions between 80-250 ms (in the fixed target task). These results indicate the influence of greater allocation of cognitive resources to early visual processing during working memory and target detection processes. Early visual discrimination effects are found during attention studies (e.g., Foxe & Simpson, 2002), but not during working memory studies (e.g., Rösler et al., 1985; Gevins et al., 1996). These components suggest that there may be parametric modulation of early visual processing

that is related to the relevance of stimulus attributes, effectively facilitating their further processing (see Desimone & Duncan, 1995; Giesbrecht et al., 2003).

There is no evidence in this study of abnormal early visual processing in PTSD; there were no abnormalities of occipital, posterior temporal or frontal activity before 200 ms. This finding is consistent with many previous ERP studies of neutral auditory processing in PTSD, which indicate no abnormality of sensory cortical responses measured by N1 or P2 ERPs (McFarlane et al., 1993; Charles et al., 1995; Metzger et al., 1997; Galletly et al., 2001; cf. Felmingham et al., 2002). However, it is possible that there are early deficits that are beyond the sensitivity of this study to identify. Several studies designed to evaluate early sensory gating have identified abnormal activity in PTSD (Paige et al., 1990; Neylan et al., 1999).

7.1.3   Selective Attention: Word Form Processing

There were indications of stimulus discrimination at 250-300 ms in the selective attention study. An occipital P250 (235-260 ms) is smaller for attended words, which is clear in a posterior temporal ND250 (265-290 ms). Similar attention effects have been reported as the negative difference component (Nd, Näätänen, 1992) or selection negativity (SN, e.g., Anllo-Vento et al., 1988; see also Kellenbach & Michie, 1996). In this study, the discrimination at this latency should involve both visual attention and the initial analysis or evaluation of the attended words. The orthographic encoding of visual word features at 150-250 ms is associated with activity in the fusiform and lingual gyri, which could interact, in parallel, with color processing in the same cortical areas (Petersen et al., 1993; Allison et al., 1994; Nobre et al., 1994, 1998; Halgren et al., 1994; Kuriki et al., 1998; Schendan et al., 1998; Smid et al., 1999; Cohen et al., 2000; Rao et al., 2003). This cortical activity might project to the occipital and posterior temporal scalp regions, where this study identifies these ERP effects. The greater

magnitude of the effect in the left hemisphere suggests that linguistic processes are engaged (cf., Gevins et al., 1995).

The attention effects in the posterior temporal ND250 are smaller in PTSD. This finding complements previous reports of abnormal N2 ERPs for rare stimuli (e.g., McFarlane et al., 1993; Galletly et al., 2001; Felmingham et al., 2002). In this case, the results indicate deficits in visual discrimination and early stages of linguistic processing.

7.1.4 Stimulus Evaluation

Once attended words are discriminated from unattended words on the basis of physical qualities, they are further processed, including comparison with a target representation. The attended non-target words should demonstrate activity related to an evaluation stage, with no further activity, such as target recognition and response initiation (no responses were required for the non-target events). The evaluation processing is most clearly apparent in ERP activity between 300-600 ms, with similar qualities to conventional P3 ERPs.

There are prominent stimulus evaluation effects in the frontal and parietal P350 and P450 ERPs, with associated PD450 in the attention difference waves (see also Kellenbach & Michie, 1996). There were similar effects in the SCD activity. These scalp components from 350-500 ms indicate the evaluation of attended non-target words in working memory. The parietal and frontal activity could arise from executive systems of a distributed, associative network, including areas of frontal and parietal cortices, which have been demonstrated in neuroimaging studies of attention and working memory (e.g., Posner & Raichle, 1994; Clark et al., 2000, 2001). In this case, however, the activity is essentially related to stimulus evaluation, as the task design entails no involvement of working memory updating or any target recognition or response processing.

There is abnormal activity in PTSD for the frontal P400 ERP and the frontal and parietal P450 SCD, which were clearly evident in the PD450 ERP/SCD over frontal regions at 440-480 ms. These results confirm a specific deficit of stimulus evaluation in PTSD (see also McFarlane et al., 1993; Charles et al., 1995; Metzger et al., 1997; Galletly et al., 2001).

7.1.5   *Working Memory Updating*

In addition to selective attention and stimulus evaluation, the variable target task requires updating of target attributes whenever an attended non-target word appears. These words and the attended common words of the fixed target task engage stimulus evaluation processing, but only the former also engage working memory updating, because the new information they convey defines the target properties in further task processing. These attended words are separated by several unattended words, so that they must be retained in working memory for 1.6 to 6.8 sec (cf., Galletly et al, 2001). Similar studies demonstrate working memory activity for non-target events that are evaluated and retained for successful task performance (Rösler et al., 1985; Gevins et al., 1996). That work demonstrates greater scalp activity over frontal, parietal and occipito-temporal regions at 400-800 ms (Rösler et al., 1985; Gevins et al., 1996). Studies of working memory in PTSD have demonstrated abnormal performance in neuropsychology tasks and some evidence of abnormal ERPs (Everly & Horton, 1989; Bremner et al., 1993; McFarlane et al., 1993; Charles et al., 1995; Metzger et al., 1997; Galletly et al., 2001).

The largest effects of working memory updating are identified in scalp potentials after 250 ms (words appeared for 200 ms), including a posterior temporal N300 (295-305 ms), a superior frontal P400 (380-420 ms) and a superior parietal P550 (515-560 ms). These effects indicate the extra activity engaged during the integration and updating of working memory representations. There are indications of visual word

encoding in posterior temporal regions, followed by associative activity at frontal and parietal areas. Gevins et al. (1996) also found earlier frontal than parietal activity; they propose that frontal activity indicates the acquisition and evaluation of information in working memory, which engages reciprocal interactions with the later parietal activation in the process of sustaining attention to the information retained in working memory. The effects identified in this study reflect additional processing to any stimulus evaluation processing and they are not related to target recognition or response activation.

There are deficits of in working memory updating in PTSD. Firstly, the superior frontal P400 is delayed, which indicates less activity during the integration of new information into working memory. This effect is coupled with a diminished parietal P550 in PTSD, which indicates a deficit in the sustained attention and retention of the new information in working memory. These effects in the P400 and the P550 are clearly indicated in the PD550, which is smaller in PTSD over both the superior prefrontal and the left superior parietal regions. These findings confirm the indications of working memory deficits in previous ERP work, which demonstrates abnormal frontal slow wave activity during working memory processing (Galletly et al., 2001). This work also confirms neuropsychology studies that demonstrate impaired verbal working memory (Gil et al., 1990; Sutker et al., 1991; Bremner et al., 1993; Uddo et al., 1993). The ERP findings of the present study demonstrate the temporal dynamics of fronto-parietal abnormalities in PTSD during the integration of new information into working memory representations (see the PET findings in Shaw et al., 2002; Clark et al., 2003). Thus, the weight of evidence clearly indicates a limited capacity to integrate information into verbal working memory.

7.1.6   Target Recognition and Response Processing

In the fixed target task, responses are required for a specific word in the attended color. So, in addition to selective attention and stimulus evaluation, the attended target words elicit greater word recognition and motor response activity. Previous reports demonstrate perceptual implicit recognition evokes parietal ERP activity at 300-500 ms, which can be accompanied by frontal explicit recognition activity, while greater depth of processing elicits later parietal activity (Fabiani et al., 1986; Rugg et al., 1998). Similar components in this study were expected to demonstrate abnormal activity in PTSD. Also, response activation was expected in scalp activity in the left fronto-central region, with delays expected in PTSD (based on McFarlane et al., 1993).

7.1.6.1   Initial Target Discrimination

There is clearly enhanced activity for targets in a left posterior temporal N300 ERP (& ND300 ERP). This is the first stage where target words are most clearly distinguished from attended common words and it is linearly related to reaction time, which suggests this stage is critical for target recognition and response processing. At this latency, visual word form processing is complete (e.g., Nobre et al., 1994; Halgren et al., 1994; Cohen et al., 2000) and semantic encoding processes are engaged (Petersen et al., 1990; Nobre et al., 1994; Buckner & Koutstaal, 1998; Cohen et al., 2000). This discrimination processing appears to be a parametric modulation; the ERP waveforms in the left hemisphere at 200--400~ms are smallest for unattended commons, larger for attended commons and largest for attended targets.

There is abnormal activity in this posterior temporal activity at 200-300 ms in PTSD. This suggests deficits in the initial linguistic encoding of target words, prior to further evaluation and recognition of target stimuli. This abnormal word processing is clear in both the selective attention and the target detection contrasts of this study.

Deficits in this activity may parallel findings of abnormal auditory discrimination, indicated by the N2 ERP (e.g., McFarlane et al., 1993).

7.1.6.2   Target Recognition

The pattern of activity for the N300 ERP indicates discrimination of the significant target event and it precedes larger positive components that indicate target recognition. At 400-500 ms, there is enhanced positive activity in parietal ERPs and the SCD difference waves at prefrontal and posterior regions. This activity resembles conventional P3 ERP activity, but there are parallels in the activity of this study with results from word recognition studies, which demonstrate enhanced positive ERPs in frontal and parietal areas for recognized words (e.g., Fabiani et al., 1986; Rugg et al., 1998). These large positive components precede motor responses, which are associated with large negative SCD over the left fronto-central area, with enhanced target activity. A parietal P700 ERP (& PD700 ERP) indicates further associative linguistic activity or the consolidation of the target representation. The task requires constant maintenance of a target representation in working memory, so the occurrence of any target event could both refresh and consolidate that representation.

There is diminished prefrontal activity at 250-450 ms in PTSD. This suggests a failure of frontal executive systems to become involved in target processing. This deficit might have been compensated by larger positive activity at posterior regions. Controls demonstrate similar amplitude at frontal and parietal areas, with earlier onset of frontal than parietal activity, while the PTSD patients demonstrate much greater parietal than frontal activity. This pattern of activity suggests there is a deficit in visual, linguistic processing and associated frontal executive engagement; PTSD patients may rely on more visual feature processing and implicit target recognition strategies (see associated PET results; Shaw et al., 2002; Clark et al., 2003; see also van der Kolk,

1997). However, this strategy is less efficient and less accurate than more controlled linguistic processing.

7.1.6.3   Response Activation

The ND350 – ND600 SCD are located over left motor cortex (for right handed responses) and they appear to be larger for controls early (300-400 ms), while larger for PTSD patients later (400-600 ms). This delay in the scalp components is consistent with the delays identified in response times.

7.1.7   Summary and Conclusions: Executive Deficits in PTSD

The first indications of abnormal activity in PTSD arise at 200-300 ms in the left posterior temporal region during stimulus discrimination and target recognition. Further deficits in executive systems are identified in frontal and parietal scalp activations during attended word processing at 300-600 ms. In the initial evaluation of an attended non-target word, PTSD patients demonstrate deficits in frontal and parietal regions at 400-500 ms. During the updating of working memory (where attended non-target words are required for further target recognition in the variable target task), the PTSD group demonstrate a delay in frontal activation, followed by smaller activity in parietal areas, at 400-600 ms. These findings suggest impaired evaluation and integration of new information in working memory. During target word recognition, PTSD patients demonstrate deficits in frontal activity and much greater occipital and parietal activity. This pattern of activity suggests failure in frontal executive systems, with greater dependence on visual processing for effective target detection (see associated PET results; Shaw et al., 2002; Clark et al., 2003). These findings from scalp recorded electrical potentials indicate that delayed and inaccurate responses during these simple tasks are related to fundamental abnormalities of executive systems.

These findings bear important similarities with previous findings of deficits in N2/P3 activity in PTSD (McFarlane et al., 1993; Charles et al., 1995; Metzger et al., 1997; Kimble et al., 2000; Galletly et al., 2001; Felmingham et al., 2002). These studies suggest impaired auditory discrimination, stimulus evaluation or context updating for infrequent target or distracter stimuli (e.g., Donchin & Coles, 1988). This study examines each of these component processes and clearly identifies abnormal stimulus discrimination, evaluation and working memory processes. In addition, the findings here apply to frequent events that do not startle or indicate any degree of novelty or threat. That is, this study has identified impairment in visual stimulus discrimination, evaluation and working memory for common neutral words. The functional implications of these findings could be more significant than previous findings related to infrequent events. More than previous findings, these results indicate general deficits in executive systems that have an impact on all stimulus processing activities, for both common and rare target events.

Previous electrophysiological studies of cognition in PTSD have employed simple auditory tone and visual pictorial stimuli, which may be processed at the level of perceptual awareness (e.g., McFarlane et al., 1993; Galletly et al., 2001). The stimulus material of this study encourages more complex linguistic encoding, which is more demanding on executive functions. This study measures the topography of specific temporal components of attention and working memory for visual linguistic information processing. The current findings confirm neuropsychological studies of PTSD that have also found deficits of attention and memory for linguistic information (Gil et al., 1990; Sutker et al., 1991; Bremner et al., 1993; Uddo et al., 1993; Yehuda et al., 1995). Abnormal executive cognition is implicated by not only symptoms of poor concentration and difficulty assimilating new information, but also abnormalities of

long-term memory retrieval that play an important part in intrusive cognitions (e.g., Yehuda et al., 1995).

This study provides insight into the temporal components and the possible neurological sources of attention and working memory in PTSD (see also Shaw et al., 2002; Clark et al., 2003). The executive attention and working memory processes arise from complex interactions between nodes of a parallel processing system that comprise primarily the temporal, parietal and frontal cortex (see Goldman-Rakic, 1990; LaBerge, 1990, 1995; Fuster, 1991, 1993, 2000; Goldman-Rakic & Friedman, 1991; Posner, 1992; Goldman-Rakic et al., 1993; Posner & Raichle, 1994; Petrides, 1994; Desimone & Duncan, 1995; McCarthy, 1995; McIntosh et al., 1996; Ungerleider et al., 1998; Rolls, 2000; Cabeza & Nyberg, 2000; Miller & Cohen, 2001; Miller & Asaad, 2002; Barbas et al., 2002; Cohen, 2002). Although the cognitive design of the present work has attempted to isolate specific components of linguistic processing and modulation of such by attention and working memory, the scalp activity raises questions about the physiological systems that generate the signals and whether these systems can be examined as discrete, isolated components. There are reasonable models of the physiological systems that generate attention and working memory processes. Many of these models have been discussed in the present work. The following discussion highlights an aspect of these models that could have important implications for abnormal activity in PTSD.

7.2 ABNORMAL COGNITIVE INTEGRATION IN PTSD

Attention and working memory systems appear to engage a distributed network of activity, including occipito-temporal, parietal and frontal regions, in strategic information processing. The integration of activity in these systems may involve synchronization of cortical activity (e.g., Basar et al., 2000; Varela et al., 2001; Rennie

et al., 2002; Wright et al., 2003). In particular, reports demonstrate the modulation of power in the theta frequency band (4-7 Hz) during working memory processes, which engage a distributed neural network, including cortical and medial temporal regions (Sarnthein et al., 1998; Yordanova & Kolev, 1998; Jensen & Tesche, 2002; see also McIntosh et al., 1996; Büchel & Friston, 1997; Tesch & Karhu, 2000). The hippocampus and parahippocampal cortex generate theta oscillations that could play an important role in the integration of association cortex during working memory and episodic memory processes (Eichenbaum & Otto, 1993; Okada, Kaufman & Williamson, 1983; Klimesch et al., 1994; Iijima et al., 1996; Sarnthein et al., 1998; Nadel & Moscovitch, 1998; Stern et al., 2001). If this system of coherent activity is disrupted by neuropathology of hippocampus circuits, the ability to create coherent, dynamic representations of experience will be impaired.

The perception and assimilation of new information is a creative process (e.g., Kant, 1781, 1901). The integration of distributed network activity is a possible mechanism of this creation or binding of experience (e.g., Triesman, 1996). With respect to the coherent spatio-temporal quality of experience, a likely physiologic explanation involves the hippocampus and parahippocampal networks (see Eichenbaum & Otto, 1993; Nadel & Moscovitch, 1998). Firstly, the distributed network systems engaged in working memory processes could be regulated by hippocampal theta rhythms. These rhythms may provide a timing device into which information can be arranged, providing a temporal organization to experience. If this is the case, given adequate sensory temporal resolution, the human capacity to discriminate temporal deviations in higher order perceptual experience may coincide with theta oscillations. Secondly, the hippocampus and parietal cortex are involved in the generation of spatial coordinate systems, providing a capacity to locate perceived objects in spatial relationships. Thus, this system of coherent distributed network activity may provide a

spatio-temporal framework into which current perceptions are integrated, along with memories of previous experiences (e.g., Baddeley, 1992). This spatio-temporal framework is the most elementary level of organization for information processing.

The experience of a traumatic event interferes with the capacity of this system to operate freely, providing an impetus for dissociation of the coherent spatio-temporal integration of experience. Trauma is often described as an overwhelming experience, often "time stands still" as the cognitive system enters a heightened state of arousal and attention. The events of an incident may appear to occur in slow motion, as if the cognitive system suddenly engaged all its resources for perceptual integration and discrimination. However, this state of pensive attention immediately prior to a traumatic incident is overwhelmed by intense emotional reactions to an aversive outcome. The intense emotion initiates a rift in the coherence of experience. The dramatic change in affective state cannot be integrated with experience prior to the trauma and learning processes engage indelible encoding processes (see LeDoux, 1990, 1995, 2002; cf. Pitman, 1989; Pitman et al., 2002; Vaiva et al., 2003). Some time after the trauma, traumatic emotions may be triggered by cues that are associated with the traumatic event, generating intense experiences that are incongruent with otherwise neutral environments. This discrepancy between intrusive traumatic recollection and otherwise normal circumstances requires resolution, yet the power of the emotions may exceed the capacity to ignore, inhibit or rationalize them. The incongruent experiences can interfere with ongoing actions, also generating acute distress and heightened self-awareness. The inability to resolve this discrepancy and the persistence of intrusions may generate further feelings of distress and helplessness. In the presence of others, obvious distress may provoke embarrassment, with associated avoidance and withdrawal from explanation of their distress, possibly leading to agoraphobia and panic states.

The episodic encoding of experience involves amygdala, hippocampal and parahippocampal circuits that are controlled, to some degree, by frontal executive systems. The lack of control over the trauma and the associated encoding of that experience, together with further intrusive recollection, may lead to a perceived lack of control over not only the external environment, but also the integrity of memory systems. Extra effort is required of executive systems to regulate recollection, which is normally an automatic associative process that provides a complex spatio-temporal record of life. At the point of trauma, this record is interrupted and the capacity to maintain the integrity and coherence of that record is challenged. The resolution of this challenge to the integrity of mind is critical for further adaptive action.

It is not possible to avoid encoding and associative integration processes, these activities operate largely below the level of conscious control (see 'ecphory' in Moscovitch, 1992). However, it may be possible to control, to some extent, the information going into and coming out of the episodic memory system. Hence, executive control may focus on (a) avoidance of any cues that might provoke trauma recollections and (b) inhibition of any trauma content recollected. As the purpose of the episodic memory system is to provide a rich tapestry of associative experience, organized by spatio-temporal relationships, the avoidance process is very difficult. The extent of avoidance necessary may interfere with not just the trauma recollection, but possibly the general processing of all experience. The capacity for traumatic experience to generalize to diverse circumstances is not only a process of instrumental learning, but also an integral component of the cognitive system that seeks to organize experience into coherent spatio-temporal relationships. The executive system in PTSD could be constantly engaged in checking and cross checking of current experience and any associated recollection, in an attempt to avoid or control aversive emotional reaction. The administration of medications that enhance the capacity of this executive system,

such as prozac, provide some extra energy into this process, enhancing the capacity of the executive control systems, but they cannot change the cognitive strategy employed by these systems to cope with the traumatic memory.

Perhaps these executive control processes exhaust the capacity of the system to maintain speed and accuracy of normal cognitive processes. At the point where current experiences are integrated with previous memories, the cognitive system is struggling to overcome a potential rift in the spatio-temporal dynamics of life. This process may be unconscious, a result of extreme tensions in physiological processes, yet the effect of this struggle is noticed in less capacity for attention and concentration, memory lapses, intrusions, etc. The ability to resolve the trauma depends critically on the capacity to effectively integrate the event into a life story while resolving the associated emotional distress. This is largely the realm of cognitive behavioral therapy, but this work must depend on appraising the integrity of fundamental physiological processes.

Cognitive neuroscience may provide not only a better understanding of PTSD, but also an opportunity for pharmacological intervention (e.g., Pitman et al., 2002; Vaiva et al., 2003). If these aspects of PTSD can be related to abnormal activity of the hippocampal system and related episodic and working memory processes, medical intervention into hippocampal systems may provide a means to avoid the condition or provide greater control over memory systems. For instance, a pharmacological intervention may provide a means for early intervention that interferes with the consolidation of episodic memory, which can take hours or days (consider Pitman et al., 2002; Vaiva et al., 2003). However, it is still important to characterize the nature of the impairment and investigate means of intervention that may not impair the cognitive system. The hypothesis that hippocampal circuits are impaired in PTSD is supported by evidence of diminished volume, but the functional integrity of the hippocampus has not been directly investigated. The evidence for abnormal working memory processes

implies some disintegration of distributed neural network functions, but a likely source for this disintegration is the medial temporal limbic and paralimbic systems.

There are several predictions to be tested. Firstly, that functional neuroimaging of hippocampal circuits may reveal abnormal activity. To date, unlike studies of amygdala activity during panic and trauma imagery, studies of neutral information processing have not directly assessed hippocampal functions. In particular, it would be valuable to assess the integrity of hippocampal processes for novelty detection and contextual evaluation (consider Dolan & Fletcher, 1997; Dolan, 2000). Secondly, the hippocampal and parahippocampal circuits may not provide an effective theta rhythm for regulation of coherent network activity. We might expect that distributed systems engaged in working memory processes are not operating coherently, which might be measured by EEG coherence studies or multivariate analyses of neuroimaging studies (consider McIntosh et al., 1996). This disruption in the coherent operation of working memory systems might be manifested by various cognitive anomalies, many of which have been documented in neuropsychology and ERP studies. The most dramatic manifestations may be the dissociative states, which indicate a severe distortion of spatio-temporal perception.

There are several recent reports that lend some support to the importance of coherent spatio-temporal experience in PTSD. Firstly, a study of auditory P3 in PTSD shows greater deficits among highly dissociative cases, which suggests that P3 is related to the spatio-temporal coherence of experience (Kaufman, 2002). Secondly, there may be greater variability in the amplitude and especially the latency of P3 ERP components in PTSD (see, Neylan et al., 2003). Lastly, an associated PET study of this work has found abnormal coherence in fronto-parietal regions (Shaw et al., 2002; Clark et al., 2003). However, these studies do not directly assess the contribution of medial temporal areas to this abnormal activity and they do not clearly identify any abnormal

theta oscillations. Further investigation of theta oscillations in PTSD will provide more direct evidence of abnormal network interactions and their relationships with symptom severity.

7.3 ONTOGENESIS OF EXECUTIVE FUNCTION DEFICITS IN PTSD

The present study cannot clarify whether cognitive disorder is a precondition or a consequence of PTSD. It is clear that the concentration and distraction symptoms of PTSD may arise from specific deficits in attention and working memory processes. Also, the capacity to control and avoid traumatic intrusions may depend on the integrity of these executive functions. It is most likely that executive disorders arise only after a traumatic experience; otherwise it might be clear that PTSD is associated with lower levels of education or occupational status. Rather, it is most likely that normal cognitive and neurological activity is disturbed by trauma. Another possibility is that PTSD occurs only in those who are predisposed to executive dysfunction, including neurological conditions and habitual patterns of cognition. In this case, the excessive demands of traumatic cognitions overwhelm a cognitive system that is already susceptible. Some evidence suggests abnormal hippocampal volume is a predisposition to PTSD (Gilbertson et al., 2002). However, this evidence is primarily related to chronic PTSD. In this case, there may be some degree of predisposition, but it is not clear what proportion of cases this would cover.

7.4 ECOLOGICAL VALIDITY OF THE FINDINGS

Patients did perform the simple tasks of this study adequately. Although their responses were less accurate and slower than controls, they were sufficient to complete the task. It is likely that the cognitive abnormalities identified in this study are not clearly apparent and do not adversely effect overt performance under simple

circumstances. However, abnormality of the essential cognitive processes examined in this study can be magnified in complex circumstances. As the complexity of stimulus discrimination and contextual evaluation increases, the cognitive performance of patients will decrease to a level that overt behavior exhibits performance deficits. For instance, patients often report difficulty concentrating when confronted with decisions in complex stimulus environments, such as supermarket isles, negotiating crowded shopping malls, sporting arenas or road traffic conditions. Given the cognitive impairments with linguistic information demonstrated here, patients may also demonstrate performance deficits in large group discussions or when reading demanding discourses. In contrast, patients report feeling more relaxed and contented when carrying out routine activities, such as gardening. These tasks are inherently familiar and safe; they do not require evaluation of novel or threatening information.

In this light, it is noteworthy that executive processes are impaired under stressful conditions. Increases in catecholamines during stressful events increase cognitive and visceral arousal, especially in the executive systems of the frontal lobes. Without experience making decisions under stressful conditions, it is easy to be distracted by excessive responses to stimulus information and unusual visceral feelings of excitement or stress. This normal reaction to stressful conditions is a chronic, debilitating condition of PTSD. This study was careful to ensure that patients rated all stimulus materials presented as neutral. There were no surprises for them in the stimuli presented, as the stimuli were presented and rated before the experiment. Despite the neutrality of the stimulus material, patients demonstrate impaired cognitive responses.

7.5 RESEARCH DESIGN CONSIDERATIONS AND FUTURE RESEARCH

Longitudinal Research: The present study is a cross-sectional design that cannot provide useful insights into the development of cognitive dysfunction in PTSD.

Longitudinal research of public and armed services recruits could provide a useful first step toward understanding whether these cognitive deficits are a predisposition or a result of trauma.

PTSD diagnosis: This study investigated male and female patients with various trauma exposures, including combat and various civil traumas, often incurred during public service duties. The study was careful to avoid comorbid conditions, such as panic attack and depression (although there was considerable depression in the patient group). The results demonstrate that avoidance and intrusive symptoms have an impact on cognition, so further work, especially studies of novelty, should be careful to quantify these symptoms and to report associations between symptoms and ERP measures (see Felmingham et al., 2002). Also, a recent study indicates that dissociative symptoms are a further important aspect of the diagnosis (Kaufman, 2002).

Control groups: This study employed a non-trauma control group (i.e., they had no exposure to any trauma). PTSD research often employs control groups who have some trauma exposure (e.g., combat veterans without PTSD). The replication of the present work with any combat veterans might evaluate whether these effects are still observed with a combat exposed control group.

Depth of Processing: This study employed linguistic stimuli to facilitate encoding and evaluation processes that are not elicited by simple auditory tones or visual shapes. An important problem when using linguistic stimuli is the control or manipulation of the depth of stimulus information processing (see Craik & Lockhart, 1972; Craik & Tulving, 1975; cf. Baddeley, 1978). Target detection might be based on simple stimulus features, such as color and letter shapes. On the other hand, stimulus encoding and target detection may involve complex linguistic features, such as lexical structure or semantic content. The task design of this study might be further developed by an additional manipulation of the depth of processing required. If targets were defined by

semantic categories (e.g., animals), stimulus evaluation and target detection processing would necessitate semantic encoding and associative processing. This design would necessitate a greater depth of processing than that required in previous studies of selective attention and evaluation processing, which often employ simple auditory tones or visual letter or number stimuli. The additional depth of processing allows analysis of selective processing activity at both early stages of visual detection and perceptual encoding, as well as later stages of semantic processing. It may be assumed that automated linguistic habits for semantic encoding are engaged in the present study, but a simple task manipulation could ensure that this is the case.

Neurochemistry and Brain Imaging: Further work must evaluate the relationships between pharmacological treatments for PTSD and cognitive functions. New avenues for prevention of PTSD are arising (e.g., Pitman et al., 2002; Vaiva et al., 2003) and it would be interesting to know the relationships between pharmacology and cognition in PTSD (e.g., Pitman, 1989). Of particular interest are the initial stages of traumatic experience and memory consolidation, including the relative importance of amygdala and hippocampal circuits and their interactions. In particular, it could be interesting to identify pharmacological manipulations of hippocampal theta.

The present study involved abstinence from psychoactive medications for at least two weeks prior to the data acquisition. The complex physiological adaptations to medication might be disrupted by this intervention. This is an important limitation of this study; the group differences observed here may be attributed to physiological changes during and after a traumatic incident and further modulation of those changes by medications. It would be interesting to assess effects of medication on ERP components before, during and after medication trials in patients who have never been medicated.

Neuroimaging Methods: The advantages of ERP methods are primarily the ability to focus on single stimulus types, such as non-target and target stimuli, and the fine temporal resolution of component processes. Some event-related fMRI techniques can now approach the capacities of ERP methods, but they are currently restrained by the relatively slow changes in haemodynamic activity during event-related processing. Alternatively, to improve the spatial resolution of ERPs, the scalp activity can be combined with physical head models, derived from anatomical MRI, to obtain cortically constrained source dynamics. This provides access to electromagnetic source activity that may be more closely coupled to brain electrical activity than haemodynamic measures (e.g., Clark et al., 2001; Moores et al., 2003). At the time this study was conceived, fMRI techniques were in their infancy and event-related fMRI did not exist. This ERP study was conducted in concert with a PET investigation, which has been reported already (Shaw et al., 2002; Clark et al., 2003). Further work at the Flinders University of South Australia is now investigating the integration of ERP and fMRI measures of cognition, with application to PTSD.