RESPONSE CHOICE, EMOTION, AND PSYCHOPATHY

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Abstract

Two broad classes of system regulate behavior: those that regulate behavior in response to affect-neutral task demands (classic executive functions) and those that regulate behavior according to reinforcement history. As discussed in Chapter One, psychopathy has been suggested to be the developmental consequence of both. In Chapter Two, I explore several manipulations of an executive measure: the parametric Number Stroop paradigm. In Chapter Three, I apply this measure, together with the Object Alternation (OA) and Spatial Alternation (SA) tasks to individuals with psychopathy. Individuals with psychopathy presented with difficulty only on the OA task adding to suggestions that the disorder is associated with difficulties choosing between objects associated with different levels of reward/punishment. This hypothesis is explored further through the use of a novel paradigm, the Differential Reward/ Punishment Learning Task in Chapter Four. Data from this task suggested that individuals with psychopathy face particular difficulty with objects associated with punishment. In Chapter Five, I further explored the processing of stimuli associated with reward/punishment in individuals with psychopathy through the use of an affective priming paradigm. In Chapter Six, I explore the interaction of systems regulating behavior in response to affect-neutral task demands and those involved in processing emotional stimuli through the use of the Affective Number Stroop paradigm. I demonstrate the effects of emotional stimuli on executive processing as well as the effects of executive processing on emotional processing. In Chapter Seven, I describe potential future directions for this work.
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Chapter One
The Regulation of Response Choice and Psychopathy

1.1.: Introduction

Poor response choices can have dire consequences. Consider the following.

'Police said a lawyer demonstrating the safety of windows in a downtown Toronto skyscraper crashed through a pane of glass with his shoulder and plunged twenty-four floors to his death. A police spokesman said Garry, thirty-nine, fell into the courtyard of the Toronto Dominion Bank Tower as he was explaining the strength of the building's windows to visiting law students by running against the windows. Garry had previously conducted the demonstration of window strength without mishap, according to police reports. The managing partner of the law firm that employed the deceased told the Toronto Sun newspaper that Garry was "one of the best and brightest" members of the two-hundred-man association (Toronto, 1996)'. Garry became a 1996 Darwin Award Nominee; an award that posthumously honours those who improve our gene pool by removing themselves from it.

Every day we face a multitude of decisions, and the ways in which it is possible to make a poor choice have become increasingly varied and colourful. However, generally speaking and not considering Garry, humans tend to engage in generally advantageous behaviours in their interactions with the environment. Most of us entertain goals that do not involve a compelling need to test the efficacy of bullet safe vests, shark repellent sprays, or the strength of reinforced windows, and, should we have these goals, we would warn ourselves away from behavioural choices that might be harmful. But why? Because we have systems that regulate and guide our behaviour. Importantly, there are at least two types of system that regulate our behaviour. One type of system regulates our behaviour according to task demands or goals that are relatively affect-neutral way. The second type of system regulates our behaviour according to reinforcement history and allows decision making on the basis of likely rewards and punishments for particular behavioural choices in particular situations. There are various types of psychiatric disorders that are associated with disruption to one or both types of
system. Examples include schizophrenia (Hugdahl, Rund et al. 2003; Pukrop, Matuschek et al. 2003; Sharma and Antonova 2003), Autism (Hughes, Russell et al. 1994; Bennetto, Pennington et al. 1996; Gilotty, Kenworthy et al. 2002), Attention Deficit Hyperactivity Disorder (Gioia, Isquith et al. 2002; Rucklidge and Tannock 2002; Wu, Anderson et al. 2002), Depression (Lockwood, Alexopoulos et al. 2002; Porter, Gallagher et al. 2003) and Psychopathy (Gray 1972; Fowles 1980; Gorenstein 1982; Fowles 1988; Newman, Schmitt et al. 1997).

In this chapter, I am going to discuss several models of executive functioning and emotional learning. This, of course, will not be a complete review of the field. Its purpose is only to introduce models that have been, or can easily be, considered in reference to the psychiatric disorder that is the focus of this thesis: Psychopathy.

1.2.: Executive Functioning

Executive functions refer to the processes that underlie flexible goal-directed behaviour, e.g., inhibiting dominant responses, creating and maintaining goal-related behaviours, and temporally sequencing behaviour (Burgess et al. 1998). Impairment of executive functions is associated with damage to prefrontal areas (Luria 1966; Fuster 1980; Baddeley and Della Sala 1998). Moreover, neuropsychological, functional imaging, and animal lesion evidence suggest that different aspects of executive functions are dissociable and mediated by distinct neural systems subserved by different regions of the prefrontal cortex (Luria 1966; Fuster 1980; Roberts, Robbins and Weiskrantz, 1998; Shallice 1988; Baddeley and Della Sala 1998). Thus, DLPFC cortex has been linked to executive functions such as the ability to plan, monitor and inhibit pre-programmed behaviour (Smith and Jonides 1999). The ventromedial/OFC has also been implicated in inhibitory control but appears to be more associated with learning to inhibit a response that is no longer rewarded but now punished (Damasio 1994; Dias, Robbins et al. 1996; Rolls 1997). Anterior cingulate has similarly been associated with response inhibition, and more specifically in the response selection in the presence of conflicting information or competing sources of information as well as error monitoring (Carter, Macdonald et al. 2000; MacLeod and MacDonald 2000).

1.2.1.: The Supervisory System Framework (SASF)

A distinction has long been made between automatic and controlled processes. Thus, in 1886 Cattell described some processing situations as being automatic, running essentially without attention, whereas others required attention (Cattell 1886). In the 1970s this distinction between different attentional processes was theoretically formalized into a distinction between
automatic and controlled processes (Posner and Snyder 1975; Shiffrin and Schneider 1977), with automatic processes viewed as developing through practice and requiring little attention, and controlled processes viewed as necessary for performing less-practiced algorithms.

The Supervisory Attentional System Framework (SASF) builds on this tradition. Thus, Shallice (Shallice 1982; Norman and Shallice 1986; Shallice 1986; Shallice 1988; Shallice 1988; Shallice, Fletcher et al. 1994; Shallice and Burgess 1996; Burgess, Veitch et al. 2000) argues that the operation of two complementary processes, the Contention Scheduling (CS) and the Supervisory Attentional System (SAS) (see Figure 1.1) corresponds to the distinction of automatic and control actions. The systems are arranged in a layered manner as shown in Figure 1.2. Automatic (over-learned or habitual) action is considered to be controlled by a set of schemas competing within the CS system for control of the motor system, whereas attentional control of action is achieved by the SAS which can influence the CS system but has no direct access to motor control.

Figure 1.1: The Supervisory Attentional System Framework.
1.2.1.1.: Contingency Scheduling (CS)

Cooper and Shallice (2000) distinguish between two sub-levels of low-level behaviour (see Figure 1.2)(Cooper and Shallice 2000). Here, the lower (motor) sub-level behaviour consists of individual motor actions required to carry out simple actions (extending/retracting muscle to pick up item). The higher (cognitive) sub-level behaviour consists of actions such as picking up items. Norman and Shallice's (Norman and Shallice 1986) CS component applies to the cognitive sub-level which regulates the motor sub-level.

![Diagram](image-url)

Figure 1.2. The Norman and Shallice (1986) framework augmented with Cooper and Shallice's (2000) distinction between cognitive and motor level action.

Shallice (Shallice and Burgess 1996; Cooper and Shallice 2000) argues that the CS system consists of a hierarchy of schemas (see Figure 1.2), where a schema can represent either a discrete action or alternatively structures organizing lower-level schemas. Lower level schemas correspond to actions that are directly carried out by motor actions such as 'put in key', 'turning', and 'extending leg'. Higher level schemas include actions such as 'starting car' which would incorporate the actions of putting in key, turning the key, and pushing down the gas pedal. At a higher level there might be such actions as driving a car. Schemas are connected in an interactive-activation network. Schemas compete for execution and a schema is activated when its activation level is higher than competing schemas (and when a certain
trigger threshold is reached) (see Figure 1.1). There is bottom-up activation of the schemas from input from the environment and top-down activation from parent schemas or by the SAS (see Figure 1.2). The action of the SAS will be detailed in the following.

1.2.1.2.: The Supervisory Attentional System (SAS)

Shallice argues that the SAS provides a second source of control on the operation of schemas in situations where the CS would be inadequate to achieve a higher goal. The SAS might be considered to be necessary for five types of situations/behaviours involving (Shallice, Fletcher et al. 1994): (1) planning or decision-making; 2) error-correction; 3) a novel response; 4) danger; and 5) the overcoming of habitual responses. The argument would be that situations 1, 2, 4, and 5 involve the SAS providing the excitation and inhibition to the activation levels of the existing schemas that are needed to be controlled to achieve a particular goal. In contrast, situation 3 involves the setting up of a temporary new schema that takes the place of the source schema triggered by the situation and also can orchestrate lower-level schemas (Shallice and Burgess 1996).

1.2.2: Cohen's Task Context Module Model

Cohen’s task context module model has undergone several formulations before its current one (Cohen, Dunbar et al. 1990; Cohen, Servan-Schreiber et al. 1992; Cohen, Botvinick et al. 2000). It has been used to explain performance on the Stroop task and the continuous performance test (Cohen, Dunbar et al. 1990; Cohen, Servan-Schreiber et al. 1992). We will consider here the version of this model that has been used to explain data from the Stroop task as this task will be considered in Chapter Two. In its simplest form, as represented in Figure 1.3, the model consists of two processing pathways, one for word reading and one for colour naming. Stimuli are coded by feature-specific representations, and converge on an output layer with units corresponding to each response. Processing occurs via activation spreading between units along the pathways. The strength of these pathways is determined by the degree of training that the model receives for a specific class of input. Learning occurs as a function of the back propagation algorithm. The model receives more extensive training on the word reading task than the colour naming task following the assumption that humans have more extensive experience with the former than the latter. This asymmetry in training intensity leads to greater connection weights in the word reading path compared to the colour naming path; i.e. following training, word reading becomes the prepotent response (represented in Figure 1.3 by thicker lines from the word input units to the output responses). The task context module
trigger threshold is reached) (see Figure 1.1). There is bottom-up activation of the schemas from input from the environment and top-down activation from parent schemas or by the SAS (see Figure 1.2). The action of the SAS will be detailed in the following.

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model also stipulates the existence of an executive feature, the context module. This contains units corresponding to each of the two task-relevant stimulus features. In conditions of response competition (i.e., naming the hue), the context module resolves the conflict by means of supporting the processing of the task relevant information, so that it can out-compete the task irrelevant information. Thus, the task context module model predicts that an individual's level of Stroop interference is not only a function of training on the respective domains but also the degree to which the context module is functioning efficiently.

Figure 1.3.: The Task Context Module Model (1990). From Cohen et al. (1990).

Later developments include the addition of mutually inhibitory representations within the layers (see Figure 1.4); (Cohen, Braver et al. 1996; Cohen, Botvinick et al. 2000). Moreover, there has been the addition of a more fully specified control system, including a layer that responds to conflict (co-activation) of response units. This drives a neuro-modulatory system that increases responsiveness of processing units globally (for instance by a change in gain, designated by connections with squares). This modulates selective attention by its influence on representations of specific task demands as well as motor preparation by its influence on response units.
In order to understand the mechanisms of supervisory control, it is of course necessary to have reliable experimental techniques for causing executive systems to be employed. The prototypical cognitive interference task is probably the word-colour Stroop (Stroop 1935) task or variants of this task. Chapter Two will explore cognitive interference in healthy individuals using the Number Stroop task. Chapter Three will explore executive function in individuals with psychopathy using the Number Stroop task, the Object Alteration and the Spatial Alteration tasks.

Having briefly considered behavioural regulation by executive control, behavioural regulation by emotional learning will now be considered.

1.3.: **Reinforcement History**

There is a considerable literature concerning models of emotional learning; i.e., instrumental learning (Dickinson, Campos et al. 1996; Bennett, Wills et al. 2000; Dickinson 2001; Hall, Parkinson et al. 2001; McLaren and Mackintosh 2002; Hall 2003). I am not going to attempt an overview of this literature. This literature focused on a theoretical consideration of the specifics of instrumental learning. This literature remains to be appropriately applied to the understanding of a psychiatric condition such as psychopathy. I will therefore confine this section of the thesis to a description of a model which has attempted to delineate specific neurocognitive systems involved in instrumental learning and to specify how they might be impaired in individuals with psychopathy. This is Gray’s (Gray 1971; Gray 1972; Gray 1975; Gray...

1.3.1.: Gray’s Behavioural Activation/Inhibition System (BIS/BAS) Model

Gray’s theory derives from the early animal learning literature (Mowrer 1960; Rescorla and Solomon 1967; Estes 1969) indicating that a fundamental distinction could be made between appetitive and aversive motivational systems. Thus, at the core of Gray’s (Gray 1971; Gray 1972; Gray 1975; Gray 1977; Gray 1982; Gray 1987; Gray and McNaughton 1996; Corr, Pickering et al. 1997; McNaughton and Gray 2000) model are two distinct (although interacting) motivational systems: the appetitive motivational system, which activates behaviour (the BAS), and the aversive motivational system, which inhibits behaviour (the BIS).

| Appetitive motivational system (behavioural activation system; BAS) |
| Approach: CSs for rewards (hope) |
| Active avoidance: CSs for relieving non-punishment (relief) |

| Aversive motivational system (behavioural inhibition system; BIS) |
| Passive avoidance: CSs for punishment (fear or anxiety) |
| Extinction: CSs for frustrative non-reward (frustration) |

| Antianxiety drugs |
| Disinhibit behaviour in extinction and passive avoidance |
| Attributed to effect on aversive motivational system |
| Aversive motivational system mediates anxiety |

Table 1.1.: Gray’s motivational theory. From Fowles (1988).

As seen in Table 1.1., the appetitive motivational system is a reward-seeking system which responds to positive incentives by activating behaviour (hence, the behavioural activation system or BAS). Gray (Gray 1971; Gray 1972; Gray 1975; Gray 1977; Gray 1982; Gray 1987; Gray and McNaughton 1996; Corr, Pickering et al. 1997; McNaughton and Gray 2000) argues that the system he terms BAS activates behaviour in response to cues or conditioned stimuli for reward – i.e., making an approach response to obtain reward. He argues that an emotional state of hope accompanies this situation. Gray argues that the system he terms BAS activates behaviour in response to safety cues or conditioned stimuli for relieving non-punishment in active avoidance situations – i.e., the animal jumping into a different
compartment to avoid shock (see Table 1.1.). He argues that an emotional state of relief accompanies this situation. The activation of the BAS, rather than the BIS, in relation to active avoidance may seem counter-intuitive. However, Gray (Gray 1975; Gray 1982; Gray 1987) argues that in active avoidance situations, responses are primarily controlled by the signalling of the safety cues or appetitive conditioned stimuli signalling that the threatened stimulus is no longer likely to occur. Similarly, Gray argues that the emotional states associated with both situations are positive because of the anticipated success in dealing with the aversive condition (e.g., hunger or shock).

As also seen in Table 1.1., the aversive motivational system inhibits responses to cues of conditioned stimuli signalling that aversive consequences will occur if a response is made by inhibiting behaviour (hence the behavioural inhibition system or BIS). Gray argues that the BIS inhibits behaviour in response to cues or conditioned stimuli of non-reward, – i.e., extinction (see Table 1.1.). He further argues that an emotional state of frustration accompanies this situation. Gray also argues that the BIS inhibits the approach behaviour in response to cues or conditioned stimuli for response-contingent punishment. He argues that an emotional state of fear or anxiety accompanies this situation.

**Figure 1.5.** Gray's (Gray and Smith 1969) model for approach-avoidance conflict. Dashed lines from the reward/ punishment comparator indicate the results from conditioning on trial n, which then provide inputs to the reward/ punishment mechanisms on trial n+. From Gray (1987).
As can be seen in Figure 1.5., a reward moderator and a punishment moderator are essential parts of the model. The exact computations of the moderator are not specified in much detail, but, the role of the moderator in reevaluating the reinforcement value of, and thus the likelihood of responding to, a particular stimulus is crucial. Thus, according to Gray (2000, pp 162-163):

1) much of the time the comparator is receiving inputs about the state of the world and the expected state of the world but produces no output as it is 'just checking';

2) These inputs code not only for simple events (and particularly for the occurrences of reinforcer) and for predictions about expected events but also for the upcoming step in the currently executing motor programs and for future steps (i.e., plans);

3) when there is a mismatch between the expected and actual events the comparator produces significant output that not only tends to halt the current motor program but also to cause it (and hence future plans) to be executed more slowly and carefully in the future or to be replaced by attempts to resolve the problems which gave rise to the mismatch (e.g., increases in exploratory behaviour).

That is, crucially, if there is a mismatch in actual and expected rewards, the moderators ensure that the reinforcer value (or category) is reevaluated and the mechanism responds correspondingly in the future situations.

Gray (Gray 1972; Gray 1977; McNaughton and Gray 2000) argues that anxiolytics (e.g., alcohol, benzodiazepines, and barbiturates) reduce the reactivity or effectiveness of the aversive motivational system (see Table 1.1.). From this proposition, Gray (1972) employed Eysenck’s two dimensions of neuroticism and extroversion. He proposed that the BIS falls along the neurotic introvert diagonal, termed anxiety, and the BAS along the neurotic extravert diagonal, termed impulsivity (see Figure 1.6.). Using this framework, the BIS/BAS model has been applied to a variety of disorders, and a weak BAS and/or a strong BAS has been linked to anxiety, depression, and schizophrenia (Gray 1972; Gray 1987; Fowles 1988; Landon, Sher et al. 1993; Corr, Pickering et al. 1997; Harmon-Jones and Allen 1997; Fowles 2000; McNaughton and Gray 2000; Kasch, Rottenberg et al. 2002). In contrast, a strong BAS combined with a weak BIS has been linked with psychopathy (Fowles 1980; Gray 1987; Fowles 1988; Fowles 1993).
Figure 1.6.: Rotation of the Eysenck (1969) dimensions of neuroticism and Introversion-extraversion proposed by Gray (1970). The dimension of trait-anxiety represents the steepest rate of growth in susceptibility to stimuli associated with inputs to the BIS (stimuli associated with punishment and non-reward). The dimension of impulsivity represents the steepest rate of growth in susceptibility to inputs to the BAS system (stimuli associated with reward and non-punishment). From Gray (1987).

Evidence cited in support of these suggestions comes from work indicating that anxiolytics will affect animal behaviour in the predicted direction on a paradigms said to measure BIS activation, including active avoidance, extinction, and rewarded bar pressing (McNaughton and Gray 2000). In addition, in psychiatric disorders, there certainly have been indications of some kind of imbalance in sensitivities to reward and punishment (Beck 1967; Beck 1972; Fowles 1988; Levenston, Patrick et al. 1996; Siegle and Hasselmo 2002; Siegle, Steinhauer et al. 2002). However, the model faces several problems. In particular, it assumes that there is a unitary fear system. However, the empirical literature strongly suggests that there is no single fear system but rather that there are a series of at least partially separable neural systems that are engaged in specific forms of processing that can be subsumed under the umbrella term fear. For example, aversive conditioning and instrumental learning are two forms of processing that the fear system is thought to be involved in (Patrick 1994; Lykken 1995). Yet the neural circuitry to achieve aversive conditioning and instrumental learning are doubly dissociable (Killcross, Robbins et al. 1997). Thus, a lesion to the central nucleus of the
amygdala will prevent aversive conditioning but still allow instrumental learning to occur. In contrast, a lesion to the basolateral nucleus of the amygdala will prevent instrumental learning but still allow aversive conditioning to occur. Moreover, early amygdala lesions result in a massive reduction of neo-phobia; the infant monkey is no longer fearful of a novel object. However, the same infant monkeys with amygdala lesions show heightened social phobia; i.e., their fear response to another infant monkey is actually heightened (Amaral 2001; Prather, Lavenex et al. 2001). These findings strongly suggest partially separable “fear” systems: for aversive conditioning/instrumental learning and for social threats.

Although data thus has demonstrated that the model in its current form is not sustainable, the model has nonetheless inspired work into behaviour according to reinforcement history and subsequent sensitivities to reward and punishment in mood and anxiety disorders. This work has now demonstrated that in many of these disorders there is dysregulation of affective regulatory systems (Levenston, Patrick et al. 1996; Drevets 2001; Sheline, Barch et al. 2001; Siegle and Hasselmo 2002; Siegle, Steinhauer et al. 2002), although the mechanisms of this dysfunction are not yet clearly operationalized. In Chapter Four and Six, the issue of dysregulation of affective regulatory systems in individuals with psychopathy is considered.

Having very briefly considered the two types of system, executive functioning and emotional learning, I will now describe the psychiatric condition to which these types of model will be applied: Psychopathy.

1.4.: Psychopathy

The origins of the current description of psychopathy can be traced back to the work of Cleckley (1967). In his book, the Mask of Sanity, Cleckley delineated 16 criteria for the diagnosis of psychopathy (Cleckley 1941). These included: superficial charm, lack of anxiety, lack of guilt, undependability, dishonesty, egocentricity, failure to form lasting intimate relationships, failure to learn from punishment, poverty of emotions, lack of insight into the impact of one’s behaviour on others, and failure to plan ahead. From these characteristics, and his own clinical impressions, Hare developed the original Psychopathy Checklist [PCL] (Hare 1980), a formalized tool for the assessment of psychopathy in adults. This has since been revised: the Psychopathy Checklist – Revised [PCL-R] (Hare 1991).

The PCL-R consists of 20 behavioural items (see Table 1.2.). The PCL-R is scored on the basis of an extensive file review and a semi-structured interview. For each behavioural item, an individual can score between 0 and 2 points. The individual’s total score can therefore
vary from 0 to 40 points. For research purposes, adults scoring 30 or above on the PCL-R are considered psychopathic while those scoring less than 20 are considered non-psychopathic.

<table>
<thead>
<tr>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Glibness/ superficial charm</td>
<td>• Need for stimulation</td>
</tr>
<tr>
<td>• Grandiose sense of self worth</td>
<td>• Parasitic lifestyle</td>
</tr>
<tr>
<td>• Pathological lying and deception</td>
<td>• Poor behavioural control</td>
</tr>
<tr>
<td>• Conning/ lack of sincerity</td>
<td>• Early behavioural problems</td>
</tr>
<tr>
<td>• Lack of remorse or guilt</td>
<td>• Lack of realistic long term plans</td>
</tr>
<tr>
<td>• Callous/ lack of empathy</td>
<td>• Impulsivity</td>
</tr>
<tr>
<td>• Failure to accept responsibility for own actions</td>
<td>• Irresponsible behaviour</td>
</tr>
<tr>
<td></td>
<td>• Frequent marital relationships</td>
</tr>
<tr>
<td></td>
<td>• Promiscuity</td>
</tr>
<tr>
<td></td>
<td>• Juvenile delinquency</td>
</tr>
<tr>
<td></td>
<td>• Revocation</td>
</tr>
<tr>
<td></td>
<td>• Criminal versatility</td>
</tr>
</tbody>
</table>

Table 1.2: Hare's Psychopathy Checklist-Revised (1991).

Psychopathy is a disorder that consists of multiple components ranging from emotional, interpersonal and behavioural. Factor analysis is a means of examining how the items of a given construct hang together. For example, while the PCL-R consists of 20 items and each item is thought to contribute something unique to the set of criteria, overlap will exist between items. Consequently, items that correlate with each other can be grouped together to form a cluster of traits, or a factor, that refers to a more general facet of the disorder.

In the original study, Harpur and his colleagues incorporated data from six samples and hundreds of individuals to determine that the predecessor to the PCL-R, the PCL, was composed of two correlated factors (Harpur, Hakstian et al. 1988); interpersonal/ affective items and impulsive/ antisocial lifestyle items. The authors argued that, while highly correlated, the two factors measured separable components of the disorder and both factors would be required to yield a comprehensive assessment of psychopathy. Subsequently, the PCL-R was established and the two-factor structure was replicated in eight samples involving
over 900 prison inmates and 350 forensic patients (Hare, Harpur et al. 1990). Moreover, the
two-factor description of psychopathy has been replicated in Belgian (Pham 1998), Scottish
(Cooke and Michie 2001), Spanish (Molto, Poy et al. 2000), and English inmates (Hobson and
Shine 1998). The two factors and their constituent parts are described in Table 1.2.

Now let us consider the models of psychopathy, and more specifically the executive
dysfunction theories of psychopathy and the emotional dysfunction theories of psychopathy.

1.4.1.: Executive Dysfunction Theories of Psychopathy

1.4.1.1.: The Frontal Lobe Hypotheses of Psychopathy

Frontal lobe and consequent executive dysfunction have long been related to
impulsivity and antisocial behaviour (Elliot 1978; Gorenstein 1982; Moffitt 1993; Barratt 1994;
Raine 1997; Raine 2002). Indeed, there is ample evidence that individuals with antisocial
behaviour show impaired performance on measures of executive functioning (Kandel and Freed
1989; Moffitt 1993; Pennington and Ozonoff 1996; Morgan and Lilienfield 2000). Moreover, a
series of brain imaging studies of aggressive individuals have supported the suggestion of
reduced frontal functioning in aggressive individuals (Volkow and Tancredi 1987; Raine,
Buchsbaum et al. 1994; Volkow, Tancredi et al. 1995; Raine, Buchsbaum et al. 1997; Raine,
Meloy et al. 1998; Raine, Phil et al. 1998; Raine, Lencz et al. 2000).

As regards psychopathy specifically, Gorenstein (1982) proposed that the behavioural
manifestation of frontal lobe lesions in humans were strikingly similar to the behavioural
manifestation of psychopathy (Gorenstein 1982). Thus, he noted that the four clusters of
behaviour problems outlined by Lezak (1976), except for the first cluster ‘are extraordinarily
369). The four clusters of behaviour described by Lezak were (Lezak 1976):

1. Slowing – apathy, loss of initiative or ambition.
2. Perseveration – failure to suppress ongoing activities when they are no longer
   appropriate.
3. Deficient self-awareness – inability to perceive performance errors, inability to
   appreciate the impact one makes on others, tendency toward self-satisfaction,
   little or no anxiety, impulsiveness, lack of concern about social conventions.
4. Concrete attitude – stimulus bondedness, inability to plan or sustain goal
directedness.
Gorenstein in his paper then assessed individuals with psychopathy on (DLPFC) frontal lobe tasks and concluded that individuals with psychopathy indeed did demonstrate a syndrome similar to that of frontal lobe lesions.

However, it should be noted that the frontal lobe positions are relatively under-specified. Thus, frontal cortex corresponds to almost half of the cortex (Fuster 1980) and has been implicated in a variety of putative processes (Luria 1966; Burgess and Shallice 1996; Pennington and Ozonoff 1996; Baddeley and Della Sala 1998; Roberts, Robbins et al. 1998). However, the frontal lobe positions typically do not distinguish between different regions of prefrontal cortex or different forms of executive function. There has been little or no reference in this literature, for example, to theories of executive functioning such as the Supervisory Attentional System or Task Demands models described above.

The neuropsychological literature, including that of Gorenstein's (1982) work, examining the relationship between frontal dysfunction and antisocial behaviour has, to a very large extent, concentrated on the use of tasks that index executive functions commonly linked to dorsolateral prefrontal cortex (DLPFC); e.g., the Wisconsin Card Sorting Task (WCST) and the Controlled Oral Word Association Test (COWAT). This literature has found that, generally, antisocial populations show impaired performance on these measures of executive functioning (Kandel and Freed 1989; Moffitt 1993; Pennington and Ozonoff 1996; Morgan and Lilienfield 2000). This suggests that antisocial populations show some indications of general Supervisory Attentional System impairment.

However, one antisocial population, which has shown no indications of general Supervisory Attentional System impairment are individuals with psychopathy. Individuals with psychopathy do not show impairment on measures of executive function linked to DLPFC (Kandel and Freed 1989; LaPierre, Braun et al. 1995; Mitchell, Colledge et al. 2002). Thus, individuals with psychopathy have been found to show no impairment on the WCST (LaPierre, Braun et al. 1995), the COWAT (Smith, Arnett et al. 1992; Roussy and Toupin 2000) or the ED-shift component of the Intradimensional/ Extradimensional (ID/ED) Task (Mitchell, Colledge et al. 2002).

This is not to say that individuals with psychopathy show no indications of executive dysfunction. Individuals with psychopathy do appear to show executive dysfunction on measures linked to ventromedial/ OFC dysfunction; e.g., the Porteus Maze Test, motor Go/No-Go tasks, and measures of response reversal/ extinction such as the ID/ED task and the One Pack Card Playing Task (LaPierre, Braun et al. 1995; Newman, Schmitt et al. 1997; Roussy and
Moreover, reduced ventromedial/OFC functioning has been reported in individuals with psychopathy during an imaging study involving an aversive conditioning task (Veit, Flor et al. 2002). Thus, individuals with psychopathy do show frontal lobe dysfunction albeit dysfunction that is selective to those executive functions mediated by ventromedial/OFC rather than DLPFC.

1.4.1.2.: The Dysfunctional Response Set Modulation Theory

A very influential theory of psychopathy is the Newman et al. (Gorenstein and Newman 1980; Newman, Schmitt et al. 1997; Lorenz and Newman 2002) response set modulation hypothesis. Response modulation involves “a rapid and relatively automatic (i.e., non-effortful or involuntary) shift of attention from the effortful organization and implementation of goal-directed behaviour to its evaluation” (Newman et al. 1997). This “brief and highly automatic shift of attention ... enables individuals to monitor and, if relevant, use information that is peripheral to their dominant response set (i.e., deliberate focus of attention)” (Lorenz & Newman, 2002; p. 92). The initial physiological frame of the model (Gorenstein & Newman 1980) was based around the work of Gray and others on the implications of septo-hippocampal lesions for emotional learning (Gray, 1971). “In animal studies, deficient response modulation typically involves response perseverance or a tendency to continue some goal-directed behaviour (e.g., running down the arm of a maze) despite punishment or frustrative non-reward (i.e., extinction)” (Newman 1998, p. 85).

It is this proposed reduced automatic processing in individuals with psychopathy that is at the core of Newman’s model. Thus: “Whereas most people automatically anticipate the consequences of their actions, automatically feel shame for unkind deeds, automatically understand why they should persist in the face of frustration, automatically distrust propositions that seem too good to be true, and are automatically aware of their commitments to others, psychopaths may only become aware of such factors with effort” (Newman 1998, p. 84). That is, individuals with psychopathy are able to regulate their behaviour, however, because they lack the “relatively automatic processes” to guide actions the process is slower and more error-prone.

The response modulation hypothesis is an attention-based model. According to the model, “the impulsivity, poor passive avoidance, and emotion-processing deficits of individuals with psychopathy may all be understood as a failure to process the meaning of information that is peripheral or incidental to their deliberate focus of attention” (Lorenz & Newman, 2002; p. 92).
In particular, the response set modulation hypothesis has received support from three sets of studies. One set of studies involve the one pack card-playing task which may be considered an extinction task under partial reinforcement conditions. In this task, on each trial the participant chooses whether to 'play' a card or not. Initially, every card choice is rewarded, but as more cards are played, the probability of reward decreases. In line with predictions from the response modulation model, individuals with psychopathy play significantly more cards than comparison individuals (Newman et al. 1987; O'Brien and Frick 1996; Fisher and Blair 1998; Shapiro et al. 1988).

The second set of studies involves a passive avoidance task. In this task, the participant is presented with a series of numbers and has to learn to respond to the ones that are rewarded and withhold responding to the numbers that are punished. Again in line with the prediction of the response modulation model, individuals with psychopathy are significantly more likely to persist responding to the numbers that are punished relative to comparison individuals (e.g., Newman and Kosson 1986; Newman and Schmitt 1998).

The third set of studies involves a sequential Stroop-like interference task. In this task, the participant is first presented with a word and a picture, which is then followed by either a picture or a word. If the second stimulus is a word, the participant would have been instructed to decide whether they two words were conceptually related, and if the second stimulus is a picture, the participant would have been instructed to decide whether the two pictures were conceptually related. The distractor stimulus for the picture-word stimulus can be either conceptually related or unrelated. It is then found that when the pictures/words are unrelated, participants respond significantly more slowly when the irrelevant stimulus is related to the test stimulus than when it is not (Gemsbacher and Faust 1991). In line with the response modulation hypothesis, however, individuals with psychopathy showed no interference from the distractor on this task (Newman, Schmitt and Voss 1997).

From these studies, then, the response modulation hypothesis has received some support. However, the hypothesis does face difficulties. First of all, the model does not appear to be compatible with current attentional models. Thus, according to the most dominant attention theory (Desimone and Duncan 1995), attention reflects competition among stimuli for neural representation according to two different processes. One process is bottom-up driven (e.g., from the salience of a stimulus). The second process is top-down (attention allocated to a particular feature/location). This second process is particularly important when the stimulus to be attended to is in competition with a more salient irrelevant stimulus, or alternatively when there is a high task load rather than a low task load. That is, a stimulus may become the focus
of attention because either it is intrinsically salient or top down feedback processes bias its processing.

Thus, within this framework, the impaired response modulation of individuals with psychopathy could reflect a deficit in bottom-up automatic processing. However, such an interpretation would also predict that individuals with psychopathy have general difficulty in picking up on salient features in a stimulus display (e.g., pop-out effects, and there is no data to suggest that may be the case). Alternatively, the response modulation deficit in individuals with psychopathy could reflect a deficit in top-down processing. The second interpretation of the response modulation hypothesis makes reference to attentional top-down feedback. According to the biased competition model, the degree to which a stimulus is processed (i.e., attended to) is determined by the degree to which it survives the competition process in sensory systems. The degree to which a stimuli that is not the focus of attention survives the competition process is thought to be a function of task load (Lavie 1995). Under difficult task conditions (high load conditions), where processing of additional stimuli may fatally disrupt the goal-directed processing of the target stimuli, top down processes will result in a tight focus on the target stimuli. As a consequence, the representation of the unattended stimuli will be sufficiently suppressed by the target stimuli as to not be processed. In contrast, under less difficult task conditions (low load conditions), where the processing of additional stimuli will not disrupt the goal-directed processing of the target stimuli, the unattended stimuli can survive the competition and be processed. For example, determining whether a centrally presented word stimulus is bi-syllabic or not (high task load) prevents the identification of whether a peripherally presented non-target stimulus is moving. In contrast, determining whether the centrally presented word stimulus is written in upper or lower case (low task load) does not (Rees, Frith et al. 1997).

As regards the response modulation hypothesis, the suggestion would therefore be that individuals with psychopathy always operate under high load conditions during goal-directed activity. That is attention to the target stimuli so suppresses the representation of the unattended stimuli that they are not processed. At first glance such an interpretation is attractive. It would appear to explain reduced processing of punishment information during goal directed attention to stimuli associated with reward (Newman and Kosson 1986; Newman, Patterson et al. 1987) as well as reduced interference in Stroop-type tasks (Newman, Schmitt et al. 1997).

This interpretation is, however, not compatible with data from the lexical decision task (where healthy individuals respond faster to emotional than neutral words while individuals
with psychopathy do not). If the stimulus to be identified as a word or not is being attended to (as must be the case to achieve the task), then the stimulus should automatically activate the semantic representations; this would not be a function of attention, it would be an inevitable function of the word's associations. The only way that the word should not activate these associations would be independent of an attentional account; i.e., if the semantic system of individuals with psychopathy was profoundly impaired. Studies examining semantic priming and semantic impact on Stroop interference all suggest no generalized semantic impairment in individuals with psychopathy. Moreover, an attentional account of the impairment seen in individuals with psychopathy in passive avoidance learning and response reversal as indexed by the one pack card playing task is only superficially attractive. In the passive avoidance and response reversal paradigms (Newman and Kosson 1986; Newman, Patterson et al. 1987), the punishment information is presented in the absence of distracting information. According to models of attention (Desimone and Duncan 1995; Lavie 1995), it would be difficult to see why this information should not be attended to/processed given the absence of competing stimuli. The fact that the punishment information does not modulate the behaviour of individuals with psychopathy would tend to suggest that these individual cannot learn from this information, rather than that the individual with psychopathy cannot attend to this information. Such a suggestion is made by the fear and integrated emotion systems accounts (Fowles 1988; Patrick, Cuthbert et al. 1994; Lykken 1995; Blair 2003).

In short, the response set modulation hypothesis has resulted in the development of an assortment of interesting paradigms. However, at the current time it is unclear the extent to which this attention-driven hypothesis is compatible with contemporary positions on attention.

1.4.2.: Emotional Base Models of Psychopathy

The clinical and empirical picture of the psychopath describes an individual who has some form of emotional deficit (Aniskiewicz 1979; 1967; 1991; Patrick, Cuthbert and Lang 1994; Schalling 1978; Williamson et al. 1991). Cleckley (1976) suggested that there was discordance in the linguistic and experiential components of emotion in psychopaths. As Johns and Quay (1962; p. 217) put it, psychopaths "know the words but not the music". Hare's (1991) Revised Psychopathy Checklist (PCL-R) suggests that the psychopath lacks Remorse or Guilt (item 6) and Empathy (item 8).
I.4.2.1.: The Fear Based Models

One of the main positions regarding the emotional impairment shared by individuals with psychopathy is that there is impairment in the neuro-physiological systems modulating fear behaviour (Eysenck 1964; Trasler 1973; Cleckley 1976; Pichot 1978; Trasler 1978; Gray 1987; Fowles 1988; Patrick 1994; Lykken 1995; Mealey 1995). For example, Cleckley (1976) wrote: “Within himself he appears almost as incapable of anxiety as of profound remorse” (p. 340). The dysfunctional fear positions all assume that moral socialization is achieved through the use of punishment (Trasler 1978; Eysenck and Gudjonsson 1989). In essence, they assume that the healthy individual is frightened by punishment and associates this fear with the action that resulted in the punishment thus making the individual less likely to engage in the action in the future. The suggestion is that individuals with psychopathy, because they are less averively aroused by punishment, make weaker associations and thus are more likely to engage in the punished action in the future than healthy individuals.

The variants of the fear dysfunction hypothesis have generated a considerable body of empirical literature. Indeed, the earliest formal experimental investigations of psychopathy were based around the fear dysfunction hypothesis (Lykken 1957). Thus, the fear dysfunction positions predict the observed findings of impairment in individuals with psychopathy in aversive conditioning (Lykken 1957; Flor, Birbaumer et al. 2002), in generating autonomic responses to anticipated threat (Hare 1982; Ogloff and Wong 1990), in the augmentation of the startle reflex to visual threat primes (Levenston, Patrick et al. 2000; Herpertz, Werth et al. 2001), in passive avoidance learning (Lykken 1957; Newman and Kosson 1986) and in response reversal (Newman, Patterson et al. 1987; Mitchell, Colledge et al. 2002).

Many theorists have thus suggested that reduced anxiety levels lead to the development of antisocial behaviour/ psychopathy (Eysenck 1964; Trasler 1973; Cleckley 1976; Gray 1987; Patrick 1994; Lykken 1995). However, in apparent contradiction of this position, there is a consistent body of literature indicating that high levels of antisocial behaviour are associated with heightened levels of anxiety. Thus, there is a well-documented positive correlation between anxiety and antisocial behaviour in children (Zoccolillo 1992; Russo and Beidel 1993; Pine, Cohen et al. 2000) and adults (Robins, Tipp et al. 1991). In other words, higher levels of anxiety are associated with higher levels of antisocial behaviour.

This presents yet another conundrum albeit one that is easily resolved. It is important to consider reactive aggressions separately from instrumental aggression. Reactive aggression occurs to very high level threat/ frustration (Blanchard, Blanchard et al. 1977). Anxiety reflects activation of neural circuitry involved in the processing of threat (Kagan and Snidman 1999).
In other words, an individual presenting with elevated anxiety is presenting with an elevated threat response and is thus more likely to display reactive aggression to an additional environmental threat or source of frustration. In contrast, according to the dysfunctional fear accounts, there should be an inverse relationship between level of anxiety and incidence of instrumental aggression. As yet, no studies have directly assessed the relationship between anxiety and reactive/ instrumental aggression. However, studies have examined the relationship between anxiety and the callous and unemotional and the impulsive and conduct disordered dimensions of psychopathy (Patrick 1994; Frick, Lilienfeld et al. 1999; Schmitt and Newman 1999; Verona, Patrick et al. 2001). Schmitt and Newman (1999) reported that both the callous and unemotional and the impulsive and conduct disordered dimensions of psychopathy are independent of level of anxiety (Schmitt and Newman 1999). However, this study did not partial out the effects of the level of conduct problems from the effects of the emotional dysfunction. This was unfortunate given the well-documented positive correlation between anxiety and aggression in antisocial populations (Robins, Tipp et al. 1991; Zoccolillo 1992; Russo and Beidel 1993; Pine, Cohen et al. 2000). Indeed, those studies that did examine the callous and unemotional and the impulsive and conduct disordered dimensions of psychopathy independently reported that anxiety level is inversely associated with the callous and unemotional dimension of psychopathy but positively associated with the impulsive and conduct disordered dimension (Patrick 1994; Frick, Lilienfeld et al. 1999; Verona, Patrick et al. 2001).

However, despite this empirical success, the variants of the fear dysfunction hypothesis face several problems. First, for the most part, the variants are under-specified at both the cognitive and neural levels. The various authors do not provide many details concerning the computational properties of the fear system. For example, it is difficult to be certain about the range of inputs to any putative fear systems or how the fear system operates in response to these inputs. The only more detailed account of a fear system that has been used in relation to explaining psychopathy is the BIS/ BAS (Gray 1987; Gray and McNaughton 1996; McNaughton and Gray 2000). As described above, the suggestion here is that there is a unitary fear system, the BIS, which is thought to generate autonomic responses to punished stimuli (through classical conditioning) as well as inhibiting responding following punishment (through instrumental conditioning).

The BIS model does provide us with a putative range of inputs to a fear system and outputs from this system. However, it assumes that there is a unitary fear system, a claim implicit in all the variants of the fear dysfunction hypothesis. However, and this brings us to
the second problem for the fear dysfunction hypothesis, the empirical literature, as discussed above, strongly suggests that there is no single fear system but rather that there are a series of at least partially separable neural systems that are engaged in specific forms of processing that can be subsumed under the umbrella term fear. For example, the systems mediating aversive conditioning are dissociable from those mediating instrumental learning (Killcross, Robbins et al. 1997). Moreover, the systems mediating neo-phobia are dissociable from those mediating anxiety in the face of conspecifics (Amaral 2001; Prather, Lavenex et al. 2001).

The third problem faced by the fear dysfunction hypotheses is that it is unclear why the fear theories should predict the very high level of antisocial behaviour shown by individuals with psychopathy. The positions usually argue that the individual with psychopathy has failed to be socialized away from using antisocial behaviour (Trasler 1978; Eysenck and Gudjonsson 1989). However, the assumption that conditioned fear responses play a crucial role in moral socialization has been questioned (Blackburn 1988; Blair and Morton 1995). Thus, the developmental literature indicates that moral socialization is not achieved through the formation of conditioned fear responses but rather through the induction and fostering of empathy (Hoffman 1984). Studies have shown, for example, that moral socialization is better achieved through the use of induction (reasoning that draws children’s attention to the effects of their misdemeanors on others and increases empathy) than through harsh authoritarian or power assertive parenting practices which rely on the use of punishment (Hoffman and Saltzstein 1967; Baumrind 1971; Baumrind 1983). Indeed, there have been suggestions that while empathy facilitates moral socialization, fear actually hinders it (Hoffman 1994). Thus, in a review of a large number of studies of disciplinary methods, it was concluded that punishment based, power assertion had an adverse effect on moral socialization regardless of age (Brody and Shaffer 1982).

In addition, according to conditioning theory and data, the conditioned stimulus (CS) that is associated with the unconditioned stimulus (US) is the CS that most consistently predicts the US (Dickinson 1980). To achieve socialization through aversive conditioning, it would therefore be crucial to ensure that the relevant CS (a representation of the transgression activity that the caregiver is attempting to ensure the child will find aversive) consistently predicts the US (the caregiver hitting the child). However, this is very difficult to achieve. In homes using punishment based techniques, the punishment is rarely contiguous with the performance of the transgression. This means that the desired CS rarely predicts the US of the caregiver’s punishment. Instead, the CS predicting the US is more likely to be the individual who delivers the US. Thus, in these households, aversive conditioning may occur but the US-CS association
will be physical pain & a particular parent, rather than physical pain & antisocial behaviour. Indeed, in households using punishment based techniques, the punished child frequently does not show fear of committing transgressions (the poorly predictive CS) but does show fear of the person who is likely to punish them (the highly predictive CS); (Hoffman 1994).

A fourth problem faced by the fear positions is also related to the idea embedded in the fear positions, that socialization should be achieved through punishment. If healthy individuals learn to avoid antisocial behaviour because of fear of punishment, it must be assumed that the healthy child judge all rules/ transgressions in a similar way. In other words, if we learn to avoid talking in class and hitting other individuals because we are punished when we commit these actions, there is no reason for us to distinguish between these two transgressions. However, as noted above, healthy developing children make a distinction between moral (victim-based) and conventional (social order based) transgressions from the age of 36 months (Smetana 1981; Smetana 1985; Smetana 1993). In other words, children do not judge all transgressions in an identical fashion. Instead, they differentiate between those transgressions that result in harm to another from those that simply cause social disorder.

Thus, in conclusion, while the fear positions have generated a considerable body of data, it remains unclear why fear impairment should result in the development of psychopathy.

1.4.2.2.: The Violence Inhibition Mechanism Model

The importance of empathy for moral socialisation was one of the reasons for the development of the original VIM model of psychopathy (Blair 1995; Blair et al. 1997). This model was prompted by work suggesting that most social animals possess mechanisms for the control of aggression (Lorenz 1966; Eibl-Eibesfeldt 1970). They noted that submission cues displayed to a conspecific aggressor terminate attacks; e.g., an aggressor dog will cease fighting if its opponent bares its throat. The VIM is considered to be a functionally similar mechanism in humans where sad facial affects (i.e., distress cues) function as a human submission response. At its simplest, the VIM is thought to be a system that when activated by distress cues, the sad and fearful expressions of others, results in increased autonomic activity, attention and activation of the brainstem threat response system (usually resulting in freezing); (Blair 1995). It should be noted that the VIM is thought to be activated whenever distress cues are displayed. It is not reliant upon contextual information about ongoing violence for activation. In line with this, the display of distress cues has been found to result in the inhibition of not only aggression (Perry and Perry 1974) but also non-violent disputes over property ownership (Camras 1977) and sexual activity (Chaplin, Rice et al. 1995).
According to the model, moral socialisation occurs through the pairing of the activation of the mechanism by distress cues with representations of the acts that caused the distress cues (i.e., moral transgressions; e.g., one person hitting another); (Blair 1995). Through association these representations of moral transgressions become triggers for the mechanism. The appropriately developing child thus initially finds the pain of others' aversive and then, through socialisation, thoughts of acts that cause pain to others aversive also. It is proposed that psychopathic individuals have had disruption to this system such that representations of acts that cause harm to others do not become triggers for the VIM (Blair 1995).

One early index of appropriate moral socialization, and thus the developmental integrity of the VIM, is the demonstration by the child of the moral/conventional distinction. From the age of 3.5 years, children distinguish in their judgments between moral (victim-based) and conventional (social disorder-based) transgressions; (Smetana 1993). Crucially for the model (Blair 1995), normally developing children best discriminate in their judgments between two types of transgressions when they are asked to imagine situations where there are no rules prohibiting the transgressions. In contrast, adults with psychopathy and children with psychopathic tendencies are least likely to make a discrimination under these conditions (Blair et al. 1995; Blair 1995; Blair 1997); see also Nucci and Herman (1982) and Arsenio and Fleiss (1996) for similar work with children with Behaviour Disorder and Conduct Disorder (House and Milligan 1976; Nucci and Herman 1982; Arsenio and Fleiss 1996). In addition, and in line with the VIM position, psychopathic adults show reduced comprehension of situations likely to induce guilt although they show appropriate comprehension of happiness, sadness and even complex emotions such as embarrassment (Blair et al. 1995). Finally, and a direct prediction of the model, psychopathic adults and children with psychopathic tendencies show reduced autonomic activity to the sadness and fear of others (Aniskiewicz 1979; Blair et al. 1997; Blair 1999; House and Milligan 1976).

However, while the original VIM model could provide an account of the emergence of instrumental antisocial behaviour in psychopathic individuals and while it did generate a variety of predictions that have been empirically confirmed, it faced a serious difficulty; it could not account for the data associated with the response set modulation and fear hypotheses. Moreover, it could not account for data on the interaction of temperament and socialization practice on the development of moral development/conscience. Kochanska has stressed the role of tearfulness as the important temperamental factor (Kochanska 1993; Kochanska 1997). Indeed, she and others have found fearful children to show higher levels of moral development/conscience using a variety of measures (Asendorpf and Nunner-Winkler 1992; Kochanska, De
Vet et al. 1994; Rothbart, Ahadi et al. 1994; Kochanska 1997). In addition, Kochanska has stressed that different socialization practices may promote moral development in children with different temperaments (Kochanska 1993; Kochanska 1997). In line with this, she found that for fearful children, maternal gentle discipline promoted moral/ conscience development. In contrast, for “fearless” children, alternative socialization practices, presumably capitalizing on mother-child positive orientation (secure attachment, maternal responsiveness), promoted the development of conscience (Kochanska 1997).

The fact that the VIM model provides an incomplete account has resulted in an expansion of the model at both the cognitive and neural levels: the integrated emotion systems model.

1.4.2.3.: The integrated emotion systems model

The integrated emotion systems (IES) model is an initial attempt to develop a more detailed model of amygdala-cortical interactions (Blair 2003; Blair 2003; Blair under revision). With respect to psychopathy, the suggestion is that psychopathy is linked to early amygdala dysfunction (Patrick 1994; Blair, Morris et al. 1999; Blair 2001; Blair 2002). In line with this suggestion individuals with psychopathy have been found to show reduced amygdaloid volume relative to comparison individuals (Tiihonen, Hodgins et al. 2000) and reduced amygdala activation during emotional memory (Kiehl, Smith et al. 2001) and aversive conditioning tasks (Veit, Flor et al. 2002). Moreover, functions that recruit the amygdala such as aversive conditioning and instrumental learning, the augmentation of startle reflex by visual threat primes and arousal to the anticipation of punishment, are all impaired in individuals with psychopathy (Blair 2001); see also below. Of course, it should be noted that other structures, such as OFC, which are interconnected with the amygdala, may also be affected (Damasio 1994; LaPierre, Braun et al. 1995; Mitchell, Colledge et al. 2002; Raine 2002).

The IES model is depicted in Figure 1.7. The amygdala is crucially involved in the formation of stimulus-reward and stimulus-punishment associations (Baxter and Murray 2002). In the IES model, this is represented by the two modules of non-linear, computational units, with one module representing the amygdala and one model representing sensory regions (e.g., auditory, visual and temporal cortex). This represents a simplified version of a model of aversive conditioning (Armony, Servan-Schreiber et al. 1997). However, in the current model, the connections between the units in the different modules are reciprocal, reflecting the interconnections of the amygdala with cortical regions (Amaral, Price et al. 1992). The strength of the connections between units in the different modules increase through Hebbian
learning (Hebb 1949). Recent data at the cellular level confirms this characterization of learning within the amygdala as Hebbian (Blair, Schafe et al. 2001).

![Diagram of neural circuits](image)

**Figure 1.7:** The IES model. Sensory cortex (auditory, visual and temporal cortex) and the hippocampus allow the representation of conditioned stimuli. Contiguous activation of representations of conditioned stimuli in sensory cortex and amygdala activation by an unconditioned stimulus will increase the connections between the two representations through Hebbian learning allowing the CS to activate the brainstem even if the US is not present. Expectations of reinforcement/punishment transmitted from the amygdala to medial orbital frontal cortex allow resolution if more than one motor response option has been activated. Goal representations also modulate this processing. It is suggested that there are comparator units in lateral orbital that would detect mismatches between expectations of reinforcement (provided by the amygdala units) and actual reinforcement (the nociceptive input). When activated these would disrupt the connections (weights) between amygdala units and orbital frontal cortex units as a function of the degree of the previous strength of these connection weights.

There are at least three possible explanations of the amygdala dysfunction shown by individuals with psychopathy. First, there could be reduced nociceptive (US) input to the amygdala. This would result in reduced activation of the amygdala neurons and thus prevent
learning. Secondly, the amygdala neurons of individuals with psychopathy may be hypo-responsive; i.e., less likely to fire than the amygdala neurons of comparison individuals to a given level of input. This would again interfere with learning. Thirdly, there might be some cellular property of the amygdala neurons of individuals with psychopathy such that they are less capable of Hebbian learning irrespective of their level of activation. While these explanations give rise to slightly different predictions, they are unlikely to be disentangled in the near future. However, functionally their impact would be similar. The amygdala's capacity to perform aversive conditioning would be detrimentally affected.

An impairment in aversive conditioning has been confirmed on several occasions (Lykken 1957; Hare and Quinn 1971; Flor, Birbaumer et al. 2002). Moreover, recent neuroimaging work has demonstrated reduced amygdala activation in individuals with psychopathy during aversive conditioning (Veit, Flor et al. 2002). Following the VIM position, the IES model considers the sadness and fearfulness of others to be aversive unconditioned stimuli (Blair 1995; Blair 2003). In line with this suggestion, functional imaging studies have shown, with a few exceptions (Kesler/West, Andersen et al. 2001), that fearful and sad expressions all modulate amygdala activity (Schneider, Gur et al. 1994; Breiter, Etcoff et al. 1996; Morris, Frith et al. 1996; Phillips, Young et al. 1997; Phillips, Young et al. 1998; Baird, Gruber et al. 1999; Blair, Morris et al. 1999; Drevets, Lowry et al. 2000). Moreover, in line with the amygdala dysfunction hypothesis, individuals with psychopathy show pronounced impairment in processing sad and fearful facial and vocal expressions (Aniskiewicz 1979; Blair, Jones et al. 1997; Blair, Colledge et al. 2001; Blair, Mitchell et al. 2002).

Words, as any other stimuli, can become aversive and appetitive CSs if they are paired with either aversive or appetitive USs. Thus, "murder" is an aversive CS and "love" is an appetitive CS. Such affective word stimuli generate a neural response within the amygdala (Hamann and Mao 2002). In line with the amygdala dysfunction hypothesis developed here, while comparison individuals show autonomic responses to unpleasant or fearful experiences they have been asked to imagine, individuals with psychopathy do not (Patrick, Cuthbert et al. 1994).

As illustrated in Figure 1, the interconnections of the amygdala with cortical regions are reciprocal (Amaral, Price et al. 1992). Thus, activation of the amygdala by a linguistic CS such as the word "murder" will subsequently result in increased activation of the representation of this linguistic CS because of reciprocal activation from the amygdala. In short, emotional words are more salient than neutral words because of these reciprocal connections and are thus likely to be processed more rapidly. It is these interconnections, according to the IES model,
that drives the emotion facilitation effect in lexical decision tasks. Dysfunction in the formation of these interconnections in individuals with psychopathy leads to their lack of facilitation for emotional words in the lexical decision task.

The amygdala, and particularly the basolateral nucleus of the amygdala, are known to be implicated in instrumental learning, including passive avoidance learning (Killcross, Robbins et al. 1997; Ambrogi Lorenzini, Baldi et al. 1999; Everitt, Cardinal et al. 2000; LeDoux 2000). Within the IES model, three additional modules of non-linear, identical computational units are used to describe instrumental learning. The first of these corresponds to units coding motor responses and includes premotor cortex and basal ganglia. The second corresponds to units coding expectation of reward/punishment (medial OFC). These expectations are provided by the amygdala. The suggestion is that units in medial OFC receive information in order to solve response competition on the basis of not only the activation of premotor units but also expectations of reinforcement provided by the amygdala. In addition, they receive input from units from the third module, possibly involving anterior cingulate, representing desired goal states. The suggestion would be that reinforcer devaluation (Gallagher, McMahan et al. 1999; Baxter, Parker et al. 2000) would reduce potential activation of the corresponding units in OFC. This would reduce the probability that a response associated with these units would be chosen; the units involved would be less likely to win out in competition with other units that had not associated with reinforcer devaluation.

Amygdala lesions impair instrumental learning, including passive avoidance learning (Killcross, Robbins et al. 1997; Ambrogi Lorenzini, Baldi et al. 1999; Everitt, Cardinal et al. 2000; LeDoux 2000). In line with the suggestion that individuals with psychopathy show amygdala dysfunction, individuals with psychopathy show marked impairment on measures of instrumental (Fine, Richell et al. submitted) and, in particular, passive avoidance learning (Newman and Kosson 1986; Thomquist and Zuckerman 1995; Newman and Schmitt 1998; Budhani, Johnston et al. under revision).

Response reversal involves changing a response to a stimulus as a function of a change in contingency; i.e., learning to withhold a response that is now punished though previously it had been rewarded (Rolls 1997). The reversal is the crucial component here; the individual must reverse their response to a stimulus. Response reversal is thus not involved in the passive avoidance task (Newman and Kosson 1986) where the individual simply learns to respond to some stimuli and withhold responses to others but never to reverse their response to a stimulus. There is a considerable neuropsychological and neuro-imaging literature demonstrating that

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OFC is crucially involved in response reversal (Rolls, Hornak et al. 1994; Rahman, Sahakian et al. 1999; Cools, Clark et al. 2002).

Within the IES model, it is suggested that there are comparator units in lateral orbital that would detect mismatches between expectations of reinforcement (provided by the amygdala units) and actual reinforcement (the nociceptive input). When activated these would disrupt the connections (weights) between amygdala units and OFC units as a function of the degree of the previous strength of these connection weights. Thus, under conditions where reinforcement had been a certainty and the connection weights were high, there would be considerable disruption. Under conditions where the reinforcement contingency was less obvious and the connection weights were lower, there would be less disruption. This disruption process would allow another unit to develop the new expectation of reinforcement associated with the changed contingency to the stimulus and thus allow faster response reversal.

Within the model, the known role of OFC in response reversal (Rolls, Hornak et al. 1994; Dias, Robbins et al. 1996; Cools, Clark et al. 2002) is seen as a function of the degree to which there is a mismatch between the expectation of reinforcement, provided by the amygdala to OFC, and the presence of reinforcement. This suggests that if there is dysfunction in either the amygdala or OFC or the connections between the amygdala and OFC, response reversal will be detrimentally affected. Moreover, the greater the degree of dysfunction, the more difficult it will be for the individual to identify the contingency change.

Children with psychopathic tendencies and adult individuals with psychopathy show comparably impaired performance on measures of amygdala functioning such as passive avoidance (Newman, Widom et al. 1985; Newman and Kosson 1986), the processing of fearful expressions (Blair, Colledge et al. 2001) and aversive conditioning (Lykken 1957; Raine, Venables et al. 1996). However, there is less clear evidence that children with psychopathic tendencies show comparably impaired performance on measures requiring OFC such as response reversal. Newman's card playing task (Newman, Patterson et al. 1987) involves response reversal; the participant learns to play the card for reward but then must extinguish this response as, proceeding through the pack of cards, the probability of reward decreases successively. Both children with psychopathic tendencies and adult individuals with psychopathy show marked impairment on this task (Newman, Patterson et al. 1987; O'Brien and Frick 1996; Fisher and Blair 1998). However, another paradigm, the ID-ED task also includes response reversal; the participant must reverse their responding from the object that, when responded to, had elicited rewarded but which now elicits punishment. While adult individuals with psychopathy show notable impairment in response reversal on this task
(Mitchell, Colledge et al. 2002), children with psychopathic tendencies do not (Blair, Colledge et al. 2001). A major difference between these two tasks is in the salience of the contingency change. In the card-playing task, the probability of reinforcement decreases by 10% over every ten trials. In the ID-ED task, the probability of reinforcement changes from 100% to 0% once the initial learning criterion has been achieved. This indicates that while both children with psychopathic tendencies and adult individuals with psychopathy are impaired in the detection of contingency change, this impairment is markedly greater in the adult individuals with psychopathy. Moreover, this suggests that if we reduce the salience of the contingency change, we should see impairment in the children with psychopathic tendencies and that the degree of impairment will be a function of the salience of the contingency change. This was tested using a probabilistic response reversal paradigm, where the probability of reward was different across pairs (i.e., for pair 1, stimulus 1 was rewarded 100% of the time, for pair 2, stimulus 3 was rewarded 90% of the time etc). While the children with psychopathic tendencies showed no difficulty reversing their responses for salient contingency changes, they did show significant difficulty as the salience of the contingency change decreased (Budhani et al in preparation). That is, the indications are that although children with psychopathic tendencies do not show the same degree of impairment of on OFC, they do have OFC impairments.

1.5.: Conclusion

In summary, there are at least two types of system that regulate our behaviour. One type of system regulates our behaviour according to task demands or goals that are frequently affect-neutral. Models of this executive system include the SASF (Norman and Shallice 1986), and the context module model (Cohen, Dunbar et al. 1990). One prototypical task used to assess this type of functioning is the Stroop task (Stroop 1935). In Chapter Two, Stroop performance in healthy individuals will be explored using the Number Stroop task. It has been suggested that in individuals with psychopathy there is an executive dysfunction (Gorenstein 1982; Newman, Schmitt et al. 1997; Raine 2002). Thus, in Chapter Three, the executive functioning in individuals with psychopathy will be assessed using neuropsychological tasks, including the Number Stroop task.

The second type of system regulates our behaviour according to reinforcement history and allows decision making on the basis of likely rewards and punishments for particular behavioural choices in particular situations. Models of this type of emotional learning system include the BIS/ BAS model (Gray 1971; Gray 1972; Gray 1975; Gray 1977; Gray 1982; Gray 1987; Patrick 1994; Gray and McNaughton 1996; Corr, Pickering et al. 1997; McNaughton and
Gray 2000). It has been suggested that in individuals with psychopathy there is an emotional learning impairment (Gray 1987; Fowles 1988). Thus, in Chapter Four and Five, emotional processing in individual with psychopathy will be assessed.

But, of course, outside the laboratory settings, these two systems will frequently interact to guide our behaviour. In Chapter Six, the results from a fMRI imaging study requiring the interaction of the two systems will be discussed.

1.6.: Ethical Considerations

The studies described in this thesis do not involve any placebo, medication washout, or provocative or painful stimuli. The paradigms used in Chapter One, Two, Three, and Four all involved relatively affect-neutral stimuli (e.g., number stimuli, simple drawings), however the paradigms used in Chapter Five and Six were specifically designed to explore emotional processing and so did involve emotionally valenced stimuli. These stimuli were screened by the research group and deemed to not involve offensive, repulsive, frightening, or erotic content.

The studies described in Chapter Three, Four, and Five involved individuals currently incarcerated. Prison-based research has been criticized on grounds that prisoners may represent a population vulnerable to coercion and with a limited capacity for voluntary informed consent (Veneziano 1986); although see Moser 2004 (Moser, Arndt et al. 2004). I was very aware of this issue throughout my dealings with this population. Thus, during recruitment it was clearly described to each potential participant that no psychiatric, financial or legal benefits would be derived from participation. However, individuals working in one of the workshops would be compensated for their time away from work with an amount equal to that received had they been at work during the testing session. Informed consent was obtained specifically by me or, in some cases, other members of the research team. Potential participants were required to read the consent form and were encouraged to ask any question they might have had. The participants would typically begin participation in the study immediately upon signing the consent form. Confidentiality provisions included the storing of participants’ names in a locked cabinet and the identification of data stored digitally by a code and not by the names of individual participants.
Chapter Two

Networking Among Numbers: The Stroop Effect Revisited

2.1.: Introduction

In Chapter One, I described two over-arching ways in which an individual’s behaviour is modified: by the influence of valence-independent executive functions and by the influence of the individual’s past reinforcement history. In this chapter, I will consider the developmental process of a new paradigm of executive control: The Number Stroop task. In addition, I will consider the implications of this work for three main forms of account of the Stroop effect: The relative speed of processing account (Morton and Chambers 1973; Posner 1978; Schooler, Neumann et al. 1997), the automaticity account (Shiffrin and Schneider 1977; Hasher and Zacks 1979; MacLeod and Hodder 1998), and the task context module model (Cohen, Dunbar et al. 1990; Cohen, Botvinick et al. 2000).

2.1.1.: The Stroop Effect

The classic word-colour Stroop task (Stroop 1935) is a very familiar paradigm. The Stroop task traditionally refers to the second of three different experiments reported by Stroop (see Figure 2.1. for example of test stimuli). Specifically, he reported that it took longer for participants to name the colour of the ink in which a colour word was written (so, for example, naming ‘blue’ for the first stimulus on our list) compared to naming the colour of colour patches (so naming ‘blue’ to the first colour patch). It is this increased colour naming latency that is referred to as the Stroop effect.

Figure 2.1.: Test stimuli from Stroop’s Experiment 2.
Much less widely reported is Stroop's Experiment 1. This experiment examined the effect of incompatible ink colours on reading words aloud (see Figure 2.2. for example of test stimuli). In the incongruent condition, colour words (e.g. GREEN) were presented in inconsistent ink colours (e.g. the word GREEN printed in blue ink). In the control condition, the colour words appeared in black ink. Stroop found that the incongruent hues did not interfere with the reading of the colour words. Thus, in the word-colour task, there are *asymmetrical interference effects*.

![Figure 2.2.: Test stimuli from Stroop's Experiment 1.](image)

The cause of the asymmetry in the Stroop effect has excited considerable debate. Three main forms of position have been proposed. These are the *relative speed of processing account* (Morton and Chambers 1973; Posner 1978; Schooler, Neumann et al. 1997), the *automaticity account* (Shiffrin and Schneider 1977; Hasher and Zacks 1979; MacLeod and Hodder 1998), and the *task context module model* (Cohen, Dunbar et al. 1990; Cohen, Botvinick et al. 2000).

**2.2.: Models of the Stroop Effect**

**2.2.1.: The Relative Speed of Processing Account**

According to the relative speed of processing account, the asymmetrical interference pattern is a direct outcome of word reading being faster than colour naming (Morton and Chambers 1973; Posner 1978; Schooler, Neumann et al. 1997). It is suggested that the word and the hue are processed in parallel until they reach a single channel exit, at which time the two responses compete for entry. During an incongruent trial, the conflicting word information arrives at the limited capacity response buffer earlier than the hue information, causing interference in the response stage. In contrast, when the task is to read the word, competition
(interference) is rare because the colour information lags behind the word information, and reaches the output buffer after the reading response.

\[\begin{array}{ll}
\text{TIME1} & \text{Both forms of information enter the processing stream.} \\
\text{TIME2} & \text{Word information is ahead of colour information.} \\
\text{TIME3} & \text{Word information has reached the response buffer ahead of time and conflict ensues.}
\end{array}\]

**Figure 2.3:** Diagram of the speed of processing account of Stroop interference.

The speed of processing account faces two major challenges. First, if the reason for the asymmetry of the Stroop effect is because colour naming is slower than word reading, then presenting the colour stimulus sufficiently before the word stimulus should abolish the Stroop effect. However, this does not appear to occur (Glaser and Glaser 1982); though, for contrasting data, (Schooler, Neumann et al. 1997). Secondly, the speed of processing account should predict that if practicing one dimension of a Stroop task speeds that dimension relative to the other, then if the initially slower dimension is practiced until it becomes the faster one, the pattern of interference should reverse. While level of practice has an impact on the magnitude of the Stroop effect and can even result in the predicted inversion of the Stroop effect, this crucially does not occur as a function of the relative speed of processing of the two dimensions (MacLeod and Dunbar 1988).

**2.2.2.: The Automaticity Account**

According to the original version of the automaticity account (Shiffrin and Schneider 1977; Hasher and Zacks 1979), certain processes are automatic; they are rapid, independent of processing strategy, and do not rely upon cognitive resources. Other processes are controlled; they are slower, dependent on processing strategy, and rely upon cognitive resources. The suggestion is that automatic processes produce interference with controlled processes because they cannot be ignored, but controlled processes do not interfere with automatic processes. As
regards the Stroop effect, the suggestion was that the automatic reading process interfered with
the controlled process of colour naming. More recently, the narrow dichotomy between
automatic and controlled processes has been rejected in favor of a continuum of automaticity
view (Kahneman and Chajczyk 1983; MacLeod and Dunbar 1988; MacLeod and MacDonald
2000). The suggestion is that it is the relative differential automaticity that accounts for the
Stroop effect (MacLeod and MacDonald 2000). Manipulations, such as increasing practice for
a dimension, should increase its automaticity and therefore the probability that it will result in a
Stroop effect on another dimension.

2.2.3.: The Task Context Module Model

In some respects, the task context module model could be considered a formal
representation of the automaticity account (Cohen, Dunbar et al. 1990; Cohen,
Servan-Schreiber et al. 1992). The model has already been described in Chapter One, however it will
be briefly summarized here. In its simplest form, the model consists of two processing
pathways, one for word reading and one for colour naming. Processing occurs via activation
spreading between units along the pathways. The strength of these pathways is determined by
the degree of training that the model receives for a specific class of input. The model receives
more extensive training on the word reading task than the colour naming task following the
assumption that humans have more extensive experience with the former than the latter. This
asymmetry in training intensity leads to greater connection weights in the word reading path
compared to the colour naming path; i.e. following training, word reading becomes the
prepotent response. Although the automaticity and task context module models have some
similarities, they differ in at least one major respect. The task context module model stipulates
the existence of an executive feature, the context module. This contains units that become
active dependent on task instructions. In conditions of response competition (i.e., naming the
hue), the context module resolves the conflict by means of supporting the processing of the task
relevant information so that it can out-compete the task irrelevant information. Thus, the task
context module model predicts that an individual’s level of Stroop interference is not only a
function of training on the respective domains but also the degree to which the context module
is functioning efficiently.

2.3.: A Question of Discriminability?

All of the above accounts have been challenged recently by claims that the Stroop
effect is due to the discriminability of the dimensions; the more discriminable dimension
interferes with the less discriminable dimension but not vice versa (Melara and Mounts 1993; Algom, Dekel et al. 1996; Pansky and Algom 2002). Thus, by varying the relative discriminability of the colours and words used, Melara and Mounts (1993) were able to produce both Stroop (when words were more discriminable than colours) and reverse Stroop (when colours were more discriminable than words) effects. Similarly, using a numerical Stroop, Algom, Dekel and Pansky (1996) manipulated the discriminability of the numerical and physical size of single digits, matching it in one condition but rendering one or other dimension more discriminable in other conditions. The more discriminable dimension disrupted the processing of the less discriminable dimension but not vice versa. These authors in addition claims that Stroop interference is also in part a result of a mismatch of the numbers of stimuli used on the two Stroop dimensions, with a many-valued stimulus dimension interfering with the fewer-valued dimension and not vice versa (Pansky and Algom 2002). If the magnitude of the Stroop effect is only affected by manipulations of discriminability or numbers of stimuli then all of the above models are in serious difficulty.

In addition, whilst the above models have considered how the interaction of two processing dimensions might impact on the Stroop effect, there is little consideration of the implications of the properties of the dimensions themselves for the Stroop effect. Thus, word reading and, presumably, colour naming involves the activation of semantic information. Intuitively, we might consider that the degree of semantic association between the stimuli processed by the competing dimensions might impact on the level of the Stroop effect. Indeed, data suggests that the degree of interference exerted by a word on hue naming is a function of the strength of the semantic association between the word and the hue (Klein 1964; Klopfer 1996). Such data is problematic for current formulations of the task context module model in particular; inter-stimulus associations are not modeled in this model.

The current lack of consensus regarding an appropriate model of the Stroop effect may be partially due to the over-reliance on the use of the word-colour task to differentiate among these models. The ability of the word-colour task to differentiate between the models is challenged by several limitations, including the lack of a formal way of determining word discriminability (Melara and Mounts 1993) and difficulties in quantifying inter-stimulus levels of association. There may be advantages to using other Stroop paradigms to distinguish between the models, for example the Number Stroop paradigm. Thus, the discriminability of the two dimensions can be matched by having the equivalent numerals and numerosities (i.e., counting 1 to 6 stimuli made up of the numerals 1 to 6).
As regards inter-stimulus association levels, the difference or strength of association between different numbers has been quantified and is a function of distance (Dehaene, Bossini et al. 1993). Distance effects can be shown in both selection and classification tasks. In selection tasks, two numbers are presented and the participant has to indicate which number is the smaller or larger. In classification tasks, a single target number is presented and the participant indicates whether it is larger or smaller than a standard of reference. In both tasks, response latencies decrease as the distance separating the items to be compared increases (Moyer and Landauer 1967; Parkman 1971; Banks, Fujii et al. 1976). This pattern of results is called the *symbolic distance effect* (Moyer and Bayer 1976). Distance effects are not only shown for individual digits but also two-digit numbers (Restle 1970; Dehaene, Dupoux et al. 1989) and dot arrays compared for numerosity (Buckley and Gillman 1974). These studies have been taken to indicate that there is a mental representation of number line representation (Moyer and Bayer 1976; Dehaene and Changeux 1993). In the view of the symbolic compressed number line hypothesis (Moyer and Landauer 1967; Restle 1970), the symbolic distance among numbers decrease as numerical value increases. Thus, in contrast to words and colours, the strength of association among numbers has been identified.

Various Number Stroop paradigms have been developed. Besner and Coltheart (Besner and Coltheart 1979) asked participants to indicate which numeral was larger in value from pairs of Arabic numerals. The numerically larger numeral could be physically larger (congruent stimuli), physically smaller (incongruent stimuli), or alternatively, the two stimuli were of equal physical size (neutral stimuli). The authors reported facilitation for congruent stimuli and interference for incongruent stimuli (Vaid and Corina 1989). Parallel findings have been reported for numerosity (rather than physical magnitude) as the task-irrelevant dimension (Morton 1969; Shor 1971; Flowers, Warner et al. 1979), as well as for judgements of physical size (Morton 1969; Flowers, Warner et al. 1979; Henik and Tzelgov 1982). However, many of these Number Stroop paradigms can be criticized on the grounds of asymmetrical stimulus dimensions (Pansky and Algom 2002). Thus, in the Besner and Coltheart (1979) study, the numbers 1 to 9 were used for the numerical dimension but only two values (2.3 X 1.7 cm ['large'] and 1.5 X 1.0 cm ['small']) were used for the physical dimension (Besner and Coltheart 1979). According to Melara and Mounts (1993), this asymmetry could in itself have determined the magnitude and pattern of the observed interaction; the mere number of stimuli on an irrelevant dimension affects classification performance on the relevant dimension.

The discriminability argument is however less easily used to explain Number Stroop effects when the participant must count different numbers of Arabic numerals (Morton 1969;
Pavese and Umilta 1998; Pavese and Umilta 1999). In these studies, the magnitude of the numerosity and numeral dimensions was equivalent; i.e., participants had to count arrays of one to nine elements that were the Arabic numerals 1-9 (Pavese and Umilta 1998; Pavese and Umilta 1999) or alternatively count arrays of one to six elements that were the Arabic numerals 1-6 (Morton 1969). In addition, because these paradigms use the same number of stimuli on the two dimensions Stroop effects also cannot be due to a mismatch in the numbers of stimuli used on the two dimensions.

The work with the Arabic numeral counting Stroop has also been interesting because of its elicitation of inter-stimulus association. Thus, Pavese and Umilta (1998; 1999) showed that symbolic distance between numerosity and digit identity modulates interference; the less the difference, the greater the interference. Moreover, Pavese and Umilta (1998; 1999) demonstrated that a distracter that was one numerical unit greater than the target number led to more interference than a distracter that was one numerical unit less than the target.

2.4: Summary of the models: Means changing the numbering

In the previous four sections, I have summarized four main accounts of the Stroop effect: the relative speed of processing account, the automaticity account, the task context module model and the discriminability account. Amongst these four, the discriminability position stands out. This is because it is a different form of account. Specifically, the discriminability position is not an information processing model. It is an account that suggests that the Stroop effect is an artifact of the form in which the stimuli are presented. It does not attempt to provide a detailed theory of why stimuli in this form (i.e., the presentation of dimensions of different discriminability) should give rise to the Stroop effect. Rather it lays down conditions under which it predicts that the Stroop effect should not occur.

The other three accounts (relative speed of processing account, the automaticity account, the task context module model) share several important similarities. First, all three are dual route models. All three models assume that there are reading and color naming processing pathways that are relatively independent. Secondly, all three assume that the Stroop effect is a consequence of the differential properties of the two routes. All three assume that over-exposure to one form of processing gives rise to a pathway that operates more efficiently than the other. This leads us on to the first major difference between these three accounts. This is that while the automaticity and task context module accounts assume that the more efficient route (reading) activates the corresponding output representation to a greater degree than the less efficient counting route, the speed of processing position suggests that the more efficient
route activates the corresponding output representation faster than the less efficient route. The second difference between these three accounts is that only the speed of processing account considers that the Stroop effect might not only be due to interference at the level of an output response. According to the automaticity and task context module models, the Stroop effect is an inverse function of the difference in the activation levels of the two competing output representations. In contrast, the speed of processing account appears to consider that the more efficient route may interfere with the less efficient route before, in the terms of that model, the response buffer (Morton 1969). Specifically, information from the reading route may interfere with the processing of the hue information at the level of semantic representations as well (Morton 1969). The third difference between these three positions is that only the task context module account speculates specifically about the existence of an executive system. The task context module model assumes that this system, the task context module itself, is crucial for appropriate Stroop performance. The task context module model can thus explain increased Stroop effects as a consequence of the lesion of one potential neural implementation of this context module; the anterior cingulate. In contrast, the speed of processing and automaticity accounts can only readily explain increases in Stroop effects in terms of the relative efficiency of the two processing pathways.

By the end of this chapter, I will have suggested the development of a model that can be considered an extension of specifically the speed of processing and task context module models. It can be considered an extension of the speed of processing position in that it suggests that the Stroop effects cannot only be considered a product of interference at the level of the output response. Indeed, I will argue that an account of the Stroop literature requires the consideration of the impact of semantic representations on the emergence of the Stroop effect. It can be considered an extension of the task context module in that the postulation of an executive system, such as the task context module, is necessary to provide a full account of the effect.

2.5.: Aims and Predictions

The first experiment attempted to replicate and extend the work of Morton (1969) and Pavese and Umilta (1998; 1999). Specifically, in addition to examining the impact of reading the Arabic numerals on counting the number of these numerals, we also examined the impact of counting the number of numerals on reading the numerals in an event-related design. The discriminability account makes predictions according to the discriminability and number of stimuli used on the two dimensions used. If the two dimensions are considered to be equated in
terms of discriminability and numbers of stimuli used there should be no interference effects. If they are considered to be mismatched there should be interference from one dimension only. The speed of processing accounts make predictions on grounds of the speed of processing of the two dimensions. Thus, if the speed of processing of the two dimensions is similar, bidirectional Stroop interference would be expected. Conversely, discrepancies in the speed of processing of the two dimensions should lead to asymmetrical interference effects. In addition, we wished to examine inter-stimulus association and, particularly, if a reverse Stroop was shown, whether the same patterns of inter-stimulus association would be shown for both forms of Stroop interference.

2.6.: Experiment 1

The first experiment involved the Arabic numeral Stroop developed by Morton (Morton 1969; Morton 1969) and Pavese and Umilta (1998; 1999). In contrast to Pavese and Umilta (1998; 1999), I chose to switch the response modality from oral to manual to maximize the possibility of interference effects. Studies of stimulus-response compatibility have consistently shown that this can influence the degree of interference; manual responses lead to heightened interference (Zakay and Glicksohn 1985; MacLeod 1991). In line with Morton (1969), the study would investigate both the impact of reading on counting and also of counting on reading. It was predicted that participants would be slower to respond to incongruent trials than to congruent trials. It was also predicted that the symbolic distance between numerosity and digit identity would modulate this interference such that interference would be an inverse function of symbolic distance. Moreover, the number of errors was expected to increase with increase degree of interference. In addition, it was predicted that a distracter that was one numerical unit greater than the target number would lead to more interference than a distracter that was one numerical unit less than the target.

2.7.: Method

2.7.1.: Participants

Forty (23 men and 17 women) native English-speaking postgraduate students and researchers were recruited from the Institute of Cognitive Neuroscience (ICN) at University College London. Their mean age was 24 years with a range of 20-41 years. Participants had not previously participated in experiments using Stroop methodology. All reported normal or corrected-to-normal vision and were unaware of the purpose of the experiment.
2.7.2.: Design

The experiment involved a repeated measures split level design with Congruence (congruent, incongruent), Target Number (one, two, three, four, five, and six), Distance (one, two, three, four, and five), and Relative Distance (1 above target and 1 below target) as within-participants factors and Task (counting, reading) as between-participants factor. The dependent variables were mean RT (measured in milliseconds) and error rates.

2.7.3.: Apparatus and Materials

Stimuli were developed and controlled by the software SuperLab Pro and presented on a Mac G3 equipped with an Apple colour monitor. The display was a standard phosphorous display with a graphic resolution of 1024 x 768. Responses were recorded by means of six keys, with key ‘E’ denoting response number 1, ‘R’ denoting 2, ‘T’ denoting 3, ‘U’ denoting 4, ‘I’ denoting 5, and key ‘O’ denoting 6. This choice of response keys, jumping key ‘Y’, assured that there was enough space for the fingers to rest relaxed on the keyboard. Stimuli appeared in black against a white background, and were presented in the center of the screen using the Macintosh system font Times (type size = 48 points).

\[
\begin{array}{ccc}
&a&b&c\\
&5&5&5\\
\end{array}
\]

\[
\begin{array}{ccc}
&d&e&f\\
&5&5&5\\
&5&5&5\\
\end{array}
\]

**Key to Figure.**: a = 1.5, b = 2.5, c = 3.5, d = 4.5, e = 5.5, f = 6.5.

**Figure 2.4.**: Test stimuli used in Experiment 1 involving the digit 5.

Stimuli were patterns of one, two, three, four, five, or six digit 1s, 2s, 3s, 4s, 5s, and 6s. The patterns were identical for all stimuli with a particular numerosity. Patterns resembled those on a dice (see Figure 2.4. for example stimuli involving the digit 5). All possible combinations of numerosities and digits occurred. So, for example, one digit 1 was depicted in one event (1.1), two digit 1s in another event (2.1), three 1s in a third event (3.1), four 1s in a
fourth event (4.1), five 1s in a fifth (5.1), and finally six 1s in a last event (6.1). The digits 2, 3, 4, 5, and 6 were similarly presented in six different patterns. Thus, the final stimuli set consisted of (6 x 6) 36 different events. Of these, six events were congruent (1.1, 2.2, 3.3, 4.4, 5.5, and 6.6) and thirty were incongruent.

2.7.4.: Procedure

The experiment was conducted in a dimly illuminated room. Participants were seated approximately fifty-five centimeters from the screen and told to rest their index, middle, and ring finger of both hands lightly on the appropriate keys. For half of the participants, instructions read: 'In this task, you are going to see numbers on the screen. You must press the button which corresponds to the number of numbers on the screen. So, if there are three 4s you must press the '3' button. Try to do this as quickly as possible without making errors'. For the other half of the participants, instructions read: 'In this task, you are going to see numbers on the screen. You must press the button which corresponds to the number on the screen. So, if there are three 4s you must press the '4' button'. In other words, half of the participants were asked to count the number of numbers presented on the screen, while the other half of the participants were asked to read the number presented on the screen. Participants initiated the first trial by pressing any key on the keyboard.

Each trial began with a fixation point (+) presented for 500 ms in the middle of the screen. When the fixation point extinguished, it was replaced immediately with the Stroop stimulus for that trial. The Stroop stimulus was exposed until a response from the participant was registered, at which point the screen went blank prior to presentation of a new fixation point initiating the next trial. Participants did not receive feedback on their performance either before or after the experiment. Trials were presented randomly within each block, and all 36 trials were presented in every block. The entire experiment consisted of 10 blocks. Thus, a total of 360 trials were presented to each participant. The first block was regarded as a practice block.

2.8.: Results

The first block of practice trials was not analyzed. Mean RTs and mean error rates were calculated for each trial subsequent to removing trials on which the RT exceeded 1500 ms or was below 250 ms (see Tables 2.1. and 2.2.). RTs were entered into split level analyses of variance (ANOVAs) to assess the effect of task, congruency, and numerosity on RTs. Both RTs and error rates were entered into additional ANOVAs to assess the effects of task and
symbolic number line distance on Stroop interference. Data from two participants were excluded as the error rates exceeded 10 percent.

<table>
<thead>
<tr>
<th>Numerosity</th>
<th>Digit</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>1-6</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>499</td>
<td>101</td>
<td>601</td>
<td>135</td>
<td>565</td>
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<td>583</td>
<td>152</td>
<td>639</td>
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<td>3</td>
<td></td>
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<td>705</td>
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<td>628</td>
<td>169</td>
<td>642</td>
</tr>
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<td></td>
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<td>696</td>
<td>142</td>
<td>727</td>
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</tr>
<tr>
<td>5</td>
<td></td>
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<td>638</td>
<td>131</td>
<td>656</td>
<td>123</td>
<td>696</td>
</tr>
<tr>
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<td></td>
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<td>102</td>
<td>578</td>
<td>83</td>
<td>584</td>
<td>98</td>
<td>620</td>
</tr>
</tbody>
</table>

Key to Table: Bold = congruent stimuli

Table 2.1.: Mean latencies to numerosity in milliseconds and S.D.s in bracket () as a function of numerosity and digit identity in the counting condition.

<table>
<thead>
<tr>
<th>Digit</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>1-6</th>
</tr>
</thead>
<tbody>
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<td>533</td>
<td>150</td>
<td>570</td>
<td>173</td>
<td>579</td>
</tr>
<tr>
<td>2</td>
<td>550</td>
<td>100</td>
<td>564</td>
<td>107</td>
<td>628</td>
<td>128</td>
<td>634</td>
</tr>
<tr>
<td>3</td>
<td>618</td>
<td>73</td>
<td>630</td>
<td>111</td>
<td>625</td>
<td>90</td>
<td>671</td>
</tr>
<tr>
<td>4</td>
<td>587</td>
<td>89</td>
<td>653</td>
<td>119</td>
<td>666</td>
<td>96</td>
<td>675</td>
</tr>
<tr>
<td>5</td>
<td>615</td>
<td>129</td>
<td>612</td>
<td>98</td>
<td>624</td>
<td>106</td>
<td>665</td>
</tr>
<tr>
<td>6</td>
<td>540</td>
<td>89</td>
<td>558</td>
<td>94</td>
<td>606</td>
<td>153</td>
<td>629</td>
</tr>
</tbody>
</table>

Key to Table: Bold = congruent stimuli

Table 2.2.: Mean latencies to digit identity (in milliseconds and S.D.s in bracket () as a function of numerosity and digit identity in the reading condition.

2.8.1.: Congruence Analysis

A split level ANOVA with Congruence (congruent, incongruent) as within-participants factor and Task (counting, reading) as between-participants factor was performed on the data. The analysis revealed a highly significant effect for Congruence; RTs to congruent stimuli were significantly faster than RTs to incongruent stimuli (F(1,38) = 36.94; p < 0.001: M(congruent) = 577, s.d. = 111; M(incongruent) = 621, s.d = 105). There was no significant Congruence by Task interaction and there was no significant main effect of Task. Thus, Stroop
and reverse Stroop effects were identified in this study; reading interfered with counting but counting also interfered with reading.

2.8.2.: Target Number Analysis

In order to examine whether RTs for the six different target numbers differed significantly, and so required separate analyses, a split level ANOVA with Target Number (one, two, three, four, five, and six) as within-participants factor and Task (counting, reading) as between-participants factor was employed. This revealed a highly significant main effect of Target Number ($F(5,190) = 29.57; p < 0.001$), with the linear ($F(1,38) = 17.13; p < 0.001$), quadratic ($F(1,38) = 56.49; p < 0.001$), cubic ($F(1,38) = 6.47; p < 0.05$), and order 4 ($F(1,38) = 7.59; p < 0.01$) contrasts being significant. That is, participants were faster in their responses to some target numbers than others (see Table 2.1. and 2.2.). There was no significant Target Number by Task interaction and there was no significant main effect of Task. That is, the effect of target numbers on RTs was similar for counting and reading.

2.8.3.: Symbolic Number Line Distance and RT Interference

To investigate the effect of symbolic number line distance on Stroop interference, a one-factor within-participants ANOVA with Distance (1, 2, and 3) as within-participants factor was initially applied to the entire data set. For each distance, trials were collapsed where two trials represented the same symbolic distance. Thus, RTs on trial 1.2, 2.1, 3.2, 3.4, 4.3, 4.5, 5.4, 5.6, and 6.5 were collapsed for distance 1; trials 1.3, 2.4, 3.1, 3.5, 4.2, 4.6, 5.3, and 6.4 made up distance 2, and finally the mean RT for distance 3 was obtained by collapsing trial 1.4, 2.5, 3.6, 4.1, 5.2, and 6.3. Mauchly's test of sphericity was significant so the more conservative Greenhouse-Geisser was used on the data. There was a highly significant main effect of Distance ($F(1.59,60.53) = 21.05; p < 0.001$), with the linear ($F(1,38) = 27.84; p < 0.001$) contrast being significant (see Figure 2.5. and 2.6.). There was no significant Distance by Task interaction and there was no significant main effect of Task. That is, the effect of Distance on RTs was similar whether the participant was counting the numerals (and showing interference from reading) or reading the numerals (and showing interference from counting). The increment of RTs as a function of decreased symbolic number line distance averaged 23.5 ms (see Table 2.3. and 2.4.).
2.8.4.: Symbolic Number Line Distance and Error Interference

To investigate the effects of symbolic number line distance on error rates, and more specifically whether symbolic number line distance would manifest in error rates as well as in RTs, a split level ANOVA with Distance (1, 2, and 3) as within-participants factor and Task (counting, reading) as between-participants factor was performed on the mean error rates obtained for the individual participants. Mauchly’s test of sphericity was significant so the more conservative Greenhouse-Geisser was used on the data. There was a highly significant main effect of Distance (F(1.6, 60.88) = 8.73; p < 0.001), with the linear (F(1, 38) = 11.86; p <
contrast being significant (see Table 2.3. and 2.4.). There was no significant Distance by Task interaction and there was no significant main effect of Task. That is, the effect of Distance on error rates was similar whether the participant was counting the numerals (and showing interference from reading) or reading the numerals (and showing interference from counting).

### Symbolic number line distance

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>674 (127)</td>
<td>653 (113)</td>
<td>618 (103)</td>
</tr>
<tr>
<td>Error</td>
<td>0.53 (0.36)</td>
<td>0.51 (0.51)</td>
<td>0.26 (0.23)</td>
</tr>
</tbody>
</table>

**Table 2.3.**: Mean latencies to numerosity, mean error number and S.D.s in bracket () as a function of symbolic number line distance in the counting condition.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT</td>
<td>626 (106)</td>
<td>622 (99)</td>
<td>589 (116)</td>
</tr>
<tr>
<td>Error</td>
<td>0.49 (0.38)</td>
<td>0.42 (0.38)</td>
<td>0.28 (0.25)</td>
</tr>
</tbody>
</table>

**Table 2.4.**: Mean latencies to digit identity, mean error number, and S.D.s in bracket () as a function of symbolic number line distance in the reading condition.

### 2.8.5.: Symbolic Number Line Distance for Individual Number Targets

To explore whether there might be differential symbolic number line distance effects for different number targets, a split level ANOVA with Task (counting, reading) as between-participants factor and Distance as within-participants factor was applied to each number target. For target numbers three and four, the within-participants factor consisted of three levels (Distance: 1, 2, 3). For target numbers two and five, it consisted of four levels (Distance: 1, 2, 3, 4). Finally, for target numbers one and six, the within-participants factor consisted of five levels (Distance: 1, 2, 3, 4, 5). As before, trials were collapsed where two trials represented the same symbolic distance. That is, for number target three, distance 3 was represented by trial 3.6, but distance 2 was calculated by collapsing trial 3.1 and 3.5. The main effects for Distance as well as the linear planned comparisons for Distance were significant for eleven of the twelve number targets (see Table 2.5. and 2.6.). Thus, symbolic number line distance effects were
Symbolic number line distance

<table>
<thead>
<tr>
<th>Numerosity</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<td>609 (100)</td>
<td>565 (94)</td>
<td>613 (105)</td>
<td>543 (105)</td>
<td>3.90***</td>
<td>4.17*</td>
</tr>
<tr>
<td>2</td>
<td>583 (152)</td>
<td>613 (107)</td>
<td>601 (116)</td>
<td>611 (85)</td>
<td>586 (113)</td>
<td>ns</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>628 (169)</td>
<td>691 (145)</td>
<td>662 (148)</td>
<td>649 (134)</td>
<td></td>
<td>2.81*</td>
<td>4.38**</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>678 (167)</td>
<td>734 (161)</td>
<td>708 (152)</td>
<td>665 (183)</td>
<td></td>
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<td>12.07***</td>
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<td>656 (123)</td>
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<td>636 (131)</td>
<td>3.32**</td>
<td>5.56**</td>
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<tr>
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<td>536 (104)</td>
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<td>584 (98)</td>
<td>578 (83)</td>
<td>561 (102)</td>
<td>6.69****</td>
<td>10.60****</td>
</tr>
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</table>

**Key to Table:** Bold = congruent stimuli, **** = p < .005, *** = p < .01, ** = p < .05, * = p < .05 one-tailed

**Table 2.5.** Mean latencies to numerosity in milliseconds and S.D.s in brackets ( ) as a function of numerosity and number line distance in the counting condition.
### Table 2.6: Mean latencies in milliseconds to digit identity and S.D.s in bracket () as a function of numerosity and digit identity in the reading condition.

<table>
<thead>
<tr>
<th>Digit identity</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Main effect</th>
<th>Linear contrast</th>
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<td>570 (174)</td>
<td>579 (197)</td>
<td>563 (196)</td>
<td>493 (128)</td>
<td>6.6****</td>
<td>4.38**</td>
</tr>
<tr>
<td>2</td>
<td>564 (107)</td>
<td>589 (111)</td>
<td>634 (155)</td>
<td>596 (158)</td>
<td>534 (108)</td>
<td></td>
<td>8.26****</td>
<td>14.5****</td>
</tr>
<tr>
<td>3</td>
<td>625 (90)</td>
<td>650 (111)</td>
<td>628 (82)</td>
<td>551 (83)</td>
<td></td>
<td></td>
<td>25.18****</td>
<td>34.05****</td>
</tr>
<tr>
<td>4</td>
<td>675 (153)</td>
<td>677 (119)</td>
<td>632 (87)</td>
<td>587 (89)</td>
<td></td>
<td></td>
<td>16.65****</td>
<td>26.25****</td>
</tr>
<tr>
<td>5</td>
<td>601 (147)</td>
<td>665 (97)</td>
<td>624 (106)</td>
<td>612 (98)</td>
<td>600 (105)</td>
<td></td>
<td>4.36***</td>
<td>7.34**</td>
</tr>
<tr>
<td>6</td>
<td>507 (94)</td>
<td>607 (159)</td>
<td>629 (164)</td>
<td>606 (152)</td>
<td>558 (94)</td>
<td>540 (89)</td>
<td>5.42****</td>
<td>7.73**</td>
</tr>
</tbody>
</table>

**Key to Table:** Bold = congruent stimuli, **** = p < .005, *** = p < .01, ** = p < .05
clearly demonstrated on both overall Stroop interference and on individual number targets. The main effect of Task was not significant for any of the targets and the Task by Distance interaction was only significant for the targets two and three (see Table 2.5. and 2.6.).

2.8.6.: Symbolic Number Line Distance and Relative Distracter Magnitude

In order to examine the effects of relative distracter magnitude in relation to target, a split level ANOVA with Relative Distance (1 above target and 1 below target) as within-participants factor and Task (counting, reading) as between-participants factor was carried out. RTs for number target ‘one’ and ‘six’ were excluded because it was impossible to have a distracter above ‘six’ and a distracter below ‘one’. Thus, distance 1 above target was made up by trials 2.3, 3.4, 4.5, and 5.6, and distance 1 below target consisted of RTs to 2.1, 3.2, 4.3, and 5.4. The main effect of Relative Distance was significant ($F(1,38) = 6.82; p < 0.05$): $M(1 \text{ below target}) = 653, \text{s.d.} = 116; M(1 \text{ above target}) = 670, \text{s.d.} = 116$). The Relative Distance by Task interaction was not significant and the main effect for Task was also not significant.

2.9.: Discussion

Experiment 1 explored the symbolic numerical interference effects from digit reading on digit counting, and from digit counting on digit reading. The experiment revealed the following: First, Stroop and reverse Stroop effects; i.e., digit reading interfered with digit counting and digit counting interfered with digit reading. Secondly, there was an inverse relationship between symbolic distance (between numerosity and digit identity) and RTs and error rate for both digit reading on digit counting and digit counting on digit reading. Thirdly, RTs were greater for stimuli diverging by a symbolic distance of one if the value of the distracting dimension was one greater, rather then one smaller, than the value of the target dimension.

The finding that the reading of digits interferes with their enumeration is in line with previous work showing interference in Number Stroop paradigms (Morton 1969; Flowers, Warner et al. 1979; Pavese and Umilta 1998; Pavese and Umilta 1999). In contrast, the finding of a reverse Stroop effect (counting interfering with reading) is not common in the literature. Generally, the difficulty of obtaining a reversed Stroop effect is one of the hallmark phenomena associated with the Stroop effect. Indeed, at the core of most models of Stroop interference is the attempt to explain asymmetrical effects of interference. However, Morton (1969) also
reported a bidirectional interference using a Number Stroop paradigm, albeit a smaller interference from digit counting on digit reading than digit reading on digit counting.

Of course, the speed of processing account would predict a symmetrical Stroop effect given the absence of any main effect for Task in our experiment (i.e., the fact that reading the digits was not significantly faster than counting the digits). As the processing of the two dimensions did not significantly differ in speed, both would arrive at the output buffer approximately simultaneously whichever dimension was being attended to and correspondingly there should be mutual interference (Morton and Chambers 1973; Posner 1978; Schooler, Neumann et al. 1997). In the view of the speed of processing model disambiguation at the response stage should be more difficult for highly related responses. That is, the competition between highly related responses should take longer to resolve, which translates into an increase of RTs. Therefore, the speed of processing model captures the finding that proximal number line representations result in greater RTs than more distant numbers.

The RT pattern from Experiment 1 would appear problematic for the none-or-all automaticity; neither reading nor counting can be fully controlled responses as they both interfere with the other dimension. At the same time, they cannot both be automatic responses as they are both receptive to intrusions from the other dimension. Thus, the two dimensions do not appear readily classifiable according to the strict labeling used in the none-or-all automaticity accounts. In contrast, the weaker classification by the continuum view of automaticity (MacLeod and MacDonald 2000) can encompass the two dimensions. Thus, if the two dimensions are neither fully controlled, nor fully automatic, bi-directional interference could happen. The continuum version of automaticity (MacLeod and Dunbar 1988) furthermore holds that as two responses become more similar, more common features are automatically activated in the distracter, thus increasing interference or RTs (MacLeod 1991). Therefore, this model also captures the symbolic distance effects found in Experiment 1.

As regards the discriminability hypothesis, this position suggests that the more discriminable dimension interferes with the less discriminable dimension but not vice versa (Melara and Mounts 1993; Algom, Dekel et al. 1996; Pansky and Algom 2002). From this proposition then, the current results of bi-directional interference would suggest that the two dimensions employed on the Number Stroop paradigm are equated. However, according to Melara and Mounts (1993) there should be no interference in a perfectly discrimicable paradigm. Thus, we might have cause for abandoning the discriminability position.

The data are problematic for the basic form of the task context module model (Cohen, Dunbar et al. 1990; Cohen, Servan-Schreiber et al. 1992). The problem of the current data for
this model is that they show a clear impact of the semantic structure of numerical processing on Number Stroop. Such data is problematic for the current formulation of the task context module model as it does not take into account inter-stimulus associations and cannot predict their influence on behaviour. The Cohen et al. (1998) model involves inhibitory connections in the output system that are all assumed to be of equivalent strength. Thus, it cannot simulate findings such as the current ones where the behavioural effects of one stimulus on another was a function of the number line distance between these stimuli. The only way to account for the number data would be to assume that the inhibitory weights in the output system are a function of distance. However, the model offers no principled way as to how this might be achieved.

In conclusion, Experiment 1 showed that digit reading interferes with digit counting, and that digit counting interferes with digit reading; i.e., that there was a symmetrical Stroop interference pattern. However, because different participants took part in the two experiments, it is not possible to make any definitive comparisons between performances on the two tasks. Accordingly, Experiment 2 addressed this issue by having the same participants perform both the tasks from Experiment 1. In addition, the robustness of the symbolic number line distance effects was explored by the employment of a blocked design.

2.10.: Experiment 2

In the second experiment, the same participants performed both the tasks from Experiment 1, thus allowing a direct comparison of the interference experienced by the participants on the two dimensions.

2.11.: Method

2.11.1.: Participants

Twenty (9 males and 11 females) native English-speaking students were recruited from University College London. Their mean age was 25 years with a range of 19-34 years. Participants had not had previous exposure to Stroop methodology and all had normal or corrected-to-normal vision. They were unaware of the purpose of the experiment.

2.11.2.: Design

The experiment involved a repeated measures design. The independent variables were Task (reading, counting), and Stimuli Type (congruent, neutral, distance 1, distance 2, and
distance 3). The independent variables were manipulated within participants. The dependent variables were mean RT (measured in milliseconds) and error rates.

2.11.3.: Apparatus and Materials

Stimuli were identical to those used in Experiment 1 with the additional inclusion of a neutral stimuli set required for the counting condition. The neutral stimuli set consisted of dots arranged in dice patterns identical to those used for the digit stimuli. Thus, the neutral stimuli set consisted of 6 new stimuli made up by one, two, three, four, five, and six dots (1Os, 2Os, 3Os, 4Os, 5Os, and 6Os), and the entire stimuli set consisted of (36 + 6) 42 different stimuli.

2.11.4.: Procedure

The testing environment and trial structure were identical to those used in Experiment 1. In contrast to Experiment 1, however, a blocked design was employed. Thus, one block consisted of congruent stimuli, another consisted of neutral stimuli, and finally three blocks consisted of respectively distance 1, distance 2, and distance 3 stimuli. In addition, participants were asked to count the stimuli in five blocks and read the stimuli in five different blocks (i.e. the counting task from Experiment 1 as well as the reading task from Experiment 1). Accordingly, both sets of instructions were employed. To minimize task switching effects, counting and reading blocks were presented separately. Additionally, prior to the presentation of each condition, participants received practice in that particular condition. Practice blocks consisted of the entire stimuli set presented randomly. In the counting condition, and as described above, neutral stimuli consisted of patterns of dots. In the reading condition, neutral stimuli consisted of one digit by itself (i.e., 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6). Blocks were counter-balanced within and between conditions. There were 30 stimuli in each of the experimental blocks. Thus, with a total of 10 blocks, participants were presented with an entity of 300 stimuli.

2.12.: Results

The two blocks of practice trials were not analysed. Mean RTs and mean error rates were calculated for each block subsequent to removing trials where RTs exceeded 1500 ms or were below 150 ms (see Table 2.7. and Table 2.8.). RTs were entered into bi-directional related ANOVAs to assess the effect of task and congruence on RTs. RTs as well as error rates were entered into ANOVAs to assess the effects of symbolic number line distance on Stroop interference. Data from one participant was excluded as the error rate exceeded 10 %.
### Table 2.7:
Mean latencies to numerosity in milliseconds and S.D.s in brackets () as a function of task and block.

<table>
<thead>
<tr>
<th>Task</th>
<th>Congruent</th>
<th>Neutral</th>
<th>Distance 1</th>
<th>Distance 2</th>
<th>Distance 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counting</td>
<td>557 (176)</td>
<td>613 (123)</td>
<td>718 (153)</td>
<td>657 (129)</td>
<td>648 (166)</td>
</tr>
<tr>
<td>Reading</td>
<td>496 (128)</td>
<td>516 (126)</td>
<td>563 (138)</td>
<td>539 (124)</td>
<td>515 (101)</td>
</tr>
</tbody>
</table>

**Key to Table:** Bold = congruent stimuli

#### 2.12.1.: Congruence Analysis

A two-factor within-participants ANOVA with Task (reading, counting) and Congruence (congruent, incongruent, neutral) as within-participants factors was performed on the data. The analysis showed a highly significant main effect of task ($F(1,19) = 59.77; p < 0.001$), with RTs in the reading condition being significantly faster than RTs in the counting condition, and a highly significant main effect of congruence ($F(2,38) = 13.1; p < 0.001$) with RTs to neutral stimuli slower than RTs to congruent stimuli and faster than incongruent stimuli (see Table 2.7.). The Task by Congruence interaction was significant ($F(2,38) = 6.18; p < 0.01$).

#### 2.12.2.: Symbolic Number Line Distance and RT Interference

To investigate the effect of symbolic number line distance on Stroop interference in the blocked counting-reading paradigm, a two-factor within-participants ANOVA with Task (reading, counting) and Distance (1, 2, 3) as within-participants factors was employed. This revealed a highly significant main effect of Task ($F(1,19) = 107.04; p < 0.001$), with RTs in the reading condition significantly faster than RTs in the counting condition. There was also a highly significant main effect of Distance ($F(2,38) = 5.37; p < 0.01$) with RTs increasing as a function of decreased symbolic number line distance (see Table 2.7.). The Task by Distance interaction was not significant. The mean RTs are plotted in Figure 2.7.
2.12.3.: Symbolic Number Line Distance and Error Interference

To investigate the effects of symbolic number line distance on error rates in the blocked design, a two-factor within-participants ANOVA with Task (reading, counting) and Distance (1, 2, and 3) as within-participants factors was performed on the mean error rates. The main effect of Task was highly significant ($F(1,19) = 59.78; p < 0.001$), with a greater number of errors in the counting condition compared to the reading condition. There was also a highly significant main effect of Distance, with error rates decreasing with increasing symbolic number line distance. Thus, manifestation of error rates as a function of symbolic number line distance is present in the blocked paradigm as well. The Task by Distance interaction was not significant. The mean error rates are shown in Table 2.8.

<table>
<thead>
<tr>
<th>Symbolic number line distance</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counting RT</td>
<td>718 (153)</td>
<td>658 (129)</td>
<td>648 (166)</td>
</tr>
<tr>
<td>Error</td>
<td>2.65 (2.13)</td>
<td>1.68 (1.10)</td>
<td>1.90 (2.32)</td>
</tr>
<tr>
<td>Reading RT</td>
<td>563 (138)</td>
<td>539 (124)</td>
<td>516 (101)</td>
</tr>
<tr>
<td>Error</td>
<td>1.15 (1.40)</td>
<td>0.80 (0.89)</td>
<td>0.25 (0.55)</td>
</tr>
</tbody>
</table>

Table 2.8.: Mean latencies, mean number of error and S.D.s in bracket () as a function of symbolic number line distance.
2.13.: Discussion

Experiment 2 compared interference effects for the counting and the reading task by having the same participants perform both tasks in a blocked design. The experiment revealed: First, that there was a bi-directional interference pattern; secondly, that reading interfered more with counting than vice versa; and thirdly, that there were symbolic distance effects in both conditions.

It should be noted that while the bi-directional interference pattern obtained in Experiment 2 was predicted from Experiment 1, it is rarely observed in the word-colour Stroop literature; indeed the hallmark of the word-colour task is the asymmetry of interference. That is, a reversed Stroop effect is only ever obtained by manipulating the word dimension by means of rotation, masking, or partial obstruction (Gumerik and Glass 1970; Dyer and Severance 1972). In contrast, numerical interference paradigms have indicated that bi-directional interference can be obtained when numerical dimensions are employed on both dimensions (Morton 1969).

The speed of processing accounts are typically considered to have a rather strict dichotomy; the faster process can interfere with the slower one, but not vice versa (MacLeod and Dunbar 1988). However, the speed of processing account can account for, and indeed would predict, bidirectional interference in paradigms employing two dimensions with similar speed of processing. Indeed, Morton (1969) reported bidirectional interference effects in his Number Stroop paradigm where the interference was indicated to be greater for one of the two dimensions used. Thus, it may be more suitable to say that according to the speed of processing accounts, a (much) slower dimension should not interfere (much) with the faster dimension. However, in Experiment 2 we found that the processing of one dimension was significantly faster than the processing of the other dimension. The question is then just how much slower the slower of the two dimensions can be and still interfere with the faster dimension according to the speed of processing accounts.

As with Experiment 1, the bi-directional interference pattern from Experiment 2 is problematic for the non-or-all automaticity view; neither reading nor counting can be fully controlled responses as they both interfere with the other dimension. However, the more weak classification by the continuum view of automaticity (MacLeod and MacDonald 2000) can encompass the two dimensions. In addition, the differential RTs to the two dimensions also does not pose a problem with the continuum view of automaticity; it is the degree of practice rather than strict speed of processing that determines the automaticity of any given process.
The implications of the results of Experiment 2 for the *task context module model* (Cohen, Dunbar et al. 1990; Cohen, Servan-Schreiber et al. 1992) remain the same as those of Experiment 1. The model needs to take into account inter-stimulus associations and cannot predict their influence on behaviour. I suggested before one way in which this might be achieved given that the 1998 version of the model incorporated inhibitory connections in the output system. While the 1998 version of the model assumed these all to be of equivalent strength, we could account for the number line data by assuming that the strength of the inhibitory weights in the output system are a function of distance (see Figure 2.8.).

This generates some interesting predictions for conditions under which multiple distracters are presented to the participant; i.e., the participant having to count three 4s and 5s. If we account for the number line data by assuming that the strength of the inhibitory weights in the output system are a function of distance, then we can predict that the condition when the distracters “bracket” the target number (i.e., three 2s and 4s) will elicit significantly higher RTs than the condition when the distracters are either numerically both above or both below the target (i.e., three 4s and 5s or three 1s and 2s). This is because, in the bracketing condition, both distracters maximally inhibit the target. In contrast, in the both above/both below conditions, one of the distracters maximally inhibits the target while the other actually maximally inhibits the other distracter (see Figure 2.8.).

![Diagram](image)

**Key to Figure:** ---- = 0.6, ------ = 0.4, ------ = 0.7, ---- = 0.5, ------ = 0.3.

**Figure 2.8.** An implementation of a set of inhibitory weights that could account for the data presented in Experiment 1 and 2 into the Cohen et al. (1998) task context module model. For simplicity, the model considers the weights that would be applicable to the target 3.

But a contrasting set of predictions can be generated. Instead of considering that the number line effects are due to the functioning of the output system, as we would have to on the basis of the current task context module model, we could consider that the symbolic number line effects are directly due to the “semantic representations” that underpin numerical
processing. In the Dehaene & Changeux (1993) computational model of elementary numerical abilities, there is a set of units called numerosity detectors (Dehaene and Changeux 1993). According to the model, the activation pattern of these numerosity units approximate the value of numerosity for each individual number; see, for a stylized depiction of the activation of these numerosity detectors, each of which is represented on the x-axis in Figure 2.9.

There are several features of Figure 2.9. that is important to note. First, the peak activations of the numerosity units that represent the different numbers decrease progressively for larger numbers. Secondly, the number of numerosity units that represent a particular number increases with the size of the number (Dehaene and Changeux 1993).

Figure 2.10. depicts an adaptation of the task context model where the hidden units of the original model have been represented by a series of units corresponding to numerosity units hypothesized by Dehaene & Changeux (1993). These numerosity units are thought to be shared by both the counting and number reading modalities (Dehaene, personal communication) and thus input units from either modality activate them. In this model, the task demand units are represented as operating on the input units, significantly boosting the activity of the task relevant modality (for the purposes of my simulation of the data by a magnitude of two).
Figure 2.10: The proposed adaptation of the task context module model with the hidden units of the original model are represented by a series of units corresponding to the numerosity units hypothesized by Dehaene and Changeux (1993).

Thus, activation of an input unit gives rise to an input unit dependent activation pattern of the numerosity units (as depicted in Figure 2.10). The activation of these units is then conveyed to the output units (the weights in this simulation are all considered to be equivalent). If two or more units are activated simultaneously, the pattern of activation of the numerosity units will be a function of the individual numbers presented to the model. In Figure 2.11, I depict the activation patterns of the numerosity units following the presentation of either three 2s or three 4s (as well as the patterns if the numbers had been presented on their own and without augmentation by the task demand units).
Figure 2.11: The hypothesized response of the numerosity detectors to the presentation of three 2s or three 4s together with the response patterns if the numbers had been presented singly.

The activations of the output units for these two contrasting conditions are represented in Table 2.9. As can be seen, under conditions where the distracter is less than the target, the activation of the target is stronger and the activation of the main distracter is weaker than if the distracter is larger than the target. In other words, the model would expect the result, identified in Experiment 1 and previously by Umiltà & Pavese (1998; 1999), that there should be greater competition from distracters larger than the target number than distracters smaller than the target number.

<table>
<thead>
<tr>
<th>Distracter</th>
<th>Two</th>
<th>Three</th>
<th>Four</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.096 (0.22)</td>
<td>0.178 (0.36)</td>
<td>0.050 (0.17)</td>
</tr>
<tr>
<td>4</td>
<td>0.019 (0.08)</td>
<td>0.166 (0.35)</td>
<td>0.127 (0.23)</td>
</tr>
</tbody>
</table>

Table 2.9: The activations of the output units to the target number 3 when the distracter is either 1 below the target (i.e., 2) or 1 above the target (i.e., 4).

However, the important predictions are for the novel conditions; i.e., when more than one distracter is present. Figure 2.12. depicts the activation patterns of the numerosity units following the presentation of either three 1s and 2s, three 2s and 4s or three 4s and 5s.
Figure 2.12: The hypothesized response of the numerosity detectors to the presentation of three 1s and 2s, three 2s and 4s or three 4s and 5s together with the response patterns if the numbers had been presented singly.

Table 2.10: The activations of the output units to the target number 3 when the distracters are either 1&2 below the target (i.e., 1 and 2), bracketing the target (i.e., 2 and 4), or 1&2 above the target (i.e., 4 and 5).

<table>
<thead>
<tr>
<th>Distracter</th>
<th>One</th>
<th>Two</th>
<th>Three</th>
<th>Four</th>
<th>Five</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 and 2</td>
<td>0.082 (0.23)</td>
<td>0.119 (0.25)</td>
<td>0.178 (0.36)</td>
<td>0.050 (0.17)</td>
<td>0.000 (0.00)</td>
</tr>
<tr>
<td>2 and 4</td>
<td>0.005 (0.02)</td>
<td>0.096 (0.22)</td>
<td>0.190 (0.36)</td>
<td>0.127 (0.23)</td>
<td>0.026 (0.08)</td>
</tr>
<tr>
<td>4 and 5</td>
<td>0.000 (0.00)</td>
<td>0.019 (0.08)</td>
<td>0.166 (0.35)</td>
<td>0.141 (0.23)</td>
<td>0.103 (0.16)</td>
</tr>
</tbody>
</table>

The activations of the output units for these three contrasting conditions are represented in Table 2.10. As can be seen, under conditions where the target is bracketed by the distracters, the activation of the target is stronger and, at least in the two above condition, the activation of the distracters are weaker than if the distracters are either both above or both below the target. In short, the model predicts the opposite of those predictions generated from the original task context module model (see above) by assuming that the number line effects are a product of inhibitory connections in the output module. Moreover, if we compare the predicted activations in Table 2.9 and Table 2.10, we see that the activation of the target unit under the
bracketing conditions (i.e., two distracters) is actually greater than its activation under the single distracter greater/less than the target conditions. In short, the model predicts that the participant should experience less interference if there are two different types of distracters but which bracket the target than if there is only one. Experiment 3 tests these contrasting sets of predictions.

2.14.: Experiment 3

The third experiment investigated the predictions from the implemented Dehaene and Changeux (1993) model of numerical cognition.

2.15.: Method

2.15.1.: Participants

Twenty participants (8 men and 12 women) were recruited from University College London. Their mean age was 23 years with a range of 21-34 years. All reported normal or corrected-to-normal vision and all were naïve to Stroop methodology. They were not aware of the purpose of the task.

2.15.2.: Design

This was a repeated measures design. The independent variable was stimulus type. There were six different types of stimuli. These were:

a) Congruent: The distracter was the same as the target
   (e.g. four 4s – 4.4);

b) 1 Below: The distracter was 1 less than the target
   (e.g. four 3s – 4.3);

c) 1 Above: The distracter was 1 more than the target
   (e.g. four 5s – 4.5);

d) Bracket: One distracter was 1 less than the target and one distracter was 1 more than the target (e.g. two 3s and two 5s – 4.3/5);

e) 1&2 Below: One distracter was 1 less than the target and one distracter was 2 less than the target (e.g. two 2s and two 3s – 4.2/3);

f) 1&2 Above: One distracter was 1 more than the target and one distracter was 2 more than the target (e.g. two 5s and two 6s – 4.5/6).

The dependent variable was mean RT measured in milliseconds.
2.15.3.: Apparatus and Materials

The apparatus was identical to that used in Experiment 1 and 2. Stimuli from Experiment 1 fulfilling the criteria laid out in condition a, b or c described above were similarly employed. Thus, five stimuli fulfilled the criteria for respectively 1 Below and 1 Above, and six fulfilled the criteria for Congruent. Accordingly, \((5 + 5 + 6)\) 16 stimuli from the original set were employed. In addition, however, Experiment 3 demanded the development of an additional stimuli set. The novel event set was created in Adobe Photoshop. As in Experiment 1, the novel stimuli set consisted of patterns of one, two, three, four, five, or six digits presented in a pattern resembling those on a dice. However, whereas the digits in any one stimulus in Experiment 1 all had the same identity (i.e. digit 1s, 2s, 3s, 4s, 5s, or 6s), the digits in any one stimulus in the new stimuli set now comprised two different digits (i.e. digit 1s, 2s, 3s, 4s, 5s, or 6s presented together with digit 1s, 2s, 3s, 4s, 5s, or 6s). See Figure 2.13. for example stimuli involving the numerosity five.

![Example Stimuli](image)

Key to Figure.: a = congruent, b = 1 Below, c = 1 Above, d = Bracket, e= 1&2 Below, f = 1&2 Above.

Figure 2.13.: Test stimuli used in Experiment 3 involving the numerosity 4.

All possible combinations of digits and patterns occurred. In addition, the design was counterbalanced so that all combinations of the number of the two different digits occurred. Thus, for numerosity 4 represented by the digits 3 and 5 there would be three different stimuli (i.e. three 3s and one 5 - \(4.3(3)/5(1)\), one 3 and three 5s - \(4.3(1)/5(3)\), and finally two 3s and two 5s - \(4.3(2)/5(2)\). The position of the digits was furthermore counterbalanced so that, for
each numerosity, two different positions in the dice pattern portrayed each digit. Thus, the entire event set consisted of \((16 + 24) 40\) different stimuli.

2.15.4.: Procedure

The procedure was identical to Experiment 1 with the exception that there were now 40 different stimuli presented randomly in one block. There was a total of 10 blocks, and the first block was a practice block. The average experiment lasted approximately 15 minutes.

2.16.: Results

As in Experiment 1 and 2, the first block of trials was regarded as practice block and was removed from further analyses. The criteria for error rates were identical to those used in Experiments 1 and 2; on the basis of average, higher, RTs, the criteria for response latencies were 2000 ms. Because crucial analyses depended on there being either two distracters below the target (e.g., three 2s and 1s) or two distracters above the target (e.g., four 5s and 6s), data analysis included RTs for targets ‘three’ and ‘four’, but not ‘two’ and ‘five’ (because it was impossible to have two distracters above ‘5’ and two distracters below ‘2’ within the confines of our design). Data from four participants were excluded as the error rates exceeded 10%.

![Figure 2.14: Mean latencies in milliseconds as a function of stimuli type.](image)

A series of targeted ANOVAs were conducted to the data to explore specific comparisons. First, we investigated whether the Bracket condition induced significant interference. A one-factor within-participants ANOVA with Condition (Bracket, Congruent) as within-participants factor demonstrated that it did; RTs to Bracket trials were significantly
slower than RTs to Congruent trials ($F(1,19) = 4.20; p < 0.06$: $M(\text{Bracket}) = 636$, s.d. = 104; $M(\text{Congruent}) = 621$, s.d. = 114) (see Figure 2.15.). Secondly, we investigated whether the Bracket condition induced significantly less interference than the 1 Below as well as the 1 Above distracter condition. Two one-factor within-participants ANOVA with Condition (Bracket, 1 Below) and (Bracket, 1 Above) respectively as within participants factor showed that it did. RTs to Bracket trials were significantly faster than RTs to 1 Below trials ($F(1,19) = 9.16; p < 0.01$: $M(\text{Bracket}) = 636$, s.d. = 104; $M(1 \text{ Below}) = 656$, s.d. = 105) and RTs to 1 Above trials ($F(1,19) = 12.08; p < 0.01$: $M(\text{Bracket}) = 636$, s.d. = 104; $M(1 \text{ Above}) = 661$, s.d. = 103). Thirdly, we investigated whether the Bracket condition induced significantly less interference than having two distracters both below, or alternatively above, the target. Two one-factor within-participants ANOVA with Condition (Bracket, 1&2 Below) and (Bracket, 1&2 Above) as within-participants factor demonstrated that it did. RTs to Bracket trials were significantly faster than RTs to 1&2 Below trials ($F(1,19) = 6.77; p < 0.05$: $M(\text{Bracket}) = 636$, s.d. = 104; $M(1&2 \text{ Below}) = 657$, s.d. = 104) and RTs to 1&2 Above ($F(1,19) = 24.58; p < 0.001$: $M(\text{Bracket}) = 636$, s.d. = 104; $M(1&2 \text{ Below}) = 680$, s.d. = 104). Fourthly, we examined whether having two distracters both above the target produced significantly more interference than having two smaller distracters both below or above the target. A one-factor within-participants ANOVA with Condition (1&2 Above, 1&2 Below) as within-participants factor showed that it did. RTs to 1&2 Above trials were significantly faster than RTs to 1&2 Below trials ($F(1,19) = 9.41; p < 0.01$: $M(1\&2 \text{ Above}) = 680$, s.d. = 104; $M(1&2 \text{ Below}) = 657$, s.d. = 104) (see Figure 2.13.). Fifth, and finally, it was investigated whether having one larger distracter compared to one smaller distracter induced more interference. A one-factor within-participants ANOVA revealed that it did not. RTs to 1&2 Above and 1&2 Below trials did not differ significantly ($F(1,19) = 0.35; ns$: $M(1&2 \text{ Above}) = 680$, s.d. = 104; $M(1&2 \text{ Below}) = 657$, s.d. = 104).

2.17.: Discussion

Experiment 3 tested predictions regarding representing the number line information in a task module context model. The experiment revealed; First, and in line with predictions, that distracters that are larger than the target resulted in greater RTs than distracters at an equivalent number line distance that are smaller than the target. Secondly, two distracters that are either both below the target or both above the target resulted in greater RTs than two distracters that bracket the target; and thirdly, two distracters that bracket the target resulted in smaller RTs than one distracter above or below the target. These data are all in line with the model.
developed above integrating the numerosity units hypothesized by Dehaene & Changeux (1993) into a version of the task context model.

The finding that distracters that are larger than the target resulted in greater RTs than distracters that are smaller than the target was in line with our data from Experiment 1 and also the results of Pavese and Umilta' (1998; 1999). However, these data can be explained by either of the accounts offered above. The inhibitory output connections variant can explain them by assuming that the inhibitory connections to units responsible for larger numbers are smaller than those responsible for smaller units (though it is important to note that the the task context module model provides no principled reasons to motivate this suggestion). For the numerosity unit variant, the results are a product of the fact that activation of the target boosts the activity of the numerosity units representing a larger distracter far more than the activity of the numerosity units representing a smaller distracter. Therefore, the activation of the output units of larger distracters will be larger than those of small distracters.

The interesting data is for the multiple distracter conditions. As far as I am aware, no previous investigation of numerical Stroop paradigms has ever explored the impact of having more than one type of number distracter. The results here clearly indicate that two distracters result in the greater RTs if they are either both below the target or both above the target rather than if they bracket the target and that two distracters that bracket the target result in smaller RTs than one distracter above the target. At first glance, these results might appear counter-intuitive. Indeed, the inhibitory output connections variant predicted the exact opposite result. Moreover, the fact that two distracters bracketing the target result in smaller RTs than a condition when there is only one of the very same distracters appears very surprising. However, these results are compatible with the numerosity unit variant of the task demands model presented above. Distracters that bracket the target should boost the activation of the numerosity units that represent the target. However, a single distracter above the target should interfere maximally. Moreover, if the two distracters are either both above or both below the target, their activation will augment the activation of each other's numerosity units rather than particularly support those of the target.

2.18.: General Discussion

The present study examined interference effects in a number Stroop paradigm. The results of the study show; firstly, that the digit reading interferes with the digit counting; secondly, that the digit counting interferes more with the digit reading; thirdly, that RTs are affected by the arithmetic distance between the enumeration response and the digit identity;
fourthly, that these effects are present in both a randomized as well as a blocked design; fifthly, that two distracters above or below the target result in greater RTs than two distracters bracketing the target; and finally, so does one single distracter above or below the target.

Three main accounts of the Stroop effect have been proposed. These are the *relative speed of processing* account (Morton and Chambers 1973; Posner 1978; Schooler, Neumann et al. 1997), the *automaticity account* (Shiffrin and Schneider 1977; Hasher and Zacks 1979; MacLeod and Hodder 1988), and the *task context module model* (Cohen, Dunbar et al. 1990; Cohen, Botvinick et al. 2000). In addition, the discriminability position has received considerable recent attention. We believe that the current data have clear implications for all of these accounts.

So to consider the speed of processing account, this account suggests that if the distracter stimulus information arrives at the limited capacity response buffer before the target stimulus information, there will be interference (Morton and Chambers 1973; Posner 1978; Schooler, Neumann et al. 1997). This suggests that if the two dimensions do not significantly differ in speed of processing, there should be bi-directional Stroop effects; the distracter stimulus information will always be present in the limited capacity response buffer at the same time as the target stimulus information. In Experiment 1, there were no significant differences in speed of processing for counting and digit reading. This therefore meant that the speed of processing account could account for the bi-directional Stroop effects seen in that experiment. However, Experiment 1 involved different participants for the counting and digit reading conditions. These differences in participants could have hidden actual differences in processing speeds for the two dimensions. Indeed, the results of Experiment 2 strongly suggest that they did. In Experiment 2, all participants experienced all conditions. In this experiment, digit reading was significantly faster than counting. However, even though this was the case, and therefore presumably in the digit reading conditions, the digit information reached the response buffer before the counting information, the counting information still caused interference for digit reading. This must be considered problematic for the speed of processing account (though it could be argued that the reaction times shown by the participant do not sufficiently index the speed of processing of information passing through the two routes).

A second set of problems the current data throw up for the speed of processing account are those associated with the number semantic information. In Experiments 1, 2 and 3, I found that distracters that were one greater in numerosity than the target resulted in greater RTs than distracters that were one less in numerosity than the target. In Experiment 3, I also found that two distracters that bracketed the target gave rise to smaller RTs than two distracters above or
below the target. This data is somewhat problematic for the speed of processing idea. Certainly, it is not accounted for by the basic speed of processing idea where interference or RT is primarily a function of competition within the response buffer. However, in Morton's (1969) model, he suggests that there may be communication of information between the dimensions before the response buffer. This would suggest that interference might occur before the response buffer. Using this specification of the speed of processing account, it would be possible to account for the interference or RT effects that were a product of number semantic information found in the current study.

With respect to the discriminability position, the data is even more problematic. The discriminability hypothesis suggests that the more discriminable dimension interferes with the less discriminable dimension but not vice versa (Melara and Mounts 1993; Algom, Dekel et al. 1996; Pansky and Algom 2002). Because we found that each dimension interfered with the processing of the other dimension, it will have to be inferred that the dimensions employed in the Number Stroop are not mismatched but may indeed be considered a perfectly discriminable paradigm. However, Melara and Mounts (1993) predicted that in a perfectly discriminable paradigm there should be no Stroop interference. The current data are therefore incompatible with Melara and Mounts' (1993) position. Moreover, the interference effects that I obtained as a function of number semantic information are also incompatible with Melara and Mounts' (1993) position. If interference effects are a function of discriminability then any influences of interference should only be because they affect discriminability. However, there is no reason to believe that the manipulations that we found to affect interference had any impact on discriminability.

Cohen et al.'s (Cohen, Dunbar et al. 1990; Cohen, Botvinick et al. 2000) task context module model has no difficulty accounting for bi-directional Stroop effects. The task context module predicts interference as a function of the relative level of training on the two dimensions. If this is roughly equivalent, as would have to be argued is the case for digit reading and counting, the bi-directional Stroop effects would be predicted to occur. However, findings that the level of interference or RT is a function of specific forms of number semantic information is far more problematic for this model. The model in its current form does not take into account inter-stimulus associations and cannot predict their influence on behaviour. Of course, the model can be modified very simply to take into explain the number line effects seen in Experiments 1 and 2. Thus, rather the having all the inhibitory connections in the output system as has been assumed (1998), we could account for the number line data by assuming that the strength of the inhibitory weights in the output system are a function of distance (see
However, this form of modification of the task context module cannot account for the data obtained in Experiment 3. Indeed, this form of modification predicts the exact opposite of the data; i.e., distracters bracketing the target minimized interference (relative to other multiple distracter conditions) rather than maximized it.

In short, I would argue that the Cohen et al task context module model is in need of the addition of a representation of semantic information to be able to account for Stroop data (both that obtained here as well as accounting for previous semantically related Stroop findings such as those of Klein, 1964). I have proposed such a modification of the task context module model in Figure 2.10. This model consists of an integration of Cohen's task context module model with ideas concerning the representation of numerosity taken from Dehaene and Changeux (1993). As developed in Figures 2.11. and 2.12., this model predicts the data obtained in Experiment 3; i.e., distracters bracketing the target minimized RTs (relative to other multiple distracter conditions) rather than maximized them.

In conclusion, I showed that digit reading interferes with digit counting and that digit counting also interferes with digit reading although digit counting was significantly faster than digit counting. I also showed that there was an inverse relation between RTs and symbolic number line distance for both the digit reading and digit counting. In addition, I showed that having distracters bracketing the target (relative to other multiple distracter conditions) minimized RTs. I believe that this data strongly suggest that accounts of Stroop, whether speed of processing or the task context module, need to consider the influence of semantic information on interference effects.
Chapter Three

Differentiating Among Different Prefrontal Substrates/ Executive Functions in Individuals with Psychopathy

3.1.: Introduction

In Chapter One, I described how psychopathy has been linked to prefrontal/ executive dysfunction. I suggested that current models of frontal/ executive dysfunction in psychopathy are underspecified and that it is necessary to differentiate among different prefrontal substructures/ executive functions in psychopathy. In this chapter, I will consider the performance of individuals with psychopathy on three measures of executive control: the Number Stroop task introduced in Chapter Two, the Object Alternation (OA) task, and the Spatial Alternation (SA) task. In addition, I will discuss the results in the context of the Cohen et al. (2000) context module model module and consider the implications of this work for executive dysfunction theories of psychopathy.

3.1.1.: Frontal Dysfunction in Psychopathy

In Chapter One, I described how antisocial behaviour has consistently been linked to prefrontal and consequent executive dysfunction. I also described how the neuropsychological literature examining the relationship between frontal dysfunction and antisocial behaviour has, to a very large extent, concentrated on the use of tasks that index executive functions commonly linked to DLPFC; e.g., the Wisconsin Card Sorting Task (WCST), the Controlled Oral Word Association Test (COWAT), and the ED shift component of the Intradimensional/ Extradimensional (ID/ED) task. Psychopathy has been linked to DLPFC dysfunction (Gorenstein 1982; Raine 2002). However, the psychopath group in these studies consisted of individuals that would not qualify as psychopathic according to the established criteria in the literature (a PCL-R score above 30). These individuals would however qualify as having antisocial behaviour. That is, the DLPFC impairment found in these studies may be linked to antisocial behaviour rather than psychopathy per se. This suggestion is supported by the fact that neuropsychological studies using PCL-R classified psychopathic individuals in their studies have found no DLPFC impairment in this group. Thus, as can be seen in Figure 3.1. individuals with psychopathy have been found to show no impairment on the WCST (LaPierre, Braun et al. 1995), the COWAT (Smith, Arnett et al. 1992; Roussy and Toupin 2000) or the ED-shift component of the ID/ED Task (Mitchell, Colledge et al. 2002).
Figure 3.1.: Schematic of the relationship between prefrontal substructures, the tasks they mediate, and antisocial populations and psychopathy.
However, as can be seen in Figure 3.1, individuals with psychopathy do appear to show executive dysfunction on measures linked to ventromedial/OFC dysfunction; e.g., the Porteus Maze Test, motor Go/No-Go tasks, and measures of response reversal/extinction such as the ID/ED task and the One Pack Card Playing Task (LaPierre, Braun et al. 1995; Newman, Schmitt et al. 1997; Roussy and Toupin 2000; Mitchell, Colledge et al. 2002). Moreover, reduced ventromedial/OFC functioning has been reported in individuals with psychopathy during an imaging study involving an aversive conditioning task (Veit, Flor et al. 2002). Thus, individuals with psychopathy do show frontal lobe dysfunction albeit dysfunction that is selective to those executive functions mediated by ventromedial/OFC rather than DLPFC.

Having successfully implicated executive functions mediated by ventromedial/OFC, what else can we say about the underpinnings of the disorder? Antisocial or impulsive behaviour has also been linked to medial-frontal/ACC dysfunction (Foster, Hillbrand et al. 1993; Bauer and Hesselbrock 1999; Bush, Frazier et al. 1999; Teichner, Golden et al. 2001). Our strictures on DLPFC do not mean that we rule ACC out for psychopathy, merely that we can assume nothing. In fact, very little is known about the possible contribution of ACC pathology in psychopathy. Recently, however, reduced ACC activation was observed in individuals with psychopathy during both an emotional memory task and an aversive conditioning task (Kiehl, Smith et al. 2001; Veit, Flor et al. 2002). From this finding of ACC hypo-activity, Kiehl concluded that some aspects of psychopathy may be related to abnormal function in ACC (Kiehl, Smith et al. 2001). The Stroop task is a task that has been consistently demonstrated to recruit ACC through functional imaging work (Pardo, Pardo et al. 1990; Bench, Frith et al. 1993; Carter, Mintun et al. 1995; Bush, Whalen et al. 1998; Derbyshire, Vogt et al. 1998; MacLeod and MacDonald 2000; Ravnkilde, Videbech et al. 2002; Fan, Flombaum et al. 2003). In addition, human lesion studies have demonstrated that the ACC is crucially involved in Stroop performance (Stuss, Floden et al. 2001; Swick and Jovanovic 2002). Only one previous study has used the classic word-colour Stroop task with individuals divided into groups according to the PCL-R. This reported that individuals with psychopathy performed similarly to comparison individuals both in terms of number of errors as well as level of interference (Smith, Arnett et al. 1992). In contrast, Newman et al. (1997) reported that individuals with psychopathy showed an abnormal pattern of interference (less interference) relative to comparison individuals on a Stroop type interference task. In this task, based on methodology introduced by Gernsbacher and Faust (1991), participants are presented with two consecutive pictures or words, and are instructed to indicate whether the two pictures (or words) are conceptually related or not (Gernsbacher and Faust 1991). On word trials, the
first word was presented with a superimposed picture. On picture trials, the first picture was presented with a superimposed word. In each case, the participants were instructed to ignore this distractor stimulus. However, on half the trials (the incongruent trials) where the consecutively presented stimuli were unrelated, the distractor stimulus was conceptually related to the first stimulus (e.g., with the words SOUP and RAIN, the picture of an umbrella was presented superimposed on SOUP). While healthy individuals were found to be slower to respond to the incongruent trials (Gernsbacher and Faust 1991), the individuals with psychopathy were not (Newman, Schmitt et al. 1997). From these studies then, it is not clear whether ACC pathology may be implicated in psychopathy.

One difficulty with previous investigations of interference in Stroop-type paradigms is that they are not very sensitive; they do not typically allow parametric manipulation of the level of interference. This makes the detection of subtle effects difficult. However, the Number Stroop task, which I described in detail in Experiment 1 Chapter One, does allow a parametric assessment of cognitive interference. That is, in this task difficulty is a function of the symbolic number line distance; i.e., task difficulty or cognitive interference increases as symbolic number line distance decreases (Pavese and Umilta 1998; Pavese and Umilta 1999; Peschardt, Morton et al. manuscript in preparation; Peschardt, Newman et al. manuscript in preparation). Importantly, an imaging study of the Number Stroop has demonstrated that this parametric interference pattern is reflected in ACC activation; i.e., ACC activation increases as the symbolic number line distance decreases (Peschardt, Morton et al. manuscript in preparation). The seductive interpretation of this finding is that increased interference requires more work in processes located in ACC. Thus, even subtle impairment in ACC should be revealed by performance on the Number Stroop, and, specifically, one should find a larger impairment as the number line distance decreases.

Our proposal to use symbolic number line distance with the Stroop test is in order to provide a strong test of ACC dysfunction contributing to psychopathy. This concludes our discussion of theories based on frontal lobe specification and we now move to psychological theories of psychopathy.

3.1.2. Cognitive Level Executive Dysfunction in Psychopathy

At the cognitive level, executive dysfunction in psychopathy has been linked to impulsivity (Whiteside and Lynam 2001; Miller, Flory et al. 2003), conceptualized as lack of premeditation and lack of perseverance, where lack of premeditation is likened to the "inability to inhibit previously rewarded behaviour when presented with changing contingencies"
(Whiteside and Lynam 2001) and lack of perseverance “may be related to disorders that involve
the inability to ignore distracting stimuli or to remain focused on a particular task” (Whiteside
and Lynam 2001). Executive dysfunction in psychopathy has also been linked to impaired
response modulation. As described in the introduction, response modulation is the “rapid and
relatively automatic (i.e., non-effortful or involuntary) shift of attention from the effortful
organization and implementation of goal-directed behaviour to its evaluation” (Newman et al.
1997). From these accounts it could be expected that individuals with psychopathy, being
impulsive and with impaired response modulation, would be impaired on a broad range of
tasks.

These characterisations of a diagnostic group are useless if they are only post hoc. But
it is not easy to make predictions in an area where neither the executive requirement of
particular tasks nor the relation between particular executive functions and brain areas has been
reliably established. Given these caveats, it seems reasonable to speculate that a group that is
characterised as impulsive and with impaired response modulation would perform badly on
tasks that could recruit the three frontal areas: ventromedial/ OFC, DLPFC, and ACC.

Thus, let us consider the ID/ED task. In this task, which is supposed to involved
DLPFC and OFC function, the stimuli are two shapes paired with two different kinds of line.
There are two principal measures: First, the number of response reversal errors (e.g., when
choosing between the two shapes, the participant continues to respond to the shape that had
resulted in reward but which now, when responded to, results in punishment). Secondly, the
number of ED errors (e.g., when the participant responds by choosing one or other shape
despite the fact that the reward contingency is based on the lines which accompany the shapes).
Both response reversal and ED shifting would appear to require the inhibition of a previously
rewarded behavior/ response modulation. During response reversal, the participant must inhibit
the response to the previously rewarded shape and shift attention to the new contingency
information. During ED shifting, the participant must inhibit the response to the previously
rewarded class of stimuli (shape rather than lines) and shift attention to the new contingency
information. However, while inhibition or response modulation accounts can explain the
response reversal impairment shown by individuals with psychopathy on the ID/ED task, they
have more difficulty explaining the lack of an impairment in ED shifting shown by the same
individuals on this task (Mitchell, Colledge et al. 2002). Yet an account of this data can be
provided from the perspective of cognitive neuroscience. Thus, individuals with psychopathy
show impairment to those processes, mediated by orbital frontal cortex, which allow the
alternation of responding to different objects as a function of contingency change (shape1 vs
shape). However, they do not show impairment to those processes, mediated by DLPFC, that allow the alternation of responding to different conceptual categories (shapes vs lines) as a function of contingency change. In short, the claim would be that even if a characterization of the impairment in individuals with psychopathy in terms of inhibition or response modulation was correct, it would be necessary to constrain such accounts such that they were not domain general but rather specific to particular neuro-cognitive systems.

The ability of individuals with psychopathy to perform attentional shifts mediated by DLPFC together with their difficulties with response reversal mediated by OFC have serious implications for the domain general accounts. Thus, it would be useful if the results from the ID/ED task (Mitchell, Colledge et al. 2002) could be replicated and extended. To examine this issue, we presented individuals with psychopathy with three different tasks: Object Alternation (OA), Spatial Alternation (SA) (also known as Delayed Alternation) and the Number Stroop task. In the OA task, their participants have to modulate their responding to objects as a function of contingency change. Orbital frontal cortex dysfunction, but not DLPFC dysfunction, disrupts performance on the OA task (Pribram and Mishkin 1956; Mishkin, Vest et al. 1969; Freedman, Black et al. 1998; Zald, Curtis et al. 2002). In the SA task, the participants have to modulate their responding to different spatial locations as function of contingency change. The SA task is particularly sensitive to DLPFC impairment (Brutkowski, Mishkin et al. 1963; Mishkin, Vest et al. 1969; Zald, Curtis et al. 2002). Both tasks have been used extensively to assess probable prefrontal dysfunction in psychiatric disorders, including Major Depressive Disorder, Obsessive Compulsive disorder and Schizophrenia (Freedman 1994; Abbruzzese, Ferri et al. 1997; Cavedini, Ferri et al. 1998). In the Number Stroop task, the participant has to either enumerate, or identify, the numbers presented to them and inhibit responding to the competing numerical information. We have already indicated how neuroimaging work has shown that the ACC is involved in mediating the Number Stroop task (Bush, Whalen et al. 1998; Peschardt, Morton et al. manuscript in preparation). If individuals with psychopathy have a frontal impairment specific to OFC, they should show impaired performance on the OA task but not the Number Stroop task or the SA task. If individuals with psychopathy have ACC impairment, they should show a different pattern of interference on the Number Stroop task relative to comparison individuals. Finally, if individuals with psychopathy have a more generalized executive deficit relating to impulsivity or reduced response modulation, it might be hypothesized that they should show impairment on the SA task as well as both the OA task and the Number Stroop task. The following study tests these hypotheses. Note that my earlier analysis of the current data led us to the conclusion that
individual with psychopathy do not have problems with tasks involving DLPFC and so should not show a problem with the SA task.

3.2.: Experiment 4

3.3.: Method

3.3.1.: Participants

Participants were 55 adult males selected from a pool of 500 individuals residing in Category B (second highest security level) institutions in England. In accordance with the established criteria of the literature and the established guidelines of the PCL-R (Hare 1991), individuals with a PCL-R score of 30 or above were included in the psychopathic group, while individuals with a PCL-R score of 20 or less were included in the comparison group. Individuals with a PCL-R score between 20 and 29 were excluded from the study.

<table>
<thead>
<tr>
<th>Group</th>
<th>PCL-R</th>
<th>Age</th>
<th>Raven</th>
</tr>
</thead>
<tbody>
<tr>
<td>The OA/SA Tasks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychopathic group (n =17)</td>
<td>32.05 (2.19; 30-37)</td>
<td>36.59 (10.27; 23-56)</td>
<td>8.00 (2.43; 3-11)</td>
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<td>Comparison group (n = 19)</td>
<td>10.09 (5.33; 1.6-8.95)</td>
<td>36.89 (9.61; 23-53)</td>
<td>8.17 (2.15; 4-12)</td>
</tr>
<tr>
<td>The Number Stroop Tasks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychopathic group (n = 19)</td>
<td>32.47 (2.08; 30-37)</td>
<td>35.47 (7.65; 22-53)</td>
<td>7.95 (1.90; 3-10)</td>
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<tr>
<td>Comparison group (n = 18)</td>
<td>8.21 (4.62; 1.1-17.50)</td>
<td>31.50 (8.26; 20-44)</td>
<td>8.22 (2.21; 5.12)</td>
</tr>
</tbody>
</table>

Key to Table: OA = Object Alternation, SA = Spatial Alternation, PCL-R = Psychopathy Cheklist - Revised

Table 3.1.: Participant characteristics, S.D., and ranges in brackets ()

Although a total of 55 inmates participated in the study, inmate transfers prevented some individuals from participating in both testing sessions. Consequently, 20 individuals took part in both studies, 18 individuals took part in the OA/ SA task only, and 17 individuals took part in the Number Stroop task only. There were no significant group differences in either age or Ravens scores for either task; see Table 3.1. for full participant details. The sample was made up of 44 Caucasian, 9 Afro-Caribbean, and 2 Asian participants (6 Afro-Caribbean
participants in the psychopathic group, and 3 Afro-Caribbean and 2 Asian participants in the comparison group).

3.3.2.: Measures

3.3.2.1.: The Psychopathy Checklist Revised (PCL-R)

The PCL-R and its constituent parts were described in Chapter One. PCL-R scores are most often obtained on the basis of a file review and a semi-structured interview but can also be reliably obtained from file notes alone (Wong 1988; Hare, Hart et al. 1991). In this study, 8 participants (5 psychopathic and 3 comparison) were unavailable for interview and so were scored on the basis of file notes only. Participants were scored independently by two raters. Inter-rater reliability was established by means of a Spearman rank correlation. The correlation, $r_{s\text{anks}} = 0.96 (p < 0.000)$, is similar to that reported in the literature (Hare 1991).

3.3.2.2.: The Object Alternation (OA) Task

The OA task was adapted from the non-computerized task administrated in the Freedman et al. (1998) paper (Freedman, Black et al. 1998). Two objects were presented to the participants on each trial, one on either side of the computer screen. One of the objects depicted a blue horse, and the second object depicted a green carrot. The location of the objects was varied at random from trial to trial. The instructions to the participants read: ‘In this task, two objects are going to appear on the screen. Behind one of them is a £20 note. I want you to try to get the £20 note every single time. Remember, your job is to get the £20 note every single time. There will always be a £20 note under one of the objects. There is a rule that you can use to get the money every time. You need to work out this rule. Any questions?’ The participants’ task was to learn that the object behind which the £20 note was located was being alternated after each correct response. On the first trial of the OA task, both objects were baited with a £20 note. For the second trial, the £20 note was located behind the object not chosen on the first trial. On each subsequent trial following a correct response, the other object was baited. A correction procedure was used so that the £20 note remained behind one object until the participant made a correct response. If the participant failed to find the £20 note after 12 consecutive responses, however, the £20 note was placed behind the other object. The time between response and next stimulus presentations was 1 s. Learning criterion was 12 consecutive correct responses. Failure criterion was 80 trials. Responses were recorded by the
means of a click with the mouse on top of the chosen object. Stimuli were controlled by the software VisualBasic and presented on a Dell Inspiron 8100.

3.3.2.3.: The Spatial Alternation (SA) Task

The SA task was adapted from the non-computerized Delayed Alternation task administrated in the Freedman et al. (1998) paper. Two objects were presented to the participants on each trial, one on either side of the computer screen. Both objects depicted an identical red car. The instructions to the participants were as in the OA task. The participant's task was to learn that the side under which the £20 note was located was being alternated after each correct response. On the first SA trial, both objects were baited with a £20 note. For the second trial, the £20 note was put under the side not chosen on the preceding trial. A correction procedure was used so that the £20 note remained under the object in one particular side until the participant made a correct response. Also, if the participant failed to find the £20 note after 12 consecutive responses, the £20 note was placed behind the object on the other side. The time between response and next stimulus presentation was 1 s. Learning criterion was 12 consecutive correct responses. Failure criterion was 80 trials. Responses were recorded by the means of a click with the mouse on top of the chosen object. Stimuli were controlled by the software VisualBasic and presented on a Dell Inspiron 8100.

3.3.2.4.: The Number Stroop Counting Task

The Number Stroop Counting task was described in Experiment 1, Chapter One. The number of trials was identical to the number of trials used in Experiment 1, Chapter One.

3.3.2.5.: The Number Stroop Reading Task

The Number Stroop Reading task was described in Experiment 1, Chapter One. The number of trials was identical to the number of trials used in Experiment 1, Chapter One.

3.3.3.: Procedure

Each participant was tested individually in a quiet interview room on the wing. Following written consent, each participant was presented with the four tasks as part of a larger neuropsychological test battery.

3.4.: Results
3.4.1.: The OA/SA Tasks

For the purpose of the analyses, on any trial, choosing the object behind which the £20 note was located, was scored as ‘correct’. In addition, the learning criterion was 12 consecutive correct responses and the failure criterion was 80 trials.

An initial 2 (Group: psychopathy vs. comparison) x 2 (Performance: pass vs. fail) Chi-Square was conducted on the OA data. This revealed a significant group difference ($\chi^2 = 9.92$; d.f. = 2; $p < 0.01$; a significant higher number of individuals with psychopathy failed the task relative to comparison individuals (Fail[psychopathic group] = 13, Pass[psychopathic group] = 4, Fail[comparison group] = 6, Pass[comparison group] = 13. All 36 participants passed the SA, thus no analysis was conducted on failure rates for the SA task. Next, a 2 (Group: psychopathy vs. comparison) x 2 (Task: OA vs. SA) ANOVA was conducted on the error data. This revealed a main effect of Task ($F(1, 34) = 5.74; p < 0.025$); there was a significantly greater number of errors on OA trials relative to SA trials ($M[OA trials] = 28.54; s.e. = 5.37, M[SA trials] = 15.84; s.e. = 1.40$. There was also a main effect of group ($F(2, 34) = 5.83; p < 0.01$); individuals with psychopathy committed more errors relative to comparison individuals ($M[psychopathic group] = 18.47; s.e. = 1.96, M[comparison group] = 12.11; s.e. = 1.96$. However, interestingly, there was a significant Group by Task interaction ($F(1, 34) = 4.24; p < 0.025$). As can be seen in Figure 3.2., while the two groups committed a comparable number of errors on the SA task, the individuals with psychopathy presented with an increased number of errors on the OA task. A follow-up t-test confirmed that the difference between the psychopathic and comparison groups on the OA task was significant ($t(34) = -2.19; p < 0.05$) ($M[psychopathic group] = 32.88; s.e. = 3.24, M[comparison group] = 21.74; s.e. = 3.85$. The t-test performed on the two groups for the SA task was not significant. In short, the individuals with psychopathy performed comparably to comparison individuals on the SA Task, but were significantly impaired relative to comparison individuals on the OA Task.
3.4.2.: The Number Stroop Tasks

Trials where the RT exceeded 1800 ms or was below 250 ms were excluded from further analysis. RTs and error rates were then entered into ANOVAs to examine the effect of group on congruence and error rates. RTs were only entered into the analyses if they were for correct responses.

First, the effect of group on congruence was examined. A 2 (Group: psychopathic vs. comparison) x 2 (Task: counting vs. reading) x 2 (Congruence: congruent vs. incongruent) was conducted on the data. The analysis revealed, first, that there was a significant main effect of Task ($F(1,35) = 18.46, p < 0.001$); RTs to reading trials were faster than RTs to counting trials ($M_{\text{reading trials}} = 810.31; \text{s.e.} = 22.50, M_{\text{counting trials}} = 881.32; \text{s.e.} = 23.46$. Second, that there was a main effect of Congruence ($F(1,35) = 41.59, p < 0.001$); RTs to congruent trials were faster than RTs to incongruent trials ($M_{\text{congruent trials}} = 822.70; \text{s.e.} = 22.49, M_{\text{incongruent trials}} = 869.30; \text{s.e.} = 21.02$). The Task by Congruence interaction was not significant. Third, that there was a main effect of Group ($F(1,35) = 5.81, p < 0.05$); the psychopathic group was slower to respond to the trials relative to the comparison group ($M_{\text{psychopathic group}} = 897.75; \text{s.e.} = 29.95, M_{\text{comparison group}} = 794.26; \text{s.e.} = 30.77$). However, there was no significant Congruence by Group, Task by Group, or Task by Congruence by Group interaction. In short, although individuals with psychopathy were overall slower at responding to the stimuli, the impact of Task and Congruence was comparable for the two groups.
We then conducted a second analysis on the data examining the impact of symbolic number line distance on group RT data. This involved a 2 (Group: psychopathic vs. comparison) x 2 (Task: counting vs. reading) x 4 (Distance: Zero, One, Two, and Three) ANOVA being conducted on the RT data. The analysis revealed, first, that there was a significant main effect of Task ($F(1,35) = 15.99$, $p < 0.001$); RTs to reading trials were faster than RTs to counting trials ($M_{\text{reading trials}} = 823.08$; s.e. = 22.26, $M_{\text{counting trials}} = 892.22$; s.e. = 23.46. Second, that there was a main effect of Distance ($F(3,105) = 22.91$, $p < 0.001$) with the linear contrast being significant ($F(1,35) = 39.25$, $p < 0.001$); RTs increased as a function of decreased symbolic number line distance ($M_{\text{distance Three}} = 873.05$; s.e. = 20.52, $M_{\text{distance Two}} = 872.06$; s.e. = 21.16), ($M_{\text{distance One}} = 862.80$; s.e. = 22.18, $M_{\text{distance Zero}} = 822.70$; s.e. = 22.49. The Task by Congruence interaction was not significant. Third, that there was a main effect of Group ($F(1,35) = 5.26$, $p < 0.05$); the psychopathic group were slower to respond to the trials relative to the comparison individuals ($M_{\text{psychopathic group}} = 906.05$; s.e. = 29.53, $M_{\text{comparison group}} = 809.26$; s.e. = 30.34) (see 3.2. for participant RTs on the Number Stroop tasks). However, there was no significant Distance by Group, Task by Group, or Task by Distance by Group interaction. In short, although individuals with psychopathy were overall slower at responding to the stimuli, they showed comparable Task and Distance effects to that of comparison individuals.

<table>
<thead>
<tr>
<th>Group</th>
<th>Symbolic number line distance</th>
<th>RTs</th>
<th>Number of error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychopathic group ($n = 19$)</td>
<td>One</td>
<td>917.34 (28.63)</td>
<td>5.05 (0.67)</td>
</tr>
<tr>
<td></td>
<td>Two</td>
<td>920.79 (29.52)</td>
<td>4.46 (0.54)</td>
</tr>
<tr>
<td></td>
<td>Three</td>
<td>904.90 (30.94)</td>
<td>4.55 (0.71)</td>
</tr>
<tr>
<td></td>
<td>Zero</td>
<td>881.16 (31.38)</td>
<td>2.08 (0.66)</td>
</tr>
<tr>
<td>Comparison group ($n = 18$)</td>
<td>One</td>
<td>828.75 (29.41)</td>
<td>6.54 (1.46)</td>
</tr>
<tr>
<td></td>
<td>Two</td>
<td>823.33 (30.32)</td>
<td>6.68 (1.33)</td>
</tr>
<tr>
<td></td>
<td>Three</td>
<td>820.69 (31.78)</td>
<td>5.85 (1.42)</td>
</tr>
<tr>
<td></td>
<td>Zero</td>
<td>764.25 (32.24)</td>
<td>1.75 (0.56)</td>
</tr>
</tbody>
</table>

Table 3.2.: Participant RTs, number of errors and S.E. in brackets () on the Number Stroop tasks.

According to our hypothesis, symbolic number line effects should be evident not only in RT, but also error data. That is, number of errors should increase as the symbolic number
line distance decreases. We thus conducted an analysis on the data examining the impact of symbolic number line distance on group error data. This involved a 2 (Group: psychopathic vs. comparison) x 2 (Task: counting vs. reading) x 4 (Distance: Zero, One, Two, and Three) ANOVA being conducted on the error data. The analysis revealed that there was a significant main effect of Distance ($F(3,105) = 20.49, p < 0.001$) with the linear contrast being significant ($F(1,35) = 32.67, p < 0.001$); the number of errors increased as a function of decreased symbolic number line distance ($M_{[distance Three]} = 5.20; s.e. = 0.81, M_{[distance Two]} = 5.57; s.e. = 0.73), ($M_{[distance One]} = 5.79; s.e. = 0.82, M_{[distance Zero]} = 1.92; s.e. = 0.43$ (see Table 3.2. for participant error rates on the Number Stroop tasks. The main effect of Task and the Task by Congruence interaction were not significant. In addition, there was no significant main effect of group and also the Distance by Group, Task by Group, and Task by Distance by Group interaction was not significant. In short, the impact of symbolic number line distance on error rates was comparable for the psychopathic and comparison groups.

3.5.: Discussion

As outlined in the introduction, there is considerable evidence linking antisocial or impulsive behaviour with impairment to DLPFC, medial-frontal cortex, and OFC (Kandel and Freed 1989; Moffitt 1993; Pennington and Ozonoff 1996; Morgan and Lilienfield 2000). However, the data with individuals with psychopathy has indicated a rather more selective form of impairment. In this study we investigated performance of individuals with psychopathy on targeted neuro-psychological tasks. As can be seen in Figure 3.3., this study revealed, first, that individuals with psychopathy did not show a general prefrontal dysfunction. In particular, individuals with psychopathy performed comparably to comparison individuals on the SA task. While their performance was generally slower than comparison individuals on the Number Stroop task, they were comparably influenced by the distractor stimuli. In contrast, the individuals with psychopathy presented with marked impairment on the OA task relative to the comparison individuals.

Given that there is clearly no general dysfunction either of frontal function or executive function we can now become more specific. To start with, what do these data tell us about frontal lobe dysfunction in psychopaths? Our experiments were designed to target the DLPFC, the OFC and the ACC. Performance on the SA task has been related to the functional integrity of DLPFC (Brutkowski, Mishkin et al. 1963; Mishkin, Vest et al. 1969; Zald, Curtis et al. 2002).
Figure 3.3: Schematic of the relationship between prefrontal substructures, the tasks they mediate, including the tasks used in present experiment, and psychopathy.
Performance on the OA task has been related to the functional integrity of OFC (Pribram and Mishkin 1956; Mishkin, Vest et al. 1969; Freedman, Black et al. 1998; Zald, Curtis et al. 2002). Finally, the Stroop task implicates the ACC.

In other studies, individuals with psychopathy have been found to perform comparably to comparison individuals on tasks indexing DLPDF such as the WCST, COWAT, and the ED-shift component of ID/ED task (Smith, Arnett et al. 1992; LaPierre, Braun et al. 1995; Roussy and Toupin 2000; Mitchell, Colledge et al. 2002). In this study, we found that individuals with psychopathy performed comparably to comparison individuals on the SA task. In this respect, then, we are in agreement with other findings.

In contrast, individuals with psychopathy have been found to be impaired on tasks indexing OFC such as the Porteus Maze task, motor Go/No-Go tasks, and measures of response reversal/ extinction such as the ID/ED task and the One Pack Card Playing Task (Newman, Patterson et al. 1987; LaPierre, Braun et al. 1995; Roussy and Toupin 2000; Mitchell, Colledge et al. 2002). In our study, the individuals with psychopathy were impaired on the OA task which also indexes OFC. Again, our data agree with others in the literature and we feel confident in suggesting an intact DLPFC, but impaired OFC, in individuals with psychopathy.

The third part of the frontal lobe in our study is the ACC. Kiehl et al. has suggested that psychopathy involves ACC dysfunction (Kiehl, Smith et al. 2001). Support for this suggestion has come from two recent imaging studies reporting reduced ACC functioning in individuals with psychopathy (Kiehl, Smith et al. 2001; Veit, Flor et al. 2002). In addition, Newman et al. (1997) reported significantly different performance on a Stroop-type interference task by individuals with psychopathy compared with controls. Of course, it should be noted that in this study the participants were less affected by the distractor items rather than, as is found in some cases with ACC dysfunction, more affected. However, and in contrast to the above results, a study using the Stroop colour-word task reported no impairment in individuals with psychopathy (Smith, Arnett et al. 1992). Moreover, Brinkley and colleagues examined the level of interference in a Stroop task as a function of semantic relatedness of the target response to the distracter, and reported that individuals with psychopathy and comparison individuals displayed comparable interference (Brinkley, Schmitt et al. submitted). Our current results are compatible with those of Smith et al. (1992) and Brinkley et al (submitted). Using the Number Stroop task, we found no indications of greater or reduced impact of distractors on task performance. This was particularly noticeable through the use of the parametric design, whereby level of interference should decrease as symbolic number line distance between the target and the distractor increases (Pavese and Umilta 1998; Pavese and Umilta 1999;
Peschardt, Morton et al. manuscript in preparation). As can be seen in Table 3.2., the impact of symbolic number line distance on interference in both groups was comparable, a result similar to that reported by Brinkley et al. (submitted) who manipulated semantic relatedness rather than symbolic number line distance.

In short, the current results and those of Smith et al. (1992) and Brinkley et al. (submitted) all suggest no impairment on Stroop measures in individuals with psychopathy and thus, by inference, no impairment in those regions of ACC that are involved in the mediation of performance on Stroop tasks (Bush, Luu et al. 2000). In contrast, Newman et al.'s (1997) results suggest anomalous Stroop performance, though the implications of ACC functioning are complex, while the neuro-imaging data could be taken to indicate reduced ACC functioning in individuals with psychopathy (Kiehl, Smith et al. 2001; Veit, Flor et al. 2002).

How can these inconsistent results be reconciled? We will consider the behavioural results initially. Probably the dominant current model of Stroop performance is the computational task context module model of Cohen and colleagues (Cohen, Dunbar et al. 1990; Cohen, Servan-Schreiber et al. 1992; Cohen, Botvinick et al. 2000). The model was described at some length in Chapter One, but what is important to note here is that the model predicts that an individual's level of Stroop interference is a function of the training on the respective domains, the relative activation of these respective domains by a stimulus and also the degree to which the context or conflict monitoring modules are functioning efficiently. Now, if either the context or conflict monitoring modules operate inefficiently in individuals with psychopathy, heightened Stroop interference is predicted (Cohen, Dunbar et al. 1990; Cohen, Servan-Schreiber et al. 1992; Cohen, Botvinick et al. 2000). This has not been reported for individuals with psychopathy on Stroop-like tasks (Smith, Arnett et al. 1992; Newman, Schmitt et al. 1997; Brinkley, Schmitt et al. submitted). Therefore, within this model, the suggestion must be that any anomalous performance on Stroop tasks in individuals with psychopathy is either a function of differential training on the respective domains or differential relative activation of the respective domains.

The response set modulation hypothesis would suggest differential relative activation of the respective domains. According to Newman, individuals with psychopathy fail "to process the meaning of information that is peripheral or incidental to their deliberate focus of attention" (Lorenz & Newman, 2002; p. 92). Thus, according to the response set modulation hypothesis, in the Newman et al. (1997) study the distractor information was less processed by the individuals with psychopathy because it was incidental to the deliberate focus of attention. The current results, and those of Brinkley et al. (submitted) and Smith et al. (1992), challenge
this suggestion however. The incidental information in these studies was processed appropriately by the individuals with psychopathy (Smith, Arnett et al. 1992). This suggests that any anomalous performance on Stroop tasks in individuals with psychopathy might be a function of differential training. It is certain that the disorder significantly interferes with schooling (Hare 1991). A reduction in schooling would reduce the strength of the processing pathways, particularly that of the prepotent reading response. This in turn would reduce Stroop interference levels. In short, the presence or failure to show reduced levels of Stroop interference would be a product of the educational history of the sample studied.

Interestingly, this account provides an explanation for the generally slower responding of the individuals with psychopathy in this study. Individuals with psychopathy do not always show increased RTs relative to comparison individuals. Indeed, individuals with psychopathy may show comparable RTs (LaPierre, Braun et al. 1995; Kiehl, Hare et al. 1999; Peschardt, Leonard et al. submitted) or even, under specific task conditions, superior RTs relative to comparison individuals (Mitchell, Richell et al. manuscript in preparation). However, in the Number Stroop task, the individuals with psychopathy presented with longer RTs than the comparison individuals across all levels of interference. Importantly, there is no prepotent response in the Number Stroop task: counting interferes with reading and reading with counting. This is unlike the word-colour Stroop task where only reading interferes with colour naming. Because there is no prepotent response formed through over-training of one process rather than another, a reduction in schooling should reduce the strength of both processing pathways equally. Importantly, however, training on digit reading and digit counting would still occur – inside and outside of school. Only, the level of training would be lower relative healthy individuals. This would in turn mean that any given stimulus would less activate an output response and thus result in slower RTs.

The current results have implications for suggestions that there is ACC dysfunction in individuals with psychopathy (Kiehl, Smith et al. 2001). They imply that such suggestions must at least be qualified with respect to the division that has been made between regions of ACC involved in emotional processing and those involved in conflict resolution (Bush, Luu et al. 2000). The current results together with those of Smith et al. (1992) and Brinkley et al. (submitted), suggest no dysfunction in those regions of ACC involved in conflict resolution, though there may be dysfunction in those regions of ACC involved in emotional processing. Of course, given the role of the proposed gating or modulatory role of the ACC (MacLeod and MacDonald 2000), its level of activation is strictly contingent on the level of input it receives from other structures involved in the primary task processing. In emotional tasks this is likely
to include the amygdala. In both the Veit et al. (2002) as well as the Kiehl et al. (2001) study, the activation of the amygdala in individuals with psychopathy was significantly reduced relative to comparison individuals. As suggested in Figure 3.3., the reduced ACC activation reported in individuals with psychopathy in the two neuro-imaging studies may therefore reflect reduced input from a dysfunctional amygdala (Blair 2002) rather than ACC dysfunction per se.

At the cognitive level, executive dysfunction in psychopathy has been linked to impulsivity, conceptualized as (lack of) premeditation and (lack of) perseverance, where lack of premeditation is likened to the "inability to inhibit previously rewarded behaviour when presented with changing contingencies" (Whiteside and Lynam 2001) and lack of perseverance "may be related to disorders that involve the inability to ignore distracting stimuli or to remain focused on a particular task" (Whiteside and Lynam 2001). Executive dysfunction in psychopathy has also been linked to impaired response modulation – the "rapid and relatively automatic (i.e., non-effortful or involuntary) shift of attention from the effortful organization and implementation of goal-directed behaviour to its evaluation" (Newman et al. 1997). These accounts might be expected to predict that individuals with psychopathy would be impaired on all the tasks presented in this study. Thus, the OA and SA task both required the inhibition of a previously rewarded behaviour and normal performance on the Number Stroop task required some ability to ignore distracting stimuli. In addition, performance on all would have been influenced by the processing "the meaning of information that is peripheral or incidental to their deliberate focus of attention" (Lorenz and Newman 2002; p. 92). The current results thus suggest that domain general inhibition/ response set modulation accounts are at least in need of modification. Specifically, it would seem that while a description of the impairment in individuals with psychopathy in terms of an inhibition or response set modulation impairment may be possible, it should be a description that is tied to a particular processing domain (or possibly domains) rather than one that is domain general.

One caveat should be noted with respect to the current results. This is that the OA and SA tasks were not matched for difficulty; the comparison participants also found the SA task easier than the OA task. However, it is important to note that there was certainly room for group differences in SA error rates to be revealed. Moreover, as figure 3.3 highlights, the data from the current study are in line with that from other studies (Mitchell, Colledge et al. 2002). However, a more difficult version of the SA task might be devised for future studies.

In conclusion, in this study it was found that individuals with psychopathy were impaired on our measure of OFC. In contrast, they were not impaired on the measures of DLPFC and ACC. Thus, there was a selective prefrontal impairment in individuals with
psychopathy. These results suggest that previous reports of an ACC dysfunction in psychopathy probably reflected reduced input to the ACC from the amygdala on those emotional tasks rather than an ACC deficit per se. All our measures required response inhibition or response modulation – both of which are suggested to be impaired in individuals with psychopathy (Newman, Schmitt et al. 1997; Whiteside and Lynam 2001). However, we of course only found individuals with psychopathy to be impaired on the measure of OFC. Our results therefore also suggest that while a description of the impairment in individuals with psychopathy in terms of an inhibition or response set modulation impairment may be possible, these explanations would have to take into account that any inhibition or response set modulation impairment clearly does not apply to all domains.
Chapter Four

Differential Stimulus-Reward and Stimulus-Punishment Learning in Individuals With Psychopathy.

4.1.: Introduction

In Chapter One, I described how an individual’s behaviour is modified by the influence of the individual’s past reinforcement history. In this chapter, I will consider how this regulatory system might be compromised in individuals with psychopathy using a new paradigm which assesses decision making on the basis of learnt stimulus-reward and stimulus-punishment associations. In addition, I will consider the implications of this work for the emotional deficits accounts of psychopathy: the BIS/BAS account (Fowles 1980; Gray 1987; Fowles 1988), the fear accounts (Lykken 1957; Patrick, Cuthbert et al. 1994), and the IES model (Blair 2003).

4.1.1.: Psychopathy and Emotional Learning

Research on the affective processes of individuals with psychopathy has revealed significant emotional impairments. Thus, for example, individuals with psychopathy show impaired augmentation of the startle reflex following visual threat primes (Patrick 1994; Levenston, Patrick et al. 2000), impaired recognition of fearful and sad facial expressions (Blair, Colledge et al. 2001; Blair, Mitchell et al. 2002; Kosson 2003), and fearful vocal expressions (Mitchell, Colledge et al. 2002). It can be argued that all these impairments are related to fundamental problems in emotional learning (Blair 2001). Certainly, and as seen in Figure 4.1., individuals with psychopathy show impairments in aversive conditioning (Lykken 1957; Hare and Quinn 1971; Flor, Birbaumer et al. 2002), passive avoidance learning (Newman, Widom et al. 1985; Newman and Kosson 1986; Thornquist and Zuckerman 1995; Newman and Schmitt 1998), and response reversal learning (LaPierre, Braun et al. 1995; Mitchell, Colledge et al. 2002; Peschardt, Leonard et al. manuscript in preparation). That is, individuals with psychopathy appear to be impaired at learning to avoid stimuli associated with punishment; i.e., with respect to aversive conditioning, they are poorer at associating aversive unconditioned stimuli (US) with conditioned stimuli (CS).

Emotional learning involves both learning to avoid stimuli associated with punishment as well as learning to approach stimuli associated with reward. This suggests a question: do individuals with psychopathy have a generalized emotional learning deficit; i.e., do they fail to
learn to avoid aversive CSs as well as fail to approach appetitive CSs? Or is their emotional learning deficit specific to learning to avoid aversive CSs? The clinical picture of psychopathy suggests that individuals with psychopathy are capable of learning about appetitive CSs. So, for example, money is a secondary appetitive CSs. If individuals with psychopathy were impaired in appetitive learning, we might predict that they would be relatively indifferent to money. But, their crimes are very often committed with the goal of obtaining money (e.g., fraud, robbery), suggesting that this is not so. Very little hard empirical data exists on this issue. However, as is summarized in Figure 4.1., the little that exists suggests that individuals with psychopathy are reactive to appetitive CSs. Thus, Patrick et al (1993) and Levenston et al. (2000) both found that whereas individuals with psychopathy failed to show augmentation of the startle reflex following the presentation of a negative visual prime, they did show reduction of the startle reflex following the presentation of a positive visual prime (Patrick, Bradley et al. 1993; Levenston, Patrick et al. 2000). In addition, Blair et al. (1995) found that whereas individuals with psychopathy made significantly fewer reference to other individuals’ pain when justifying positive moral acts (e.g., a child comforting another child crying), they made a comparably number of references to other individuals’ pleasure relative to comparison individuals (Blair, Jones et al. 1995). That is, these studies might suggest that whereas individuals with psychopathy are insensitive to aversive CSs, they are sensitive to appetitive CSs. These studies however do not tell us anything about the speed of acquisition of appetitive CSs in individuals with psychopathy, or indeed whether the ability to form CSs exists in the adult psychopathic individual.

4.1.2.: BIS/ BAS and Fear Models of Psychopathy

The BIS/ BAS model was described in detail in Chapter One, but briefly, the BAS system is a reward-seeking system which responds to positive incentives by activating behaviour. In contrast, the BIS system inhibits responses to cues of conditioned stimuli signaling that aversive consequences will occur if a response is made. It has been suggested that in psychopathy there is a hypo-active BIS system but an intact, or indeed, hyper-active BAS system (Fowles 1980; Gray 1987; Fowles 1988; Fowles 2003). The BIS/ BAS model of psychopathy has clear predictions for our current study investigating the formation of stimulus-reward and stimulus-punishment associations in individuals with psychopathy: They should be impaired in the formation of and decision making from stimulus-punishment associations but normal or superior at the formation of stimulus-reward associations.
Formation of Stimulus-Reward Associations:
- Passive Avoidance Learning
- Aversive Conditioning

Formation of Stimulus-Punishment Associations:
- Reduced Startle Reflex Following Positive Prime
- Increased SCR to Positive Pictures
- Reference to Other Individuals' Pleasure.

Psychopath

Figure 4.1: Schematic of the relationship between the ability to form stimulus-reinforcement associations and psychopathy as indicated by existing data.
The fear models of psychopathy (Lykken 1957; Patrick, Cuthbert et al. 1994), which were also described in detail in Chapter One, similarly hold clear predictions for our current study. Thus, in these models the individuals with psychopathy, because they are less averingly aroused by punishment, make weaker stimulus-punishment associations relative to healthy individuals. The models do not specify stimulus-reward formation in individuals with psychopathy, however, an implicit assumption is that this process must be intact. These models therefore clearly predict that individuals with psychopathy will be impaired at the formation of stimulus-punishment associations and intact at the formation of stimulus-reward associations.

For the BIS/BAS and fear accounts of psychopathy then it is of considerate interest to determine whether individuals with psychopathy have difficulties in the formation of both stimulus-reward and stimulus-punishment associations, whether they have difficulties in the formation of stimulus-punishment associations only, or whether they, as suggested by the BIS/BAS account, are superior at the formation of stimulus-reward associations.

4.1.3.: The Integrated Emotions Model (IES)

The IES account of psychopathy (Blair 2003) was described in detail in Chapter One. However, briefly, this model consists of a series of 'modular' systems that operate in specific integrated ways in order to perform specific tasks (see Figure 4.2., for a simplified version of this model). The first of these systems consists of representational units that code potential conditioned stimuli. At the anatomical level, these units are thought to be implemented within temporal cortex but also other regions, such as the hippocampus. These units can form weighted connections with valence units representing reward and punishment. These can be activated by nociceptive input (USs) or conditioned reinforcers (e.g., in the current context, point reward/punishment). At the anatomical level these valence units are thought to be implemented within the amygdala. The strength of the connections between units in the different modules increase though Hebbian learning.

The model provides three alternative explanations for the emotional learning impairment in psychopathy. First, that there could be reduced nociceptive (US) input to which would result in reduced activation of the valence units and thus lead to impaired learning. Second, that the valence units of individuals with psychopathy could be hypo-responsive and thus less likely to fire at any given level of input. Third, that the Hebbian learning process itself, at least for emotional learning, might be impaired in individuals with psychopathy. While the disentanglement of these three alternative explanations of the emotional learning deficit in individuals with psychopathy is of interest, for the purposes of the current study, they
all hold the same prediction: Individuals with psychopathy should be impaired in the formation of both stimuli-reward and stimuli-punishment associations.

Figure 4.2.: A simplified version of the IES model. Module A contains representational units that code potential conditioned stimuli (these units are thought to be implemented within temporal cortex and other regions including the hippocampus). These units can form weighted connections with the valence units in module B that represent reward and punishment. These connections form through Hebbian learning on the basis of activation of the valence units by nociceptive input (USs). The valence units are thought to be implemented within the amygdala. Module C allows conflict resolution to occur. Expectations of reward/punishment fed from the valence units activate ‘selection’ units which are self-excitatory but mutually inhibitory. When the conflict between these ‘selection’ units is resolved, a response to one of the two stimuli will be initiated.

The third ‘module’ depicted in Figure 4.2. allows conflict resolution to occur; i.e., it allows the choice of a particular response when stimuli present in the environment might suggest more than one possible response. For example, if the goal is to win point rewards and responding to both stimuli present in the environment will provide these point rewards, how does the system decide which one to choose? The IES model borrows heavily from an implementation of stimulus selection proposed by Usher and Cohen (1999). Very briefly, the Usher and Cohen (1999) model assumes the existence of modality specific posterior units that are limited by temporal decay while anterior units use active reverberations which can sustain themselves and which are limited by displacement from competing new information. The anterior units, by being self excitatory, but mutually inhibitory allow rapid selection between competing, multiple active posterior response options (Usher and Cohen 1999). Blair’s
suggestion is that there are comparable ‘selection’ units for choices on the basis of stimuli associated with different levels of reward/punishment. The units in orbital frontal cortex would receive information in order to solve response competition on the basis of expectations of reinforcement provided by the valence units. At the anatomical level, these ‘selection’ units are thought to be implemented by medial OFC.

Importantly, the function of these ‘selection’ units leads to a clear prediction regarding error rates for selections involving stimuli associated with different levels of reward or punishment. In particular, the model predicts that the closer the difference between the expected levels of reward/punishment associated with the two different stimuli, the greater the probability of a selection error. With respect to psychopathy, the effects of distance should be even more extreme. This is because any impairment in the valence units should result in reduced coding of expected reward/punishment levels; i.e., less precise signals being communicated to the selection units. A predicted error pattern on the basis of this model is presented in Figure 4.3. Note that if the valence units are generally impaired in individuals with psychopathy, then individuals with psychopathy should also show significant impairment for stimulus selection on the basis of stimulus-reward associations as well as for stimulus-punishment associations.

![Figure 4.3: The predicted error pattern for the psychopathic and comparison group on the Differential Reward/Punishment Learning Task according to the IES model.](image)

Thus, for this model it is of considerable interest to determine: First, whether individuals with psychopathy show difficulties in response choice based on both stimulus-reward and stimulus-punishment associations, or whether they show difficulties in response choice based only on stimulus-punishment associations. Secondly, whether difficulty in response choice is a function of the distance, in valence level, of the stimuli. Given this, I
designed a graded stimulus-reinforcement task, the Differential Reward/Punishment Learning Task, to investigate response choice governed by stimulus-reward/stimulus-punishment associations in individuals with psychopathy. In this task, the participant has to choose between two objects presented on a computer screen. These objects can either involve one rewarding and one punishing object, two objects with different levels of punishment, or two objects with different levels of rewards. The participant has to choose the object that will gain the most points or lose the least points. If individuals with psychopathy have difficulties in the formation of stimulus-reward and stimulus-punishment associations, it is predicted that they will show a general impairment with respect to comparison individuals for all three choice situations (between one stimulus associated with reward and the other with punishment, between two stimuli associated with punishment, between two stimuli associated with reward). In contrast, if individuals with psychopathy only have difficulties in the formation of stimulus-punishment associations, then they should only show impairment when choosing between stimuli associated with different levels of punishment. In addition, if individuals with psychopathy are hyper-sensitivity to the processing of appetitive stimuli, then they should be superior performance in choosing between two rewarding stimuli. Moreover, if difficulty of response competition resolution in the formation of stimulus-reward and stimulus-punishment associations is indeed a function of stimuli desirability difference, it should be more difficult to choose between two stimuli of similar reward, or alternatively punishment, value. The current study tests these predictions.

4.2.: Experiment 5

4.3.: Method

4.3.1.: Participants

Participants were 41 adult males selected from a pool of 250 individuals residing in Category B (second highest security level) institutions in England. In accordance with the established criteria of the literature and the established guidelines of the PCL-R (Hare 1991), individuals with a PCL-R score of 30 or above were included in the psychopathic group, while individuals with a PCL-R score of 20 or less were included in the comparison group (see Table 4.1. for full participant details). There were no significant group differences in either age, Ravens scores or NART scores. The sample was made up of 32 Caucasian, 7 Afro-Caribbean,
<table>
<thead>
<tr>
<th>Group</th>
<th>PCL-R</th>
<th>Age</th>
<th>Raven</th>
<th>NART</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psychopathic group (n = 21)</td>
<td>32.86 (1.86; 30-36)</td>
<td>36.71 (7.52; 22-51)</td>
<td>8.15 (2.03; 3-11)</td>
<td>22.43 (9.06; 9-45)</td>
</tr>
<tr>
<td>Comparison group (n = 20)</td>
<td>6.17 (4.68; 1.5-16)</td>
<td>31.60 (9.23; 21-50)</td>
<td>7.60 (2.44; 4-12)</td>
<td>22.70 (7.62; 14-36)</td>
</tr>
</tbody>
</table>

**Table 4.1.:** Participant characteristics, S.D., and ranges in brackets ( ).
and 2 Asian participants (5 Afro-Caribbean participants in the psychopathic group, and 2 Afro-Caribbean and 2 Asian participants in the comparison group). In addition to satisfying PCL-R criteria for high and low levels of psychopathy, psychiatric files were screened for evidence of psychosis or neurological disorder, and individuals who had received diagnoses for psychosis or organic brain damage were excluded from testing.

4.3.2.: Design

The study involved a 2 (Group; psychopathic and comparison) x 3 (Trial Type; Reward/ Punishment (RewPun), Punishment/ Punishment (Pun-Pun), and Reward/ Reward (RewRew) mixed model factorial design. The dependent variable was number of errors made; i.e., choosing the inferior object over the superior object.

4.3.3.: Measures

4.3.3.1.: The Psychopathy Checklist Revised (PCL-R)

The PCL-R was described in detail in Chapter One. In this study, 5 participants (3 psychopathic and 2 comparison) were unavailable for interview and so were scored on the basis of file notes only. Participants were scored independently by two raters. Inter-rater reliability was established by means of a Spearman rank correlation. The correlation, \( r_{\text{ranks}} = 0.95 \) (\( p < 0.000 \)), is similar to that reported in the literature (Hare 1991).

4.3.3.2.: The Differential Reward/ Punishment Learning Task

The Differential Reward/ Punishment Learning Task consists of 10 objects, each depicting a different object (house, cup, fork, duck, pineapple, necklace, raccoon, door, torch, or shoe). For each participant, each object is randomly assigned a value (-1600, -800, -400, -200, -100, 100, 200, 400, 800, or 1600) for the whole task. During the task, the objects are presented together in pairs, and appear in two of four different locations positioned around the middle of the screen. The participant is told that on each trial one of the two objects must be chosen, and that choosing some objects will mean losing points and that choosing some objects will mean winning points. When the participant chooses the wanted object for that trial (with the click of a mouse), its assigned value is revealed. Thus, if an object has been assigned the value 1600, the text: ‘You have WON 1600 points’ appears in the middle of the screen. Conversely, if an object has been assigned the value -1600, the text: ‘You have LOST 1600 points’ appears in the middle of the screen. This text stays on the screen for 1000 ms and is
then replaced by the two objects for the subsequent trial. The participant is told to try to win as many points as possible or, if they believe that for a particular trial they cannot win any points, then to lose as few points as possible. There is no time limit for making a response.

Although participants are told how many points they have won or lost on any one trial, they do not receive feedback as to whether their choice of object is correct or incorrect. For example, choosing the door for 200 points over the torch for 400 points would be an incorrect response even though the participant won points because they could have won more points by choosing the torch. At the end of the study they are told how many points they have accumulated.

<table>
<thead>
<tr>
<th></th>
<th>-800</th>
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<th>-200</th>
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<td>2</td>
<td>14</td>
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Table 4.2.: A schematic of the number of times that values were presented together.

All objects are paired with each other, leading to three task conditions: RewPun, PunPun, and RewRew. In the RewPun condition, one object is associated with reward and one object is associated with punishment. In the PunPun condition, both objects presented are associated with punishment. In the RewRew condition, both objects are associated with reward. Again, the participant's goal is to choose the object that will gain them the most points or lose them the least points. Caution was taken to ensure that all the objects, with the exception of the 1600/-1600 'endpoints', would be the superior, as well as the inferior, choice in an equal number of trials. This was achieved by using the two extreme values (-1600 and 1600) to 'top up' the number of wins and loses for each object (see Table 4.2. for a depiction of all trial conditions). Two blocks of trials (234 in total) were presented to the participants. The Differential Reward/Punishment Learning Task was programmed in VisualBasic and presented on a Dell Inspiron 8100 laptop.
4.3.4: Procedure

Each participant was tested individually in a quiet interview room within the institution and was seated approximately fifty centimeters from the computer screen. The task was described without informing the participant of the investigation's specific objectives and expectations. Following written consent, each participant was then presented with the Differential Reward/Punishment Learning Task presented within a larger neuro-cognitive test battery. The duration of the study was approximately 22 minutes for each participant.

4.4: Results

On any trial, choosing the superior object over the more inferior object was scored as 'correct'. Thus, on RewPun trials where one object represented a gain and one a loss (e.g., -200 and 200), choosing the object representing a gain of 200 would be correct. On PunPun trials where both objects represented a loss (e.g., -100 and -200), choosing the object representing the smaller loss of -100 would be correct. Finally, on RewRew trials where both objects represented a gain (e.g., 100 and 200), choosing the object representing the greater gain of 200 would be correct. The data points pertaining to the first time any object was presented were excluded from the analysis. As there were more RewPun trials than either PunPun and RewRew trials, participants' error scores were converted into error percentages for the three trial types.

An initial 2 (Group: psychopathic vs. comparison) x 3 (Trial type: RewPun, PunPun, RewRew) ANOVA was conducted on the data. This revealed a main effect of group (F(1, 39) = 10.91; p < 0.005); the individuals with psychopathy showed significant impairment on this task relative to comparison individuals (M[psychopathic group] = 14.10; s.e. = 1.66, M[comparison group] = 6.27; s.e. = 1.68. There was also a main effect of trial type (F(2, 78) = 30.47; p < 0.001); the participants made a higher percentage of errors on PunPun trials relative to RewRew trials and on RewRew trials relative to RewPun trials (M[PunPun] = 15.45; s.e. = 1.74, M[RewRew] = 10.61; s.e. = 1.45, M[RewPun] = 4.50; s.e. = 0.97). Importantly, there was also a striking group by trial type interaction (F(2, 78) = 6.54; p < 0.005). As can be seen in Figure 4.4., while the comparison individuals were as likely to make errors on RewRew trials as on PunPun trials, the individuals with psychopathy were significantly more likely to make errors on PunPun trials as on RewRew trials (confirmed by a planned comparison (F(1, 19) = 12.96; p < 0.005). In short, while the individuals with psychopathy showed general impairment on the task, their impairment was particularly marked for PunPun trials.
The design of the Differential Reward/ Punishment Learning Task allowed not only a general examination of participant performance according to trial type (i.e., RewRew vs. PunPun) but also a more finely detailed analysis for sensitivity to reward/punishment level according to inter-reinforcement level interval. Thus, each of the ten stimuli engendered a different level of reward: -1600, -800, -400, -200, -100, 100, 200, 400, 800, or 1600 points. The difficulty in choosing between stimuli should be related to the differential in their reward levels; i.e., choosing between the stimulus engendering 100 points and the stimulus engendering 200 points should be more difficult than choosing between the stimulus engendering 100 points and the stimulus engendering 800 points.

<table>
<thead>
<tr>
<th></th>
<th>PunPun</th>
<th>RewRew</th>
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<tbody>
<tr>
<td><strong>Psychopathic group</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance One</td>
<td>25.56 (2.80)</td>
<td>13.49 (1.87)</td>
</tr>
<tr>
<td>Distance Two</td>
<td>22.14 (2.61)</td>
<td>13.57 (2.82)</td>
</tr>
<tr>
<td>Distance Three</td>
<td>18.16 (2.92)</td>
<td>16.67 (3.21)</td>
</tr>
<tr>
<td>Distance One</td>
<td>9.58 (2.87)</td>
<td>11.46 (1.92)</td>
</tr>
<tr>
<td><strong>Comparison group</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance Two</td>
<td>9.00 (2.67)</td>
<td>7.75 (2.89)</td>
</tr>
<tr>
<td>Distance Three</td>
<td>8.75 (2.99)</td>
<td>5.94 (3.29)</td>
</tr>
</tbody>
</table>

**Key to Table:** PunPun = Punishment/ Punishment condition, RewRew = Reward/ Reward condition.

**Table 4.3.** Error percentage and S.E.s in bracket () for the psychopathic and comparison group.
We thus conducted a second analysis on the PunPun and RewRew trials examining the impact of inter-stimulus reward/punishment level distance on group performance. This involved a 2 (Group: psychopathic vs. comparison) x 2 (Trial type: PunPun or RewRew) x 3 (Distance: One [e.g., 100 vs. 200]; Two [e.g, 100 vs 400] or Three [e.g., 100 vs 800]) ANOVA being conducted on the data. This revealed a main effect of group (F(1, 39) = 10.03; p < 0.005); as before, the individuals with psychopathy showed significant impairment on this task relative to comparison individuals. The main effect of trial type was also again significant (F(1, 39) = 8.14; p < 0.01); the participants made more errors on PunPun than RewRew trials (M[PunPun] = 15.45; s.e. = 1.74, M[RewRew] = 10.61; s.e. = 1.45), M[RewPun] = 4.50; s.e. = 0.97). Moreover, there was again a significant group by valence interaction group (F(1, 39) = 5.48; p < 0.005); as seen in Figure 4.4., while the comparison individuals were as likely to make errors on RewRew trials as on PunPun trials, the individuals with psychopathy were significantly more likely to make errors on PunPun trials as on RewRew trials. The main effect of distance was also significant (F(2, 78) = 2.93; p < 0.05; one tailed); (M[Distance One] = 15.03; s.e. = 1.39, M[Distance Two] = 13.12; s.e. = 1.77), M[Distance Three] = 12.38; s.e. = 1.74). However, interestingly, there was a significant group by trial type by distance interaction (F(2, 78) = 3.80; p < 0.05). As can be seen in Table 4.3., while the comparison individuals presented with a distance effect for both PunPun and RewRew trials (albeit muted for PunPun trials), the individuals with psychopathy presented with a striking distance effect for PunPun trials but demonstrated no effect for distance for the RewRew trials.

4.5: Discussion

This study investigated response choice as a function of learnt stimulus-reward/stimulus-punishment associations in individuals with psychopathy using the Differential Reward/ Punishment Learning Task. This study revealed that individuals with psychopathy presented with impaired response choice and that this impairment was particularly marked when the participant had to choose between two stimuli that engendered punishment. Interestingly, the performance of comparison individuals was affected by the degree of difference in the level of punishment/reward engendered by the stimuli (i.e., there was an inverse relationship between task performance and the differential between the levels of punishment/reward engendered by the two stimuli). However, while the performance of the individuals with psychopathy was highly affected by the degree of difference in the level of punishment, it was not affected by the differential in level of reward.
As regards the ability of individuals with psychopathy to form stimuli-punishment associations, the current results demonstrated a striking impairment in response choice as a function of learnt stimulus-punishment associations. These results were compatible with previous demonstrations that individuals with psychopathy show impairment in the formation of stimulus-punishment associations during aversive conditioning and passive avoidance learning (Hare and Quinn 1971; Newman and Kosson 1986; Flor, Birbaumer et al. 2002) and impairment in response choice as a function of these associations (Mitchell, Colledge et al. 2002).

As regards the ability of individuals with psychopathy to form stimuli-reward associations, no previous study has directly investigated this issue. However, there was data to suggest that individuals with psychopathy might be intact at forming these associations. Thus, Levenston et al. (1996) found that individuals with psychopathy show reduction of the startle reflex to positive visual prime (see also Patrick, 1993). In addition, Patrick et al. (1994) found that individuals with psychopathy showed increased SCRs to positive stimuli. Finally, Blair et al. (1995) found that individuals with psychopathy and comparison individuals made a comparable number of references to other individuals' pleasure when justifying positive moral acts (e.g., a child comforting another child crying). That is, these results indicated that individuals with psychopathy had acquired and thus responded to appetitive CSs. But of course they did not inform us about the speed of acquisition of appetitive CSs in psychopathy. This study indicated that individuals with psychopathy are impaired at acquiring appetitive CSs relative to comparison individuals (albeit to far less of an extent than their impairment for acquiring aversive CSs).

The current results may be considered problematic for the BIS/ BAS and fear accounts of psychopathy (Lykken 1957; Fowles 1980; Gray 1987; Fowles 1988; Patrick, Cuthbert et al. 1994). Thus, the BIS/ BAS account of psychopathy (Lykken 1957; Fowles 1980; Gray 1987; Fowles 1988; Patrick, Cuthbert et al. 1994) predicted that individuals with psychopathy should be intact or possibly superior at the formation of stimulus-reward associations while the fear accounts (Lykken 1957; Fowles 1980; Gray 1987; Fowles 1988; Patrick, Cuthbert et al. 1994) predicted that they should be intact at this process. But of course we found that individuals were actually impaired at the formation of stimulus-reward associations. While the BIS/ BAS and fear accounts of psychopathy could quite easily incorporate this finding by considering psychopathy to involve impairments of not only the BIS but also the BAS, it is clear that this implementation is not in line with the theoretical underpinnings of these models. The current results are therefore problematic for these accounts.
At first glance the current results appear to be predicted by the IES model of psychopathy (e.g., Blair 2003). This model appears to suggest that individuals with psychopathy should show impairment for decision making not only on the basis of stimulus-punishment associations but also on the basis of stimulus-reward associations. However, it is important to note that this model specifically predicted the same degree of impairment in decision making on the basis of stimulus-reward associations as that found with stimulus-punishment associations. This was clearly not found here. The present data suggests that the IES model must be qualified such that the impairment in the valence units coding positive information is significantly less than that present for the valence units coding negative information.

The IES model also predicted that there would be an inverse relationship between task difficulty (as measured by number of errors) and the differential in expected reward/punishment associated with particular stimuli and that this relationship would be more pronounced in individuals with psychopathy than comparison individuals. As regards stimulus selection on the basis of punishment information, the current results strongly supported this prediction (see Table 4.3.). Thus, for both groups there was an inverse relationship between number of errors committed and the differential in expected punishment associated with particular stimuli. In addition, this relationship was more pronounced in individuals with psychopathy than comparison individuals. With respect to stimulus selection on the basis of reward information, the behaviour of the comparison individuals supports the model. That is, for the comparison group there was an inverse relationship between the number of errors committed and the differential in expected reward associated with particular stimuli. However, the behaviour of the individuals with psychopathy clearly does not. As seen in Table 4.3. these individuals showed absolutely no distance effect as a function of task difficulty on the basis of reward information.

Of course this could be a chance result. It will be important to replicate the finding. However, the result does suggest an interesting possibility that the individuals with psychopathy are recruiting a computational process which the comparison individuals do not need to in order to solve stimulus selection on the basis of stimulus-reward information. Of course, this is highly speculative. Moreover, it is not precisely clear what form of compensatory strategies the individuals with psychopathy could have been adopting and more importantly why they could not utilize them for stimulus selection on the basis of stimulus-punishment information. Future studies will have to investigate this phenomenon further.
In conclusion, this study investigated response choice as a function of learnt stimulus-reward/ stimulus-punishment associations in individuals with psychopathy using the Differential Reward/ Punishment Learning Task. I predicted that if individuals have impaired formation of stimulus-reward and stimulus-punishment associations, they should: (1) find response choice on the basis of these associations particularly difficult; and (2) show greater difficulties relative to comparison individuals for choices between objects associated with similar reward/ punishment levels than for choices between objects associated with very different levels of reward/ punishment. In the study, the individuals with psychopathy did show impairment in response choice on the basis of learnt stimulus-reward/ stimulus-punishment associations but their impairment was strikingly more marked for response choices on the basis of stimulus-punishment associations. Moreover, they did show greater difficulties relative to comparison individuals for choices between objects associated with similar punishment levels than for choices between objects associated with very different levels of punishment. These results have implications for the BIS/BAS and fear models of psychopathy (Lykken 1957; Fowles 1980; Gray 1987; Fowles 1988; Patrick, Cuthbert et al. 1994) that suggest that individuals with psychopathy are intact, or possibly superior, at the formation of stimulus-reward associations, but impaired at the formation of stimulus-punishment associations. These results also have implications for the IES model of psychopathy (Blair 2003) that suggest that individuals with psychopathy are equally impaired at the formation of stimulus-reward and stimulus-punishment associations.
Chapter Five
Affective Priming in Individuals With Psychopathy

5.1.: Introduction

In Chapter Four, I considered the ability of individuals with psychopathy to make decisions between stimuli based on differential stimulus-reward/ stimulus-punishment associations made with these stimuli. In this chapter, I will consider a particular type of stimulus-reward/ stimulus-punishment association; that is when the stimulus associated with reward/ punishment is a word. In short, I will consider affective priming in individuals with psychopathy.

5.1.1.: Psychopathy and Emotional Learning

As argued in Chapters One and Four, considerable research on the affective processes of individuals with psychopathy has revealed significant emotional impairments. I and others have argued that all these impairments are related to fundamental problems in emotional learning. That is, individuals with psychopathy appear to be impaired at learning to avoid stimuli associated with punishment; i.e., with respect to aversive conditioning, they are poorer at associating aversive unconditioned stimuli (US) with conditioned stimuli (CS). Moreover, as indicated particularly by Chapter Four, they may show difficulties forming stimulus-reward associations also, albeit to a lesser degree than their impairment in the formation of stimulus-punishment associations.

Words paired with aversive USs can become aversive CSs. Thus, the word ‘pain’ can become an aversive CS if it is paired with the primary US of the individual’s own pain. Words that become CSs (either appetitive or aversive) become more salient than neutral words; presumably the association of the word with the valence representation increases the activity of those units coding the word when the word is activated; see Figure 5.1.

The effect of this increased salience can be seen in the lexical decision task. In this task, participants are presented with letter strings and must respond ‘yes’ when the letter strings presented to them form a word and ‘no’ if they do not. The greater salience of emotional CS words is shown in the faster response to emotional than neutral words in healthy individuals (Graves, Landis et al. 1981). In addition, healthy individuals show larger evoked related potentials (ERPs) over central and parietal sites to emotional CS words than to neutral words (Begleiter, Gross et al. 1967). If, as suggested, individuals with psychopathy are poorer at associating aversive USs with CSs, they should show less of these effects. In line with this
prediction, individuals with psychopathy do fail to show any reaction time (RT) or ERP differences between neutral and emotional words (Williamson, Harpur et al. 1991; Kiehl, Hare et al. 1999; Lorenz and Newman 2002). Of course, affective language interaction impairments might not reflect impairment in affect but rather a more generalized impairment in linguistic/semantic processing. Thus, Kiehl et al., (1999) examined the influence of word concreteness on lexical decision and found that individuals with psychopathy made significantly more errors than comparison individuals in rejecting abstract words. However, there were no group differences for concrete words. In addition, Lorenz and Newman (2002) examined the influence of word frequency on lexical decision and found that whereas healthy individuals were faster to state that high, rather than low, frequency words are words, individuals with psychopathy were not.

Two further studies, however, suggest no generalized linguistic/semantic processing impairment in individuals with psychopathy. Thus, Brinkley et al. examined the extent of semantic processing using a semantic priming task and reported that individuals with psychopathy and comparison individuals displayed comparable priming (Brinkley, Schmitt et al. submitted). In addition, Brinkley and colleagues examined the level of interference in a Stroop task as a function of semantic relatedness of the target response to the distracter and reported that individuals with psychopathy and comparison individuals displayed comparable

![Diagram](image.png)

**Figure 5.1.** Language-affect interactions in lexical decision.
interference (Brinkley, Schmitt et al. submitted). It is not clear from the existing data then, whether individuals with psychopathy have a generalized impairment in linguistic/semantic processing or whether they have a specific impairment in affective linguistic processing.

The tasks that have been used to examine affective linguistic processing in individuals with psychopathy are relatively indirect measures of affect-language interactions. So, for example, in the lexical decision task, an emotional word is easier to recognize than a non-emotional word because of its affect-driven increased salience. In terms of the model developed in Figure 5.1, the word representation activates the valence representation which, in turn, due to the reciprocal interconnections, serves to increase the activation of the word representation. This augmentation of the activation of the emotional word representation means that it is faster to be 'recognized' as a word than a neutral word.

In affective priming paradigms participants are typically asked to judge the affective valence (positive, negative) of a target word (e.g., love, hate) that is preceded by a positive, neutral, or negative prime word. In such tasks, healthy individuals are faster to make affective connotation judgments if the prime word and the target word have the same connotation; e.g., RTs to respond positive to the target word 'love' are faster if the prime word is 'happy' rather than 'chair' or 'hate' (Klauer 1998). I develop a model of affective priming, embedded in the IES model, in Figure 5.2. The suggestion is that emotion facilitation occurs if the prime word primes the same valence representation, and in turn the same output response, as the target word. Thus, if the target word 'happy' is preceded by the prime word 'love' the 'positive' valence representation is already primed by the word 'love' and thus the output response is more ready to be activated by the target word 'happy'. In contrast, if the target word 'happy' is preceded by the prime word 'hate', the 'negative' valence representation will have been primed up by the word 'hate'. Thus, not only will the 'positive' valence representation not have been primed but there will be response competition between the 'positive' and 'negative' valence representations.

In the study to be presented in this chapter, I will assess affective and semantic priming in individuals with psychopathy. If individuals with psychopathy have a generalized learning impairment extending to both aversive and appetitive CSs they should show impaired affective priming for both positive and negative target words. In contrast, if the emotional learning impairment of individuals with psychopathy is more strongly linked to stimulus-punishment associations, they should show impaired affective priming for negative target words only. Finally, if there is a generalized linguistic/semantic impairment in individuals with
psychopathy, they should show with reduced semantic as well as affective priming. The current study tests these predictions.

**Responses**

![Diagram of affective priming]

**Figure 5.2.** Model of affective priming.

5.2.: **Experiment 6**

5.3.: **Method**

5.3.1.: **Participants**

Participants were 50 adult males selected from a pool of 250 individuals residing in Category B (second highest security level) institutions in England. In accordance with the established criteria of the literature and the established guidelines of the PCL-R (Hare 1991), individuals with a PCL-R score of 30 or above were included in the psychopathic group, while individuals with a PCL-R score of 20 or less were included in the comparison group. Individuals with a PCL-R score between 20 and 29 were excluded from the study.

Although a total of 50 inmates participated in the study, inmate transfers prevented some individuals from participating in both testing sessions. Consequently, 28 individuals took
part in both studies, 14 individuals took part in the Affective Priming Task only, and 8 individuals took part in the Semantic Priming Task only. The age of the participants ranged from 20 to 54 with a mean of 34.84 years (SD = 9.22). Raven's scores ranged from 3 to 12 with a mean of 8.10 (SD = 2.09). NART scores ranged from 9 to 45 with a mean of 22.90 (SD = 9.08). There were no significant group differences in either age, Raven's scores, or NART scores for either task; see Table 5.1. for full participant details. The sample was made up of 40 Caucasian, 8 Afro-Caribbean, and 2 Asian participants (6 Afro-Caribbean participants in the psychopathic group, and 2 Afro-Caribbean and 2 Asian participants in the comparison group).

5.3.2.: Design

The Affective Priming Task involved a 2 (Group: psychopathic and comparison group) x 3 (Prime: positive, neutral, negative) x 2 (Target: positive, negative) mixed-model factorial design. The dependent variables were RT and error rate. The Semantic Priming Task involved a 2 (Group: psychopathic and comparison group) x 2 (Prime: animal, fruit/vegetable) x 2 (Target: animal, fruit/vegetable) mixed-model factorial design. The dependent variable was RTs. The groups were made up of incarcerated adults separated into two groups based on their Psychopathy Checklist Revised (PCL-R) scores. The Raven's Advanced Matrix-Set I (Raven 1965) was used as an estimate of general intelligence and the National Adult Reading Test (NART) was used as an estimate of verbal intelligence.

5.3.3.: Measures

5.3.3.1.: The Psychopathy Checklist Revised (PCL-R)

The PCL-R was described in detail in Chapter One. In this study, 6 participants (4 psychopathic and 2 comparison) inmates were unavailable for interview and so were scored on the basis of file notes only. Participants were scored independently by two raters. Inter-rater reliability was established by means of a Spearman rank correlation. The correlation, \( r_{\text{ranks}} = 0.88 \) (\( p < 0.000 \)), is similar to that reported in the literature.
<table>
<thead>
<tr>
<th>Group</th>
<th>PCL-R</th>
<th>Age</th>
<th>Raven</th>
<th>NART</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The Affective Priming Task</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychopathic group (n = 22)</td>
<td>33.10 (2.25; 30-36)</td>
<td>35.00 (9.61; 20-54)</td>
<td>8.05 (1.99; 3-11)</td>
<td>21.23 (8.61; 9-45)</td>
</tr>
<tr>
<td>Comparison group (n = 20)</td>
<td>8.56 (1.95; 1.5-16)</td>
<td>32.35 (9.21; 21-50)</td>
<td>8.05 (2.44; 4-12)</td>
<td>23.65 (8.24; 13-39)</td>
</tr>
<tr>
<td><strong>The Semantic Priming task</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychopathic group (n = 18)</td>
<td>34.10 (2.46; 30-37)</td>
<td>37.22 (8.01; 23-54)</td>
<td>8.06 (1.48; 6-10)</td>
<td>21.28 (9.09; 9-45)</td>
</tr>
<tr>
<td>Comparison group (n = 18)</td>
<td>9.04 (2.12; 1.5-14)</td>
<td>32.00 (9.16; 21-50)</td>
<td>8.39 (2.20; 5.12)</td>
<td>24.67 (7.88; 14-36)</td>
</tr>
<tr>
<td><strong>The Affective and Semantic Priming Tasks (overall N)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychopathic group (n = 28)</td>
<td>33.87 (2.36; 30-37)</td>
<td>36.07 (9.25; 20-54)</td>
<td>7.96 (1.87; 3-11)</td>
<td>21.39 (8.03; 9-45)</td>
</tr>
<tr>
<td>Comparison group (n = 22)</td>
<td>8.89 (2.10; 1.5-16)</td>
<td>33.61 (9.18; 21-50)</td>
<td>8.26 (2.36; 4-12)</td>
<td>24.52 (8.37; 13-39)</td>
</tr>
</tbody>
</table>

**Table 5.1.** Participant characteristics, S.D., and ranges in brackets ().
5.3.3.2.: The Affective Priming Task

Stimuli were developed and controlled by the software SuperLab Pro and presented on a Mac PowerBook G4. The display was a standard phosphorous display with a graphic resolution of 1024 x 768. Responses were recorded by means of two keys 'C' or 'N' denoting 'positive' or 'negative' (counterbalanced across participants). Stimuli appeared in white against a black background, and were presented in the centre of the screen using the Macintosh system font Times (type size = 36 points).

Stimuli consisted of 6 positive, neutral, and negative word primes (e.g., love, chair, horrid) and 24 positive, and negative target words selected from Toglia and Battig's book on semantic word norms (Toglia and Battig 1978). Positive, neutral, and negative prime and target words were matched on familiarity, relative valence, and length. The task had two phases. The first phase was designed to familiarize the participants with the response keys, and the second phase was the testing phase. In the practice phase, one of two different words, 'filth' or 'money', would appear on the screen following the presentation of a fixation point, and participants were asked to classify the word as positive or negative using one of the two response keys. Both words were presented 80 times, making a total of 160 trials in a pseudo-random sequence. In the testing phrase, each trial began with a fixation point (+) presented for 300 ms in the middle of the screen. When the fixation point extinguished, it was replaced immediately with the prime word stimulus for that trial. After 200 ms, the target word for that trial would appear either above or below the prime word. The two words then remained together on the screen for 100ms, at which point the prime word extinguished. The target word was exposed until a response from the participant was registered, at which point the screen went blank prior to presentation of a new fixation point initiating the next trial. A total of 288 trials were presented to the participants.

5.3.3.3.: Affective Word Rating

The purpose of this component of the study was to access the participant's subjective ratings of the affective words used in the Affective Priming Task (two words 'rape' and 'sex' were excluded from rating as the experimenter was female). The words from the Affective Priming Task were read out aloud and the participants were asked to provide a pleasantness rating for each word according to a 7-point pleasantness Likert scale. The endpoint valences for the scale were counterbalanced across participants so that 1 would mean extremely unpleasant and 7 extremely pleasant for half the participants, and 1 extremely pleasant and 7
extremely unpleasant for the other half of the participants. Participants were instructed that they could use the entire scale 1, 2, 3, 4, 5, 6, and 7 in their word rating.

5.3.3.4.: The Semantic Priming Task

This task was developed to provide a measure of semantic priming using a task similar in demands to the Affective Priming task. Previous studies have reported semantic priming for the categories animals and fruits. Because of a lack of sufficient high familiarity and low length fruit words, vegetables were included in the fruit category to give rise to a fruit/vegetable category. The test stimuli set consisted of 6 animal and 6 fruit/vegetable word primes (e.g., horse, apple) and 24 animal and 24 fruit/vegetable target words. Words were matched on word length. The appearance and trial presentation of the words was identical to the appearance and trial presentation of the words in the Affective Priming Task.

There were slight differences in procedure between the semantic and affective priming tasks. Thus, the Semantic Priming Task involved two rather than one experimental runs. In the first run, participants were asked to think about the question ‘Is this a fruit/vegetable?’ throughout the study and press ‘yes’ or ‘no’ (C or N counterbalanced across participants) accordingly when presented with the target words. In the second run, participants were asked to think about the question ‘Is this an animal?’ throughout the study and press ‘yes’ or ‘no’ accordingly when presented with the target words. A total of 384 trials (192 in each run) were presented to the participants.

5.3.3.5.: Animal Word Rating

This task was developed to provide a measure of scale use on a 7-point Likert scale using a task similar in demands to the affective word rating. The names of 22 animals were read aloud and the participants were asked to provide a size rating for each animal according to a 7-point Likert scale. The endpoint valences for the scale were counterbalanced across participants so that 1 would mean extremely large and 7 extremely small for half the participants, and 1 would mean extremely small and 7 extremely large for the other half of the participants. Participants were instructed that they could use the entire scale 1, 2, 3, 4, 5, 6, and 7 in their word rating.

5.3.4.: Procedure

Each participant was tested individually in a quiet interview room on the wing. Following written consent, each participant was presented with the four tasks as part of a larger
neuropsychological test battery. The duration of the four tasks was approximately 45 minutes for each participant.

5.4.: Results

5.4.1.: The Affective Priming Task

Trials where the RT exceeded 1500 ms or was below 250 ms were excluded from further analysis. RTs were then entered into ANOVAs to examine the effect of group on congruence. RTs were only entered into the analyses if they were for correct responses.

Figure 5.3.: Participant RTs and error bars for the Affective Priming Task for the Psychopathic and Comparison Groups.

First, the effect of group on congruence was examined. A mixed ANOVA with Group (psychopathic, comparison) as between-subjects variable and Prime (positive, neutral, negative) and Target (positive, negative) as within-subjects variables was conducted on the data. The analysis revealed first that there was a significant main effect of Prime ($F(2,80) = 3.53, p < 0.05$); RTs following positive prime words were faster than RTs following neutral or negative prime words ($M_{positive prime words} = 726.46; s.d. = 18.98$, $M_{neutral prime words} = 744.91; s.d. = 20.25$, $M_{negative prime words} = 741.66; s.d. = 21.37$). Second, there was a main effect of Target ($F(1,40) = 5.75, p < 0.05$); RTs to positive target words were faster than RTs to negative target words ($M_{positive target words} = 729.61; s.d. = 20.15$, $M_{negative target words} = 745.76; s.d. = 19.96$). The Prime x Target interaction was significant ($F(2,80)$...
relative to neutral primes, positive and negative primes reduced RTs to positive and negative targets respectively (i.e., congruent conditions) and increased RTs to negative and positive targets (i.e., incongruent conditions). Finally, and crucially, there was a significant Prime x Target x Group interaction \(F(2,80) = 5.02, p < 0.001\); see Figure 5.3. The individuals with psychopathy showed less affective priming than the comparison individuals and this was particularly marked for negative target words. Although the individuals with psychopathy showed generally slower RTs there was no significant group difference \(F(1,40) = 1.56, \text{ns}\).

5.4.2.: The Semantic Priming Task

Trials where the RT exceeded 1500 ms or was below 250 ms were excluded from further analysis. RTs were then entered into ANOVAs to examine the effect of group on congruence. RTs were only entered into the analyses if they were for correct responses.

![Figure 5.4.](image)

Figure 5.4.: Participant RTs and error bars for the Semantic Priming Task for the Psychopathic and Comparison Groups.

First, the effect of group on congruence was examined. A mixed ANOVA with Group (psychopathic, comparison) as between-subjects variable and Prime (animal, fruit/vegetable) and Target (animal, fruit/vegetable) as within-subjects variables was conducted on the data. The analysis revealed that there was a significant main effect of Target \(F(1,34) = 14.85, p < 0.001\); RTs to animal target words were faster than RTs to fruit/vegetable target words \((M_{\text{animal target words}} = 631.90; \text{s.d.} = 16.02, M_{\text{fruit/vegetable target words}} = 653.56; \text{s.d.} = 17.56)\). In addition, there was a significant Prime x Target interaction \(F(1,34) = 13.70, p = \ldots\).
RTs to congruent conditions (animal prime – animal target; fruit/vegetable prime – fruit/vegetable target) were significantly faster than RTs to incongruent conditions (animal prime – fruit/vegetable target; animal prime – fruit/vegetable target). Crucially, although the individuals with psychopathy showed generally slower RTs there was no significant group difference ($F(1,34) = 1.39$, ns). There were also no significant interactions with Group. That is, the psychopathic and the comparison group showed a similar pattern of semantic priming.

5.4.3.: Affective Word Rating Task

In the study, half the participants were asked to rate words according to a scale where 1 meant extremely pleasant and 7 extremely unpleasant. For the purpose of the analysis, the scores from these participants were converted so that they corresponded to the scale used by the other half of the participants where 1 meant extremely unpleasant and 7 extremely pleasant.

In order to test for differences in word ratings, a mixed ANOVA with Group (psychopathic, comparison) as between-subjects variable and Valence (positive, neutral, negative) as within-subjects variable was conducted on the data. The analysis revealed that there was a significant main effect for Valence ($F(2,76) = 326.15, p < 0.001$); across groups, participants rated the positive words as more positive than the neutral words, which in turn were rated more positive than the negative words ($M[positive words] = 5.99; s.d. = 0.12$, $M[neutral words] = 4.05; s.d. = 0.18$, $M[negative words] = 1.61; s.d. = 0.07$). In addition, there was a main effect of Group ($F(1,38) = 5.94, p < 0.05$). On inspection of Table 5.2, it was clear that the main effect of Group was almost entirely contributed by the responses to neutral stimuli which were rated more positively by the psychopathic group ($M[psychopathic group rating for neutral words] = 4.56; s.d. = 0.24$, $M[comparison group rating for neutral words] = 3.54; s.d. = 0.27$). This impression was supported by the significant Group x Valence interaction ($F(1,76) = 4.77, p < 0.05$); see Table 5.2.

5.4.4.: The Animal Rating Task

In the study, half the participants were asked to rate words according to a scale where 1 meant extremely large and 7 extremely small. For the purpose of the analysis, the scores from these participants were converted so that they corresponded to the scale used by the other half of the participants where 1 meant extremely small and 7 extremely large. That is, the data
discussed here correspond to a scale where 1 means extremely small and 7 means extremely large.

In order to test for differences in word ratings, a mixed ANOVA with Group (psychopathic, comparison) as between-subjects variable and Size (small, medium, large) as within-subjects variable was conducted on the data. The analysis revealed that there was a significant main effect for Size ($F(2,68) = 1596.50, p < 0.001$); across groups, participants rated the large animals as larger than the medium sized animals, which in turn were rated larger than the small animals ($M_{[large \ animals]} = 5.51; \ s.d. = 0.08, \ M_{[medium \ animals]} = 3.61; \ s.d. = 0.08, \ M_{[small \ animals]} = 1.82; \ s.d. = 0.07$). There was no significant main effect of Group and there was no significant Group x Size interaction; the psychopathic group and the comparison group demonstrated a similar rating pattern on the Animal Rating Task (see Table 5.2.).

<table>
<thead>
<tr>
<th>Word rating category</th>
<th>Psychopathic group</th>
<th>Comparison group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valence (negative)</td>
<td>1.67 (0.42)</td>
<td>1.55 (0.40)</td>
</tr>
<tr>
<td>Valence (neutral)</td>
<td>4.56 (1.43)</td>
<td>3.51 (0.59)</td>
</tr>
<tr>
<td>Valence (positive)</td>
<td>6.05 (0.79)</td>
<td>5.95 (0.69)</td>
</tr>
<tr>
<td>Size (small)</td>
<td>1.88 (0.42)</td>
<td>1.75 (0.37)</td>
</tr>
<tr>
<td>Size (medium)</td>
<td>3.63 (0.50)</td>
<td>3.60 (0.47)</td>
</tr>
<tr>
<td>Size (large)</td>
<td>5.52 (0.50)</td>
<td>5.50 (0.41)</td>
</tr>
</tbody>
</table>

Table 5.2.: Ratings and S.D. in bracket () for word ratings on the affective and animal rating tasks for the psychopathic and comparison groups.

5.5.: Discussion

This study investigated affective and semantic priming in individuals with psychopathy and comparison individuals. This study revealed that individuals with psychopathy showed reduced affective priming relative to comparison individuals. However, in contrast to the marked reduction in affective priming, individuals with psychopathy showed comparable semantic priming relative to comparison individuals. Finally, individuals with psychopathy rated affective words as significantly more positive than the comparison individual; in
particular, they scored the neutral words as more positive than the comparison individuals. However, there were no group differences for the verbal ratings of animal words.

In this study, individuals with psychopathy showed impaired affective priming. I argued above that affective priming relies on stimulus-reward/stimulus-punishment associations. Activation of a specific valence representation (reward or punishment) by a prime stimulus will decrease reaction time to the target stimulus if the target stimulus activates the same valence representation (because of the existing prior activation) and increase reaction time to the target stimulus if it activates a competing valence representation. In short, affective priming relies on affect-language interactions; the degree of affective priming is related to the degree to which the prime and target words are associated with a given valence. Previous work has indicated that individuals with psychopathy show reduced affect-language interactions; relative to comparison individuals, individuals with psychopathy show reduced facilitation in word recognition by the emotional component of emotional words (Williamson, Harpur et al. 1991; Kiehl, Hare et al. 1999; Lorenz and Newman 2002). The current study thus strengthens the suggestion that there are significant impairments in affect language interactions in individuals with psychopathy.

There have been suggestions that the affect language processing impairments indicated in individuals with psychopathy might reflect a more generalized impairment in linguistic/semantic processing rather than an affect-based impairment (Kiehl, Hare et al. 1999; Lorenz and Newman 2002). However, in this study, we found no group differences in performance on a semantic priming task. That is, both individuals with psychopathy and comparison individuals categorized words more quickly when they were preceded by a semantically related word (e.g., dog-tiger) relative to a semantically unrelated word (e.g., apple-tiger). Previous work investigating semantic processing in individuals with psychopathy has been divided (Brinkley, Schmitt et al. submitted). Brinkley et al. (submitted), using a similar semantic priming task to our own, also found intact semantic priming in individuals with psychopathy. In addition, Brinkley et al. used a modified Stroop paradigm and demonstrated a comparable interference effect for semantically related distractors in both individuals with psychopathy and comparison individuals. Our results are clearly compatible with these two findings, indicating no generalized semantic processing impairment. However, Kiehl et al. (1999) reported that individuals with psychopathy made significantly more errors than comparison individuals in recognizing that abstract words were words on a lexical decision task. In addition, Lorenz and Newman (2002) found that whereas healthy individuals were faster to recognize high, rather than low, frequency words as words, individuals with
psychopathy were not. These two findings, in contrast to our own, might suggest more general differences in the structure of the semantic system in individuals with psychopathy. However, it is worth noting that participant IQ was not recorded in the Kiehl et al. (1999) study. This is important because the individuals with psychopathy only showed difficulties in recognizing that some of the abstract words were words; there were no group differences in reaction time for those abstract words that the individuals with psychopathy did recognize. In other words, the observed group differences in error rate might reflect IQ/schooling difficulties. However, the fact that both groups showed reduced RTs for concrete words suggests similar semantic processing in individuals with psychopathy and comparison individuals. In the Lorenz and Newman (2002) study, the high and low frequency words were made up of both emotional and neutral words. It is unclear whether the individuals with psychopathy received less benefit from a given word’s higher frequency because of an insensitivity to this higher frequency or because, in healthy individuals, the influence of affect and frequency interacts. Thus, healthy individuals may be particularly fast to state that high frequency emotional words are words. Recent data indeed suggests that this is the case (Kosson 2003). In other words, the reduced affect of frequency shown by the individuals with psychopathy may actually reflect reduced affect language interactions.

One of the goals of this study was to investigate whether individuals with psychopathy have a generalized emotion deficit and thus show reduced affective priming for both positive and negative targets or a more specific emotion deficit for aversive emotional stimuli and thus more pronounced difficulty for negative targets (as was indicated in Chapter Four). The current data is, to a certain extent, more indicative of the former suggestion. Individuals with psychopathy showed no affective priming for either positive or negative word targets. As considered previously, there have been suggestions that individuals with psychopathy show a specific emotion deficit for aversive emotional stimuli (Fowles 1988; Levenston, Patrick et al. 2000). Thus, Fowles (1988) argued that individuals with psychopathy show intact reward processing but dysfunctional punishment-based processing. Levenston and colleagues, from work on the startle reflex to positive and negative primes, suggested that ‘psychopathy involves (a) normal or perhaps enhanced appetitive reactivity, and (b), defensive reactivity that is weak but not wholly absent’ (Levenston, Patrick et al.). However, while the current results suggest that the emotion dysfunction in individuals with psychopathy is present for negative stimuli, they also suggest that it is present for positive stimuli. Specifically, individuals with psychopathy showed reduced congruent valence facilitation (of positive relative to neutral primes) for positive targets relative to comparison individuals. If there was normal or enhanced
appetitive reactivity, one might have predicted comparable or even enhanced congruent valence facilitation for positive targets. Thus, the current data indicate that individuals with psychopathy show profound dysfunction in punishment-based processing but also profound difficulties in reward-based processing.

This result, of course, is not entirely consistent with the findings presented in Chapter Four. It also would appear to contrast with the data from the startle reflex literature (where appetitive visual primes suppress the startle response equivalently in individuals with psychopathy and comparison individuals). However, the current data is not alone in suggesting that the processing of reward and punishment information in equally affected in individuals with psychopathy. Thus, individuals with psychopathy show reduced SCRs to positive and negative sounds relative to comparison individuals (Verona, Patrick et al. 2004) and they show comparably reduced interference by positive and negative visual images during simple operant behaviour (Mitchell, Richell et al. under revision). In addition, as mentioned above, studies examining affect-driven facilitation in lexical decision paradigms have reported reduced facilitation for emotional words in individuals with psychopathy –(Williamson, Harpur et al. 1991; Kiehl, Hare et al. 1999; Lorenz and Newman 2002). It is currently unclear what parameters determine the degree to which the processing of positive emotional material is impaired in individuals with psychopathy. One possibility is that we are observing the effects of task sensitivity; tasks such as the current one and the lexical decision task may be more sensitive indices of the impairment in processing positive material in individuals with psychopathy. Of course, such a position currently provides no a priori reason for why this should be the case nor does it explain why the impairment for negative material is revealed so consistently across studies. A second, more interesting possibility, and plausible given the wide range in tasks, is that there are processing reasons for the effects across tasks. At present there is no clear evidence to suggest what these processing reasons might be. However, the continued investigation into the parameters determining the degree to which the processing of positive emotional material is impaired in individuals with psychopathy may prove to be useful in understanding this disorder.

In this study we found that individuals with psychopathy rated affective words as more positive than did the comparison individuals. This was particularly evident for neutral words. Individuals with psychopathy did not give higher ratings of animal size relative to comparison individuals. This indicates that their more positive ratings of affective words cannot be attributed to a lack of understanding of, or different perception of, the 7-point Likert scale used in the study. The Kiehl et al., (1999) study participants were not asked to rate the neutral
words. However, Williamson et al. (1991) and the Lorenz & Newman (2002) studies did get such rating and neither reported group differences in ratings. One possible explanation for this discrepancy may be due to differences in the proportions of positive, neutral, and negative words between our study and those of Williamson et al. (1991) and Lorenz & Newman (2002). In the Williamson et al. (1991) and the Lorenz & Newman (2002) studies, the ratio of positive, negative and neutral words was 1:1:1 (i.e., a 1/3 were positive, a 1/3 neutral, and a 1/3 negative). In contrast, we only included six neutral words (the neutral prime words used in the affective priming task) but 23 positive and 23 negative words. Thus, in the current study, the task would have led to the expectation that any given stimulus is likely to be positive or negative. Therefore, if as suggested, individuals with psychopathy have reduced valence connotations for words and have to sort words according to learnt associations rather than their emotional significance (Williamson, Harpur et al. 1991), the presentation of an unexpected neutral stimuli might be expected to cause difficulty. Certainly, observations made during the testing sessions would appear to support this suggestion. Thus, individuals with psychopathy would often display confusion when presented with one of the six neutral words and then attempt to categorize the word by way of learned association/deduction (e.g., a chair is useful – I'm sitting on one right now and that's better than sitting on the floor - so I guess chair should get a 6'). Because most of our neutral words were useful appliances (e.g., chair, desk, door) such deductions would probably tend to render a positive rather than negative rating, and this then, may be why individuals with psychopathy rated neutral words as more positive than did the comparison individuals. This possible effect of expectancy on neutral word ratings in individuals with psychopathy should be further examined in future affect-language interactions studies.

In conclusion, this study considered whether individuals with psychopathy show specific difficulties in affect language processing or a more general semantic processing deficit and whether, if there are difficulties in affect language processing, these are general for both appetitive and aversive stimuli or more pronounced for aversive stimuli. Our data suggest that individuals with psychopathy do not show general semantic processing difficulties but rather that their impairment is specific for affect-language interactions. In addition, our data suggest that individuals with psychopathy show pronounced difficulties processing aversive stimuli but also pronounced difficulties in processing appetitive stimuli.
Chapter Six

Modulation of Cognition by Emotion and Emotion by Cognition

6.1.: Introduction

In Chapter One, I described how there are at least two types of system that regulate our behavior: one that regulates behavior according to task demands or goals in a relatively affect-neutral way and a second type of system that regulates our behavior according to reinforcement history and allows decision making on the basis of likely rewards and punishments. In Chapter Two and Three I considered this former type of system in healthy individuals and in individuals with psychopathy. In Chapter Four and Five, I considered the latter type of system in healthy individuals and in individuals with psychopathy. In this chapter, I will consider how these two types of system can interact. In particular, I will consider the impact of cognitive load on the processing of emotionality (and the impact of emotion on the cognitive processing), using an amended form of the Number Stroop paradigm introduced in Chapter Two.

Following James (1890), a distinction has often been made between active and passive attention (James 1890). Active attention is typically conceptualized as goal-driven and voluntarily controlled in a top-down manner, whereas passive attention is stimulus-driven, automatic, and governed by bottom-up perceptual processes. In addition, a distinction is typically made between the stimuli driving these two types of attention, where active goal-driven attention is associated with positive or rewarding stimuli (e.g., food, mating partners) and passive, automatic attention is associated with negative or threatening stimuli (e.g., angry faces, snakes).

In support of the suggestion of a passive, automatic, detection of threatening stimuli, healthy individuals have been found to show skin conductance responses (SCR) to masked fear-conditioned faces, even when the faces apparently are not consciously perceived (Globisch, Hamm et al. 1999). In addition, Whalen et al. found increased amygdala activation in response to masked fearful faces (Whalen, Rauch et al. 1998). When threatening stimuli are consciously perceived by participants, they tend to capture attention more readily than neutral stimuli (Pratto and John 1991; Roskos-Ewoldsen and Fazio 1992; Bradley, Mogg et al. 1997; Lane, Chua et al. 1999; Simpson, Ongur et al. 2000; Vuilleumier, Armony et al. 2001). Indeed, threatening or negative stimuli tend to capture attention even when they are irrelevant to the task at hand. Thus, Simpson et al. (2000) found that participants were slower at determining
how many humans, or parts of humans, appeared in negative pictures relative to neutral pictures. This apparent impact of negative task-irrelevant information was evident at the psychophysiological and neural level also. Thus, participants showed increased SCRs as well as increased neural activation of the OFC, ACC, and the amygdala when counting humans/parts of humans on negative relative to neutral pictures (Simpson, Ongur et al. 2000).

Vuilleumier and colleagues similarly found that unattended negative information interfered with a cognitive task (Vuilleumier, Armony et al. 2001). In this task, participants were presented with two houses and two faces and asked to state whether either the two faces or the two houses were identical. Interestingly, Vuilleumier et al. (2001) found that participants were significantly slower in making house matching judgments in the presence of fearful, rather the neutral, irrelevant face distractors. That is fearful faces interfered more with the cognitive task than neutral faces. At the neural level Vuilleumier et al. (2001) reported that although some regions (inferior temporal pole, ACC, and occipital visual cortex) responded more to fearful faces when these were the focus of attention, the response to fearful faces in the amygdala was not significantly modulated by attention. These results were taken as support for the suggestion of a bottom-up, automatic, involuntary, detection of negative or threatening stimuli by the amygdala. In addition, they suggest that this bottom-up attentional demand can interact with, and indeed compromise, top-down goal-driven attentional resources.

Conversely, there is evidence to suggest that top-down goal-driven attention can also interfere with the processing of emotional information. Thus, functional imaging has indicated that the form of the task demands, and thus the form of top-down, goal-driven attention, can significantly influence neural responses to emotional stimuli. That is, across a series of imaging studies, emotional stimuli have typically been found to activate the amygdala, occipital-temporal areas, and frontal/OFC areas (Lang, Bradley et al. 1998; Lane, Chua et al. 1999; Critchley, Daly et al. 2000; Hariri, Bookheimer et al. 2000; Liberzon, Taylor et al. 2000; Northoff, Richter et al. 2000; Simpson, Ongur et al. 2000; Kesler/West, Andersen et al. 2001; Keightley, Winocur et al. 2003; Wrase, Klein et al. 2003). However, activation of these three areas has not been consistent across studies. Recently, research has addressed the reason for this inconsistent pattern of results through the systematic manipulation of task demands. Thus, Hariri et al. asked participants to either match the affect (angry or fearful) of a face to that of a simultaneously presented target face or to label the affect (angry or fearful) of a target face (referred to, by the authors, as the perceptual and intellectual task respectively). They reported that matching angry or frightened expressions was associated with increased amygdala activity (Hariri, Bookheimer et al. 2000). In contrast, labeling was associated with decreased amygdala
activity as well as increased PFC activity. Hariri et al. (2000) concluded that the amygdala is subject to cognitive modulation by the PFC and that this interaction of PFC and amygdala activity may ‘represent the neural basis by which humans can modulate their instinctive emotional processes such as reasoning and labeling’. In support of this suggestion, Liberzon et al. found that whereas rating fearful expressions was associated with increased activation of the amygdala, it was associated with decreased activation of OFC (BA 11) (Liberzon, Taylor et al. 2000). Further evidence in support of a top-down modulation of the amygdala comes from a study by Critchley et al. (2000). In their study, amygdala responses to emotional faces relied on whether the participants’ attention to the emotional component of the stimulus was implicit (i.e., they were performing a gender judgement) or explicit (they were judging the stimulus’ emotional expression) (Critchley, Daly et al. 2000). That is, these results suggest that the type of instruction and thus top-down goal-driven attention is highly instrumental to the extent or way in which emotional stimuli are processed.

Currently then there are two general assumptions in the field. The first is that only negative, and particularly frightening, stimuli are automatically processed and as such necessarily interfere with cognitive processing. Thus, with the notable exceptions of Whalen et al. (1998) and Critchley et al. (2000), positive stimuli have not been included in studies examining attention and emotion. Certainly, no study, to my knowledge, has found that positive stimuli can interfere with cognitive processing. The explanation for this bottom-up bias for negative material is typically provided within an evolutionary framework where the rapid and automatic detection of frightening stimuli is considered crucial for the successful adaptation of the organism (Hariri, Bookheimer et al. 2000; Ohman, Flykt et al. 2001; Vuilleumier, Armony et al. 2001). In addition, the neural substrate facilitating this bottom-up negative bias is typically considered to be the amygdala. Early imaging data did seem to suggest that only negative, and not positive, material could activate the amygdala. However, more recently, there is considerable work showing that positively valenced stimuli can also activate the amygdala (Garavan, Pendergrass et al. 2001; Baxter and Murray 2002). Given this, it becomes plausible to consider that positively valenced stimuli might also be able to activate bottom-up, automatic attention.

The second assumption is that it is the type of task, rather than task load, that crucially determines (the extent and areas of) neural activity associated with emotional processing (Critchley, Daly et al. 2000; Hariri, Bookheimer et al. 2000; Liberzon, Taylor et al. 2000). Only two studies (Lane, Chua et al. 1999; Simpson, Ongur et al. 2000) have employed an emotional cognitive task with differential levels of cognitive load. In the Simpson et al. study,
participants indicated whether there were one or less or two or more bodies/ body parts depicted in negative or neutral pictures. Behavioural results indicated a main effect for both cognitive task load (i.e., number of body parts) and valence (negative or neutral); participants were slower at responding when there were two/ more bodies depicted in the pictures, and they were slower at responding when the pictures were negative. In the Lane et al. (1999) study, there was a main effect of distractor task (i.e., two different difficulty levels of a task involving the matching of keypad responses to auditory tones). However, the presence or absence of emotional material had no impact either on RT or skin conductance. Also, crucially, there was no significant cognitive task load by valence interaction reported for either of these studies. Of course, in the Simpson et al. study this may be due to the minimal cognitive load differences between counting one or more than one. In the Lane et al. (1999) study, it may be considered a bit worrying that they did not obtain any differential skin conductance to emotional and neutral content. In addition, in particular their low distractor task (repeating a fixed motor pattern to the repeated tone sequence low-medium-high -> low-medium-high) represents a very poor choice for cognitive processing. It would therefore be interesting, within a behavioural paradigm involving significant differences in cognitive load to examine the effects of task load on emotional processing as well as the effect of emotional processing on a cognitive task with variable load.

In this study we wanted to investigate the interactions of emotion and cognition within a cognitive task with differential (within-task) cognitive load. For this purpose we adapted a basic non-affective number Stroop task developed by Pansky and Algom. In this number Stroop, and as in the number Stroop used in Chapter Two, the target stimuli consist of numerosities and the distractor stimuli consist of number magnitudes (Pansky and Algom 2002). However, for the current purpose, and in contrast to the number Stroop used in Chapter Two, the Pansky and Algom (2002) paradigm had a crucial advantage; it involved a sequential comparison of numerosities, and thus allowed the opportunity of bracketing the number stimuli with emotional stimuli before, and after, but also crucially in-between the number stimuli presented. Thus, in this study two congruent, or alternatively incongruent, numerical displays bracketed by negative, neutral, or positive pictures selected from the IAPS International Affective Picture System (IAPS) (Lang, Bradley et al. 1995) were presented to the participants (e.g., four 5s -> picture of snake -> five 4s -> picture of snake). This enabled us to look at the impact of emotionality on the neural response to congruent and incongruent number stimuli. We also presented participants with pictures only. This enabled us to compare the neural response to uninterrupted viewing of emotional pictures to the viewing of emotional pictures in
the context of two different levels of a cognitive task. However, first, we investigated the behavioural interactions between emotion and cognitive load in the novel Affective Stroop task.

6.2.: Experiment 7: The behavioural task

The first experiment involved the behavioural implementation of the Affective Number Stroop task. Pansky and Algom (2002) had demonstrated a congruence effect for the sequential Number Stroop paradigm, and I wanted to determine the impact of the bracketing of emotional stimuli on this congruence effect. As discussed in the introduction, it has been demonstrated that irrelevant negative or threatening stimuli can interfere with (non-emotional) cognitive task processing (Simpson, Ongur et al. 2000; Vuilleumier, Armony et al. 2001). However, as also discussed in the introduction, these studies have rarely employed a differential within-task cognitive task load. Indeed, when differential within-task cognitive load has been utilized, no significant emotion by task load interaction was obtained (Simpson, Ongur et al. 2000). In this Experiment 8, I tested whether such effects might be obtained with the novel Affective Number Stroop task.

6.3: Method

6.3.1.: Participants

Twenty participants (8 men and 12 women) were recruited from the National Institutes of Health (NIH) subject pool. Their mean age was 26 years with a range of 18-39 years. The participants were screened for neurological, psychiatric, or medical illness using SCID and a medical examination. All participants gave informed consent and the study was approved by the NIH ethics committee.

6.3.2.: Design

This was a repeated measures design. The independent variable was event type. There were six different event types. These were:

a) Positive Congruent: The two numerical displays were congruent and were bracketed by positive pictures (e.g., 2.2. -> puppy -> 4.4. -> puppy).

f) Neutral Congruent: The two numerical displays were congruent and were bracketed by neutral pictures (e.g., 2.2. -> chair -> 4.4. -> chair).
g) Negative Congruent: The two numerical displays were congruent and were bracketed by negative pictures (e.g., 2.2. -> snake -> 4.4. -> snake).

h) Positive Incongruent: The two numerical displays were incongruent and were bracketed by positive pictures (e.g., 5.4. -> puppy -> 4.5. -> puppy). All of the incongruent numerical displays were reciprocal; i.e., the numerosity of the numbers on one stimulus was the number to be counted on the other.

i) Neutral Incongruent: The two numerical displays were incongruent and were bracketed by neutral pictures (e.g., 5.4. -> chair -> 4.5. -> chair).

j) Negative Incongruent: The two numerical displays were incongruent and were bracketed by negative pictures (e.g., 5.4. -> snake -> 4.5. -> snake).

In addition, because an implementation of this study for fMRI would require the inclusion of trials consisting of fixation points, as well as negative, neutral, and positive pictures, such trials were also included in the behavioural paradigm. Participants made no response to this stimuli set. The dependent variable was mean RT (measured in milliseconds).

6.3.3: Materials

Stimuli were developed and controlled by the software SuperLab Pro and presented on a Mac G3 equipped with an Apple colour monitor. The display was a standard phosphorous display with a graphic resolution of 1024 x 768. Responses were recorded by means of two keys, with key ‘F’ denoting that there were more numbers in the first numerical display, and key ‘J’ denoting that there were more numbers in the second numerical display.

The picture stimuli consisted of 40 positive (e.g., puppy, kissing couple), 40 neutral (e.g., cow, boring landscape), and 40 negative (e.g., snake, sinking ship) pictures selected from the International Affective Picture System (IAPS). The positive and negative pictures were matched for relative valence (F(1, 84) = 2.80; n.s.); i.e., M(neutral images) = 0.29, s.e. = 0.08; M(positive images) = 2.39, s.e. = 0.08; M(negative images) = (-)2.18, s.e. = 0.08. However, it was not possible to match the positive and negative pictures for arousal (F(1, 84) = 35.96; p < 0.001); M(neutral images) = 2.74, s.e. = 0.46; M(positive images) = 4.81, s.e. = 0.61; M(negative images) = 5.91, s.e. = 0.72.

The numerical stimuli were similar to those employed in Experiment 1, and 2 in Chapter Two. However, in the present experiment numerosities one and six were excluded in order to prevent participants from making responses on the basis of one numerical stimulus only. That is, if a numerosity of one had been presented in the first numerical display, the participant would have been able to deduce that the second numerical display involved a greater
numerosity. Thus, the participant would not have needed to inspect the second numerical display in order to make a correct response. In addition, following debriefing after the Number Stroop employed in Chapter Two, it was clear that some participants had purposefully concentrated on the pattern of numbers, rather than the counting of the numbers, in order to make their response. Therefore, and in contrast to the experiments in Chapter Two, in this experiment, numerosities no-longer represented the pattern of a dice (e.g., two = line; three = triangle). Instead, numerosities were randomly presented within a nine-point pattern (see Figure 6.1. for stimuli example). Incongruent stimuli consisted of two numerical displays each representing a within-stimulus symbolic number line distance of 1, as well as a between-stimuli target symbolic number line distance of 1, and a between-stimuli distractor symbolic number line distance of 1 (e.g., 4.5. followed by 5.4.). Congruent stimuli consisted of two congruent numerical stimuli (e.g., 2.2. followed by 4.4.). Target numerosities and digit distractors were matched across the two conditions. In addition, the number of correct responses ‘F’ and ‘J’ were also matched across the two conditions.

**Figure 6.1.:** Sample stimuli for Experiment 1. The top-row represents an example of the event series for the negative incongruent event type and the bottom-row represents an example of the event series for the negative viewing event type.

**6.3.4.: Procedure**

The experiment was conducted in a dimly illuminated room. Participants were seated approximately fifty-five centimeters from the screen and told to rest their left index finger on the key ‘F’ and their right index finger on the key ‘J’. Participants were instructed to count the number of numbers in the first numerical display and compare this number with the number of numbers in the second numerical display. They were instructed that if there more numbers in
the first numerical display they should respond by pressing the key 'F' and if there were more numbers in the second numerical display they should respond by pressing the key 'J'. They were also informed to pay attention to the pictures presented as they might be questioned about them later.

Each trial began with a fixation point (+) presented for 400 ms in the middle of the screen. For the numerical trials, the fixation point was then replaced by the first numerical display presented for 400 ms, followed by the first picture stimuli presented for 400 ms, followed by the second numerical display presented for 400 ms, followed by the second picture display presented for 400 ms, followed by a blank stimulus for 600 (see Figure 6.1 for example stimuli). For the picture trials, the number stimuli were replaced by fixation points (see Figure 6.1 for example stimuli). Participants did not receive feedback on their performance either before or after the experiment. Trials were presented randomly within each run, and each experimental or viewing condition was presented 10 times within each run resulting in 100 (10 x 10) trials. The entire experiment consisted of 4 runs. The numerical stimuli were consistent across runs, however, the picture stimuli was different for each run. The runs were randomized between participants.

6.4.: Results

Mean error rates and RTs were calculated for each trial (see Table 6.1). RTs were only calculated for correct responses and if the RT exceeded 200ms but was less than 1500ms.

6.4.1.: Congruence, Emotion and Error Interference

In order to assess the effect of congruence and emotion on error rates, a 3 (Emotion: negative, neutral, positive) x 2 (Congruence: Incongruent, congruent) repeated measures ANOVA was next applied to the error data. This analysis revealed a significant main effect for Congruence; the error rates to congruent stimuli were smaller than error rates to incongruent stimuli (F(1,19) = 4.43; p < 0.05: M(congruent) = 1.98, s.e. = 0.41; M(incongruent) = 4.50, s.e. = 1.53). There was no main effect of Emotion (F < 1, ns) or significant Congruence by Emotion interaction (F < 1, ns); see Table 6.1. for mean error rates.

6.4.2.: Congruence, Emotion and RT Interference

In order to assess the effect of congruence and emotion on RTs, a 3 (Emotion: negative, neutral, positive) x 2 (Congruence: Incongruent, congruent) repeated measures ANOVA was applied to the RT data. This analysis revealed a significant main effect for Congruence; RTs
to congruent stimuli were significantly faster than RTs to incongruent stimuli ($F(1,19) = 10.03; p < 0.005$: $M_{\text{congruent}} = 755.16, s.e. = 42.97; M_{\text{incongruent}} = 778.90, s.e. = 42.24$). There was no main effect of Emotion ($F < 1, \text{ns}$). However, and crucially, there was a significant Congruence by Emotion interaction ($F(2, 38) = 3.20; p < 0.05, \text{one tailed}$). Planned comparisons demonstrated that both negative and positive emotional content increased RTs, relative to neutral content, for incongruent stimuli ($F(1, 19) = 3.02 \& 3.38$ respectively; $p < 0.05, \text{one tailed}$). However, neither negative nor positive emotional content significantly altered RTs, relative to neutral content, for congruent stimuli ($F(1, 19) = 1.05 \& 1.69$ respectively; n.s.); see Table 6.1. for mean RTs.

<table>
<thead>
<tr>
<th>Emotion</th>
<th>Congruent</th>
<th>Incongruent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RTs</td>
<td>Error rate</td>
</tr>
<tr>
<td>Negative</td>
<td>750.96 (43.21)</td>
<td>2.30 (0.57)</td>
</tr>
<tr>
<td></td>
<td>785.18 (44.67)</td>
<td>4.75 (1.61)</td>
</tr>
<tr>
<td>Neutral</td>
<td>760.78 (42.95)</td>
<td>1.85 (0.45)</td>
</tr>
<tr>
<td></td>
<td>759.76 (42.94)</td>
<td>4.45 (1.50)</td>
</tr>
<tr>
<td>Positive</td>
<td>753.74 (43.51)</td>
<td>1.80 (0.48)</td>
</tr>
<tr>
<td></td>
<td>782.77 (41.02)</td>
<td>4.30 (1.56)</td>
</tr>
</tbody>
</table>

Table 6.1.: Mean RTs and S.D.s in bracket () as a function of emotion and congruence.

In short, the current paradigm demonstrated the expected Stroop effect; participants made more errors on incongruent trials than congruent trials and participants' RTs were longer for incongruent trials than congruent trials (though non-significantly so, with respect to the RT analysis for neutral content trials). In addition, emotional content did significantly interfere with cognitive task processing (at least when indexed by RTs) but only in the higher load condition. It is surprising to note the absence of a Stroop effect when measured by RT for the neutral trials. This could be taken to indicate that neutral content improved performance in the incongruent condition such that the Stroop effect disappeared. However, such a position would appear to have no theoretical basis. Indeed, almost all Stroop paradigms are delivered in a neutral emotional content (see Chapter Two), albeit one with without the presence of neutral
pictures. Moreover, the error data strongly suggested a Stroop effect for the neutral content condition. I thus assume that the absence of an RT Stroop effect in the neutral content condition was a chance result (Type II error).

In Experiment 8, I consider the neural substrates of the behavioral effects obtained in Experiment 7.

6.5.: Experiment 8: Imaging of the Affective Number Stroop

6.6.: Method

6.6.1.: Participants

Twelve new right-handed participants (8 men and 4 women) were recruited from the National Institutes of Health (NIH) subject pool. Their mean age was 29 years with a range of 18-42 years. The participants were screened for neurological, psychiatric, or medical illness using SCID and a medical examination. All participants gave informed consent and the study was approved by the NIH ethics committee.

6.6.2: Design and Materials

The experimental design was identical to the experimental design employed in Experiment 1, Chapter Six with a few exceptions. First, the response type was changed so that now rather than pressing keys 'F' and 'J', participants pressed one of two response buttons held in either hand. Participants pressed with their left hand if there were more numbers in the first numerical display, and with the right hand if there were more numbers in the second numerical display. In addition, in order to allow for T1 equilibration effects, four fixation points were inserted at the beginning of each run, and three fixation points were inserted at the end of each run. This resulted in 4 runs of 107, rather than 100, trials and thus a total of 428 trials overall.

6.6.3.: Apparatus and Scanning Procedure

Whole-brain blood oxygen level dependent (BOLD) fMRI data were acquired using a 1.5 Tesla Siemens MRI scanner. Following sagital localization, functional T2* weighted images were acquired using an echo-planar single-shot gradient echo pulse sequence with a matrix of 64 X 64 mm, repetition time (TR) of 3000 ms, echo time (TE) of 40 ms, field of view (FOC) of 240 mm, and voxels of 3.75 X 3.75 X 4 mm. Images were acquired in 31 contiguous 4 mm axial slices per brain volume. The functional data was acquired over four runs, each lasting 5 minutes 21 seconds.
In the same session, a high-resolution T1-weighed anatomical image was acquired to aid with spatial normalization (three-dimensional Spoiled GRASS; TR = 8.1 milliseconds; TE = 3.2 milliseconds, flip angle = 20°; field of view = 240 mm, 128 axial slices, thickness = 1.0 mm; 256 x 256 acquisition matrix).

6.6.4.: Data Analysis

For each subject, reconstructed fMRI images were examined for excessive motion using the MedX software (Medical Numerics, Sterling, Virginia). No subject scanned moved more than 2 mm in any plane. All subsequent analyses were conducted with SPM software (SPM99b, Wellcome Department of Imaging Neuroscience, London, UK) and other routines written in Matlab 5.3 (Mathworks, Natick, Massachussets). Functional data were corrected for slice timing, motion corrected, coregistered to the anatomical data, spatially normalized to Montreal Neurologic Institute (MNI) space, and smoothed with an isotropic 6-mm full width at half maximum (FWHM) Gaussian kernel. After preprocessing, fMRI images were visually inspected for quality of the normalization procedure.

At the individual subject level, event-related response amplitudes were estimated using the General Linear Model (GLM) for each event type. The waveform used to model each type of event-related response in the GLM was a rectangular pulse (4-second duration) convolved with the hemodynamic response function specified by SPM99b. Contrast images were generated for each subject using pairwise comparisons of the event-related BOLD responses across event types. Each contrast image was divided by the subject-specific voxel time series means, yielding values proportional to percentage fMRI signal change. Each contrast image was then subjected to another level of smoothing with an isotropic Gaussian kernel (FWHM = 11.4) to decrease nonstationarity in spatial autocorrelation structure introduced by the previous step (Friston, Josephs et al. 2000). For the group-level analysis, a random effects model was employed to permit population-level inferences (Holmes and Friston 1998).

6.7.: Results

6.7.1.: Main Effects of Emotion and Task

I first determined which brain regions showed a main effect of the emotional stimuli. This was assessed by comparing the events where participants viewed negative or positive pictures bracketed by fixation points, to the events where participants viewed neutral pictures bracketed by fixation points (see Table 6.2. and Figure 6.2.). Viewing of positive pictures
relative to neutral were associated with activation of temporal/ fusiform and ventromedial/ OFC (BA 10, 47) regions. Negative pictures relative to neutral (Table 6.2.) were similarly associated with activation of temporal/ fusiform and ventromedial/ OFC (BA 11, 47). These are all areas that have been associated with the processing of positive and negative stimuli in previous studies (Lang, Bradley et al. 1998; Lane, Chua et al. 1999; Critchley, Daly et al. 2000; Hariri, Bookheimer et al. 2000; Libzeron, Taylor et al. 2000; Northoff, Richter et al. 2000; Simpson, Ongur et al. 2000; Kesler/West, Andersen et al. 2001; Keightley, Winocur et al. 2003; Wrase, Klein et al. 2003).

Second, I determined which brain regions showed a main effect of the cognitive task load. This was assessed by comparing the events where participants responded to incongruent stimuli to events where participants responded to congruent stimuli (see Table 6.3. and Figure 6.3.). Responding to incongruent stimuli relative to congruent stimuli was associated with activation of parietal/ precuneus (BA 7, BA 40), AC (BA 24, BA 32), medial PFC/ OFC (BA 9, BA 10, BA 11), and premotor regions (BA 2, BA 6). Parietal/ precuneus regions are strongly associated with the processing of numbers, and activation of this area has been found to represent an inverse function of the symbolic number line distance effect (Pinel, Dehaene et al. 2001). AC, medial PFC/ OFC, and premotor areas have all been associated with the inhibition of prepotent responses (Cabeza and Nyberg 2000).

Third, I determined which brain regions showed an effect of the cognitive task load under the neutral content conditions. The purpose of this contrast was to determine whether the neural response to incongruent neutral trials relative to congruent neutral trials was consistent with the empirical literature regarding neural systems involved in the mediation of the Stroop effect (as well as consistent with the main effect of task load described above). This was assessed by comparing the events where participants responded to incongruent stimuli bracketed by neutral stimuli to events where participants responded to congruent stimuli bracketed by neutral stimuli (see Table 6.3.). Responding to incongruent stimuli relative to congruent stimuli was associated with greater activation of parietal/ precuneus (BA 7) and AC (BA 23, BA 24). The increased AC activation in the neutral incongruent relative to the neutral congruent trials is important. First, increased AC activation during the mediation of Stroop performance has been noted in a series of studies (Pardo, Pardo et al. 1990; Bench, Frith et al. 1993; Carter, Mintun et al. 1995; Bush, Whalen et al. 1998; Derbyshire, Vogt et al. 1998; Carter, Macdonald et al. 2000). Secondly, this increased activation was also seen in the main contrast described above.
6.7.2.: Interactions Between Task and Emotion

Next, I investigated the neural correlates of the impact of emotional material on the cognitive task. An initial analysis investigated the participant’s neural response to incongruent stimuli bracketed by neutral, relative to emotional, stimuli. The purpose of this analysis was to determine which regions involved in the resolution of stimulus conflict were affected by the introduction of emotional material. This analysis revealed greater activation of OFC (BA 11), hippocampal, and occipito-temporal areas (BA 18, BA 19, BA 22); see Table 6.4. and Figure 6.4.

Following this, I conducted the inverse of the above analysis to determine which neural regions showed greater activity to incongruent trials bracketed by emotional material as opposed to incongruent trials bracketed by neutral material (see Table 6.5. and Figure 6.4.). This revealed greater activation of bilateral anterior cingulate (BA 32) as well as hippocampus. Interestingly, attending to incongruent stimuli bracketed by positive emotional material relative to incongruent stimuli bracketed by neutral material was also associated with increased activation of the anterior cingulate (BA 32) and hippocampus. These two regions have both consistently been associated with cognitive interference and memory tasks (Cabeza and Nyberg 2000). Attending to incongruent stimuli bracketed by positive emotional material relative to incongruent stimuli bracketed by neutral material did not reveal greater anterior cingulate activity but other medial frontal regions (BA 10) were involved as was the left hippocampus.

Next, I wanted to determine whether there was an impact of processing the cognitive task on the participants’ neural responses to the emotional material. I therefore contrasted the participants’ neural responses when passively viewing the emotional pictures to their responses when viewing the same pictures but whilst these were interspersed with incongruent number stimuli. This contrast revealed increased activation of OFC (BA 10, BA 11/47) and temporal regions (BA 21, BA 22, BA 39); see Table 6.6. and Figure 6.5. As noted above, these regions have been previously associated with emotional processing in a series of studies. These data indicate that the response to emotional material, as indexed by activity in OFC and temporal regions, is reduced when the concurrent cognitive task load is increased. Finally, I examined the participants’ neural response when processing congruent trials bracketed by emotional stimuli relative to incongruent trials bracketed by emotional stimuli (see Table 6.6.). This was of interest because, if performance on the cognitive task could suppress the neural response to emotional material (as was suggested by the previous analysis), then lower “cognitive loads” associated with congruent trials might be associated with greater neural responses associated with the processing of emotional material relative to higher “cognitive loads” of the
incongruent trials. Interestingly, this contrast did indeed reveal greater activity in regions of OFC, at least, (BA 10, BA 11, BA 47) that are associated with emotional processing.

<table>
<thead>
<tr>
<th>Structure</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>Z score</th>
<th>Cluster size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(a) View emotion &gt; view neutral:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>R middle frontal gyrus (BA 47)</td>
<td>48</td>
<td>48</td>
<td>-6</td>
<td>3.32</td>
<td>583***</td>
</tr>
<tr>
<td>L medial frontal gyrus (BA 10/11)</td>
<td>-6</td>
<td>58</td>
<td>-16</td>
<td>2.61</td>
<td>468**</td>
</tr>
<tr>
<td>R middle temporal gyrus (BA 39)</td>
<td>60</td>
<td>-64</td>
<td>10</td>
<td>2.60</td>
<td>633**</td>
</tr>
<tr>
<td>L middle temporal gyrus (BA 39)</td>
<td>-52</td>
<td>-74</td>
<td>28</td>
<td>2.90</td>
<td>171**</td>
</tr>
<tr>
<td>L fusiform gyrus (BA 19)</td>
<td>-42</td>
<td>-66</td>
<td>-22</td>
<td>2.53</td>
<td>110**</td>
</tr>
<tr>
<td>R precuneus (BA 7)</td>
<td>4</td>
<td>-66</td>
<td>32</td>
<td>2.46</td>
<td>826*</td>
</tr>
<tr>
<td>L precuneus (BA 7)</td>
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<td>18</td>
<td>2</td>
<td>2.42</td>
<td>280*</td>
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<tr>
<td><strong>(b) View positive &gt; view neutral:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>R middle frontal gyrus (BA 47)</td>
<td>50</td>
<td>48</td>
<td>-6</td>
<td>2.89</td>
<td>541**</td>
</tr>
<tr>
<td>L superior frontal gyrus (BA 10)</td>
<td>-4</td>
<td>72</td>
<td>4</td>
<td>2.59</td>
<td>616**</td>
</tr>
<tr>
<td>L superior temporal gyrus (BA 22)</td>
<td>-60</td>
<td>-48</td>
<td>16</td>
<td>2.77</td>
<td>330**</td>
</tr>
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<td>R superior temporal gyrus (BA 22)</td>
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Table 6.2.: Regional cerebral blood flow (rCBF) increases during the viewing of (a) emotional (positive and negative) pictures relative to neutral pictures, (b) positive pictures relative to neutral pictures, and (c) negative pictures relative to neutral pictures.  
**Key to table:** *** = < 0.000    ** = < 0.005    * = < 0.01 uncorrected
Figure 6.2.: Comparison of neural response to emotional and neutral pictures. In (a), top of figure, is shown BA 47 (48, 48, -6) significantly activated to the viewing of emotional relative to neutral pictures in the View emotion > view neutral contrast, Table 6.2. (a). In (b), bottom of figure, is shown BA 10/11 (-6, 58, -16) significantly activated to the viewing of emotional relative to neutral pictures in the View emotion > view neutral contrast, Table 6.2. (a).
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Table 6.3.: Regional cerebral blood flow (rCBF) increases during the attending to (a) incongruent number stimuli bracketed by negative, neutral, and positive pictures relative to attending to congruent number stimuli bracketed by negative, neutral, and positive pictures, (b) incongruent number stimuli bracketed by neutral pictures relative to attending to congruent number stimuli bracketed by neutral pictures. 

Key to table: *** = < 0.000    ** = < 0.005    * = < 0.01 uncorrected
Figure 6.3.: Comparison of neural response to incongruent and congruent number stimuli. In (a), top of figure, is shown BA 10 (2, 52, 14) significantly activated to incongruent relative to congruent stimuli in the Incongruent > congruent contrast, Table 6.3. (a). In (b), bottom of figure, is shown BA 32 (10, 20, -12) significantly activated to incongruent relative to congruent stimuli in the Incongruent > congruent contrast, Table 6.3. (a).
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Table 6.4.: Regional cerebral blood flow (rCBF) increases during the (a) attending to incongruent number stimuli bracketed by neutral pictures relative to attending to incongruent number stimuli bracketed by emotional (positive and negative) pictures, and (b) attending to incongruent number stimuli bracketed by neutral pictures relative to attending to incongruent number stimuli bracketed by positive pictures, and (c) attending to incongruent number stimuli bracketed by neutral pictures relative to attending to incongruent number stimuli bracketed by negative pictures.

**Key to table:** *** = < 0.000    ** = < 0.005    * = < 0.01 uncorrected
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Table 6.5.: Regional cerebral blood flow (rCBF) increases during the attending to (a) incongruent number stimuli bracketed by emotional (positive and negative) pictures relative to attending to incongruent number stimuli bracketed by neutral pictures, (b) incongruent number stimuli bracketed by positive pictures relative to attending to incongruent number stimuli bracketed by neutral pictures, and (c) incongruent number stimuli bracketed by negative pictures relative to attending to incongruent number stimuli bracketed by neutral pictures. Key to table: *** = < 0.000  ** = < 0.005  * = < 0.01 uncorrected
Figure 6.4.: Comparison of neural response to incongruent emotional and neutral trials. In (a), top of figure, is shown BA 11 (26, 42, -10) significantly activated to the incongruent neutral, relative to emotional, trials in the Incongruent neutral > incongruent emotion contrast. Table 6.4. (a). In (b), bottom of figure, is shown BA 32 (-28, 10, 30) significantly activated to the incongruent emotional, relative to neutral, trials in the Incongruent emotion > incongruent neutral contrast, Table 6.5. (a).
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Table 6.6.: Regional cerebral blood flow (rCBF) increases during the (a) viewing of emotional pictures relative to attending to incongruent number stimuli bracketed by emotional (positive and negative) pictures, (b) attending to incongruent number stimuli bracketed by emotional (positive and negative) pictures relative to viewing of emotional pictures, and (c) attending to congruent number stimuli bracketed by emotional (positive and negative) pictures relative to attending to incongruent number stimuli bracketed by emotional (positive and negative) stimuli.

Key to table: *** = < 0.000  ** = < 0.005  * = < 0.01 uncorrected
Figure 6.5.: Comparison of neural response to emotional pictures and incongruent emotion trials. In (a), top of figure, is shown BA 47 (-34, 34, -18) significantly activated to emotional pictures relative to incongruent emotional trials in the View emotion > incongruent emotion contrast, Table 6.6. (a). In (b), bottom of figure, is shown BA 10 (0, 58, 2)
significantly activated to emotional pictures relative to incongruent emotional trials in the View emotion > incongruent emotion contrast, Table 6.6. (a).

6.8.: Discussion

In this chapter, behavioural (Experiment 7) and functional MRI (Experiment 8) studies were used to explore the interactions of emotion and cognitive task load using the novel Affective Number Stroop. There were five principle findings: 1) Behaviourally, emotion did modulate the impact of cognitive task load, as indicated by prolonged reaction times to incongruent trials bracketed by emotional, rather than neutral, pictures. 2) The anterior cingulate which has been hypothesized to allocate attentional resources when faced with competing information processing streams, was indeed more active during incongruent trials bracketed by emotional, rather than neutral, pictures. 3) In contrast, the OFC (BA 11) showed decreased activity during this contrast. I believe that this reflects that this area was particularly compromised by the introduction of emotional content. 4) The results also indicated a cognitive modulation of emotional processing with OFC and temporal regions more active during the viewing of emotional pictures bracketed by fixation points, rather than number stimuli. 5) Furthermore, there were indications that this cognitive modulation of emotional processing was dependent on (within-task) cognitive load, with OFC more active during the viewing of emotional pictures bracketed by congruent, rather than incongruent, number stimuli.

6.8.1.: Behavioural Modulation of Cognitive Processing By Emotional Information

When we compared behavioural response to incongruent stimuli bracketed by emotional stimuli to incongruent stimuli bracketed by neutral stimuli, we found a significant increase in response time. In other words, there was an impact of the (task-irrelevant) emotional stimuli on the processing of the cognitive task such that there was a decrement in performance. As discussed in the introduction, irrelevant negative or threatening stimuli have previously been demonstrated to interfere with cognitive task processing (Pratto and John 1991; Roskos-Ewoldsen and Fazio 1992; Bradley, Mogg et al. 1997; Lane, Chua et al. 1999; Simpson, Ongur et al. 2000; Vuilleumier, Armony et al. 2001). Therefore, our finding that negative picture information interfered with cognitive task performance is in line with the previous literature. However, as also discussed in the introduction, irrelevant positive stimuli have not previously been demonstrated to interfere with cognitive task processing in previous work. However, we found that both positive and negative stimuli interfered with cognitive task processing. This result has implications for the theoretical specification of bottom-up
processing. Thus, it is widely assumed that only negative, and in particular frightening, stimuli are automatically processed and as such can interfere with cognitive or top-down processing. The theoretical rationale for this is typically placed within an evolutionary perspective where automatic detection of frightening stimuli is considered crucial for the organism’s survival — e.g., in avoiding a snake in the grass (Hariri, Bookheimer et al. 2000; Ohman, Flykt et al. 2001; Vuilleumier, Armony et al. 2001). Within this view then, positive stimuli can not ‘grab’ bottom-up attention, as the failure to do so does not result in the immediate endangerment of the organism. Indeed, within this view, and in contrast to negative stimuli, positive stimuli employ goal-driven top-down attention. In the words of Ohman: ‘Resources such as food and mating partners were the objects of active foraging, whereas dangers had to be reflexively detected to be adaptively avoided… Thus, in foraging for food, mammals would rely on active goal-driven processes, and in detecting threat, on passive, stimulus-driven attention’ (2001, p.446). But the current behavioural and imaging data demonstrate that bottom-up attention involve both irrelevant negative and positive information. Thus, a successful explanation of bottom-up attention needs to reconsider its adaptive advantage; possibly by considering it to be crucial not just for the organism’s immediate survival (i.e., avoiding the bite of the snake), but also the organism’s slightly longer-term survival (e.g., noticing berries although actively scavenging for food).

When we compared behavioural response to congruent stimuli bracketed by emotional stimuli to congruent stimuli bracketed by neutral stimuli, there was no significant difference in RTs (753 ms versus 761 ms). In other words, there was a task by emotion interaction such that emotional content modulated cognitive task load. As discussed in the introduction, when negative stimuli have been demonstrated to interfere with cognitive task processing, these studies have rarely employed a (within-task) differential load. In addition, when a within-task differential cognitive load has been utilized, no significant emotion by task load interaction was obtained (Lane, Chua et al. 1999; Simpson, Ongur et al. 2000). However, we did obtain a significant emotion by task load interaction. This result again is of interest for the theoretical specification of bottom-up processing. Thus, it is (explicitly or implicitly) assumed that the interfering properties of negative stimuli are independent of current on-line top-down processing. Certainly, it has been found that negative material interferes with a wide range of cognitive processes including body counting (Simpson, Ongur et al. 2000), word detection (Bradley, Mogg et al. 1997), word colour naming (Pratto and John 1991), visual search task (Roskos-Ewoldsen and Fazio 1992), and object matching (Vuilleumier, Armony et al. 2001). The theoretical rationale for this is again typically placed within an evolutionary perspective.
where the bottom-up detection of a negative stimulus requires the organism's immediate (cessation of) current online action. In the words of Hariri: 'Many animals, including humans, exhibit strong instinctive (i.e., fight or flight) responses to fearful stimuli (2000, p. 43). But, the current behavioural data indicate that the interfering property of bottom-up processing is modulated by extent of attentional resource currently allocated to the goal-driven top-down processing (here for congruent relative to incongruent material). From this data then, bottom-up 'fight or flight' becomes 'fight, flight, or follow on' dependent on top-down task load.

6.8.2. Neural Response to Emotional Pictures

In agreement with previous studies, we found significantly greater activation of temporo-occipital and orbitofrontal cortex (BA 10, BA 11, BA 47) regions in response to emotional stimuli relative to neutral stimuli across task conditions (Lang, Bradley et al. 1998; Lane, Chua et al. 1999; Critchley, Daly et al. 2000; Hariri, Bookheimer et al. 2000; Liberzon, Taylor et al. 2000; Northoff, Richter et al. 2000; Simpson, Ongur et al. 2000; Kesler/West, Andersen et al. 2001; Keightley, Winocur et al. 2003; Wrase, Klein et al. 2003). These areas have all been implicated previously in the processing of emotional stimuli though the functions accorded to each differ. Thus, temporal and fusiform cortex are implicated within an emotional associative network while regions of orbital frontal cortex are typically ascribed a more “executive” role, including the reappraising emotional information and the selection between competing emotion stimuli (Lane, Chua et al. 1999; Davidson, Putnam et al. 2000; Hariri, Bookheimer et al. 2000; Ochsner, Bunge et al. 2002; Blair 2003).

In addition to the above regions, the amygdala is often reported to be active during emotional processing (Blair and Curran 1999; Blair, Morris et al. 1999; Lane, Chua et al. 1999; Liberzon, Taylor et al. 2000). However, many studies have failed to find amygdala activation to emotional material (Lang, Bradley et al. 1998; Northoff, Richter et al. 2000; Kesler/West, Andersen et al. 2001; Wrase, Klein et al. 2003). Several authors have considered that the probability of observing amygdala activity to emotional stimuli is dependent on various factors including emotional valence (Lane, Chua et al. 1999), participant gender (Wrase, Klein et al. 2003), and task, with matching faces, explicit processing of pictures, implicit processing of faces, and gender judgment reported to recruit the amygdala, and labelling faces, implicit processing of faces, explicit processing of pictures, and expression judgment reported not to recruit the amygdala (Critchley, Daly et al. 2000; Hariri, Bookheimer et al. 2000; Keightley, Winocur et al. 2003). In addition, methodological variables associated with the scanner sequence appear to influence the probability of detecting an amygdala signal. Thus, the
absence of an amygdala response in the current study does not necessarily indicate that this region did not play a role in the determination of the current results.

6.8.3.: Neural Response to Cognitive Task

When we compared neural responses to incongruent stimuli with those to congruent stimuli we found significantly greater activation of parietal/ precuneus (BA 7, BA 40), AC (BA 24, BA 32), medial PFC/ OFC (BA 9, BA 10, BA 11), and premotor regions (BA 2, BA 6). These findings are again in line with the existing cognitive/ number processing literature. The Dehaene model of the cognitive architecture of number processing (Dehaene and Changeux 1993) was described in detail in Chapter Two, however, for the current purpose it is interesting to note that within this model, and at the anatomical level, Dehaene reserves a unique and specialized role for the intraparietal sulcus (BA 7/40) in numerical processing. In particular, this area is speculated to be uniquely involved in the representation of the symbolic number line with its activation representing an inverse function of the symbolic number line distance. Indeed, Dehaene and colleagues did report this pattern of result in their MRI investigation of the number line distance effect (Pinel, Dehaene et al. 2001). Thus, our finding of increased activation of BA 7 and BA 40 during the presentation of incongruent (symbolic number line distance 1) relative to congruent (symbolic number line distance 0) is very much in line with these results. The AC has also been reported in numerical Stroop-like imaging studies (Pinel, Dehaene et al. 2001), however, as also pointed out by Dehaene it is unlikely that the AC has any specialized function in relation to number processing. Indeed, the AC appears to be much more generally involved in any task that requires the allocation of attentional resources when faced with the two competing processing streams in the incongruent condition.

As discussed in Chapter Two, the Stroop task is considered the archetypal cognitive interference task. In the majority of imaging studies involving this task, the maximal differential activation when incongruent and control conditions were compared, was in the AC (Pardo, Pardo et al. 1990; Bench, Frith et al. 1993; Carter, Mintun et al. 1995; Bush, Whalen et al. 1998; Derbyshire, Vogt et al. 1998; Carter, Macdonald et al. 2000). The increased activation of the AC in response incongruent, relative to congruent, stimuli in the current task then, is likely to reflect the cognitive Stroop-like interference in the current paradigm rather than any number-specific impact. Other studies that have consistently showed differential increases in activation for the incongruent condition in Stroop tasks are medial/ frontal polar cortex areas (Bench, Frith et al. 1993; Carter, Mintun et al. 1995; Bush, Whalen et al. 1998). It has been suggested that the role of the OFC is in the selection of the correct response in
situations of response competition (Kawashima, Satoh et al. 1996; Casey, Trainor et al. 1997). The finding of increased frontal activity in the incongruent, relative to the congruent, trials is therefore also in line with the previous literature. Finally, we observed increased premotor activation in response to the incongruent condition. This pattern is often observed in incongruent conditions. The reason for this is not entirely clear. However, it seems likely considering the extensive reciprocal connections between the AC and premotor areas (Pandya, Van Hoesen et al. 1981; Devinsky, Morrell et al. 1995), that the representation and suppression of multiple motor response options in the incongruent, relative to the congruent, condition would lead to this pattern of result. In support of this suggestion, imaging and electrodemal studies involving the GO/NO-GO tasks have reported activation of the premotor regions in the NO-GO condition in humans and animals (Kalaska and Crammond 1995; Kawashima, Satoh et al. 1996).

6.8.4.: Modulation of Cognitive Processing By Emotional Information

In Experiment 7, I found that task-irrelevant emotional information interfered with the processing of task relevant stimuli but only in higher load, incongruent condition. At the neural level, my results suggested that it is the OFC (in particular, BA 11) that becomes compromised by the emotional stimuli in the incongruent condition. Thus, BA 11 was one of the regions that showed increased activity during incongruent trials relative to congruent trials (see Table 6.3). I suggest that this indicates that it was particularly involved in the selection of a correct response during incongruent trials. Importantly, while other regions such as AC, other regions of medial prefrontal cortex and also BA 10 also increased activity during incongruent trials relative to congruent trials, it was only BA 11 that showed greater activity during incongruent trials when these were bracketed by neutral rather than emotional images (see Table 6.4). That is, this area, recruited particularly during incongruent trials, and which has previously been implicated in stimulus conflict resolution (Cabeza and Nyberg 2000), effectively showed decreased activation during incongruent trials bracketed by emotional rather than neutral images. Interestingly, BA 11 has been implicated in other studies examining the impact of emotional material on task performance (Critchley, Daly et al. 2000; Hariri, Bookheimer et al. 2000; Vuilleumier, Armony et al. 2001; Keightley, Winocur et al. 2003), suggesting a modulatory role of this region in the processing of emotional material. Indeed, Vuilleumier et al. (2001), on finding increased activity in BA 11 when emotional faces were task irrelevant, relative to relevant, concluded that their results ‘support previous suggestions of a role in suppression of prepotent responses to affective stimuli’ (p. 837). Hariri et al. (2000), on finding
an inverse relation between amygdala and OFC (BA 11/47) in their emotional processing tasks, similarly suggested a modulatory role of the OFC, and more specifically they suggested that ‘a subcortical amygdalae-based associative level of emotional processing is subject to cognitive modulation by cortical networks involving the PFC’ and that ‘this functional system may represent the neural basis by which humans can effectively control and modulate their instinctive emotional responses through cognitive processes such as reasoning and labelling’ (p. 47). Thus, if BA 11 is indeed to be considered to have an important modulation of emotional impact, it would explain why in our study, in the incongruent condition, this region would be particularly compromised by emotional stimuli.

At the neural level, our results further suggested that AC compensated, during incongruent trials, for the increased interference from emotional, relative to neutral, stimuli (see Table 6.5.). It is important to note here that all neural responses recorded in these analyses were to correct trials. Thus, given the performance decrement for incongruent trials bracketed by emotional stimuli and the suppression of the appropriate BA 11 response during incongruent trials by emotional stimuli, we might suspect that some regions are compensating for this suppression to allow correct responding. To identify potential regions, we examined the neural response to incongruent trials bracketed by emotional stimuli relative to the neural response to incongruent stimuli bracketed by neutral stimuli. This revealed, in particular, increased activation of the AC. I suggest that this may reflect a compensatory role of this region in this task. As discussed above, previous studies have consistently reported AC activation during incongruent Stroop trials. The suggestion here is that it allocates attentional resources when faced with the two competing processing streams in the incongruent condition (Cabeza and Nyberg 2000; MacLeod and MacDonald 2000). The increased activation of AC during incongruent trials bracketed by emotional stimuli relative to incongruent trials bracketed by neutral stimuli may therefore represent increased allocation of attentional resources to effect a correct response (albeit at a RT cost; Experiment 7).

6.8.5.: Modulation of Emotional Processing By Task

My first goal in this study was to determine was to examine, at the neural level, the impact of emotional stimuli on the frontal, executive systems mediating performance on my Number Stroop paradigm. The result of this goal has been described above. A secondary goal was to consider what impact cognitive functioning, performance on the Number Stroop paradigm, might have on the neural response to emotional stimuli. To investigate this goal, I compared the neural response when viewing emotional stimuli bracketed by fixation points
(i.e., there was no competing ‘cognitive’ task) to the neural response to the same emotional stimuli during incongruent trials. This analysis revealed increased neural responses to the emotional stimuli in the view condition in OFC (BA 10, BA 11/47) and temporal regions (BA 21, BA 22, BA 39). As discussed in Section 6.8.2, these areas are strongly associated with emotional processing, with temporal areas implicated within an emotional associative network while regions of orbital frontal cortex are often ascribed a more “executive” role, including the reappraising of emotional information and the selection between competing emotion stimuli (Lane, Chua et al. 1999; Davidson, Putnam et al. 2000; Hariri, Bookheimer et al. 2000; Ochsner, Bunge et al. 2002; Blair 2003). Therefore, the increased activation of these areas during the view as opposed to incongruent trials, suggests that the “cognitive” task did indeed disrupt the processing of the emotional stimuli.

Although previous studies have demonstrated a modulation of emotional processing by task (Critchley, Daly et al. 2000; Hariri, Bookheimer et al. 2000; Liberzon, Taylor et al. 2000; Keightley, Winocur et al. 2003), to my knowledge, no study has demonstrated a modulation of emotional processing by cognitive task where behavioural results have supported such interaction. Thus, the current results indicate that the executive modulation of emotional processing is rather more intricate than the reduction into a modulatory conscious/unconscious (Critchley, Daly et al. 2000), rating/recognition (Liberzon, Taylor et al. 2000), intellectual/perceptual (Hariri, Bookheimer et al. 2000), or direct/indirect processing, divide (Keightley, Winocur et al. 2003). In this respect it is worthwhile to note that although the context of viewing emotional pictures differed in our task (i.e., the bracketing by numbers in the congruent and incongruent conditions and bracketing by fixation points in the viewing condition), the task instructions regarding the pictures were always the same; participants were asked to attend to all pictures as they might be questioned about them later. In other words, the modulation of emotional processing by cognitive task-load indicated in our study was not an artefact of differential emotional type task.

6.8.6.: Overall Conclusions

In this study, we found modulation of task by positive as well as negative emotional information. This is of interest for theoretical specification of bottom-up processing where it is widely assumed that only negative, and in particular threatening stimuli can ‘grab’ bottom-up attention and interfere with cognitive processing. We also found a modulation of task-load by emotional information. In particular, we found that it was the OFC area BA 11 that was comprised by the impact of emotional information in the incongruent condition. This result
further supports the suggestion of the BA 11 having an important role in the modulation of emotional processing (Hariri, Bookheimer et al. 2000; Vuilleumier, Armony et al. 2001). In contrast, we found that the AC compensated for the impact of emotional stimuli in the incongruent condition. We also found indications of a modulation of emotional processing by cognitive task. Thus, there was increased activation in OFC and temporal areas in response to the viewing of emotional pictures bracketed by fixation, rather than number, stimuli. In addition, there appeared to be a modulation of emotional processing by task load. Thus, there was an increased activation in OFC in response to the viewing of emotional pictures in the congruent, relative to the incongruent, condition. These results indicate that interactions between emotion and cognition are much more extensive and intrinsically more complex than previously assumed.
Chapter Seven

Summary, Conclusions, and Future Directions

7.1: Introduction

There are two aims of this chapter: The first is to review the conclusions that can be drawn from the work presented in this thesis. These conclusions concern the two broad classes of system that regulate our behaviour: i.e., systems which regulate our behaviour according to task demands or goals that are frequently affect-neutral and systems that regulate our behaviour according to reinforcement history and allow decision making on the basis of likely rewards and punishments for particular behavioural choices in particular situations. In addition, the way that these systems interact will be considered. The second aim of this chapter is to detail potential future directions for this research. This comprises further investigation into differential reward/ punishment sensitivity in individuals with psychopathy, investigation into differential reward/ punishment sensitivity in other psychiatric populations, most notably individuals with depression and preliminary investigations into putative neuro-chemical systems that may be involved in the coding of reward/ punishment.

7.2: Summary and Conclusions

This thesis began with a consideration of the two broad classes of system that regulate our behaviour. A number of researchers have proposed models for various forms of both types of system. These were discussed in Chapter One. In addition, the clinical disorder, psychopathy, was considered. Theories of psychopathy were discussed not only as theories in their own right but also in relation to the two broad classes of system that regulate our behaviour. Researchers have considered that individuals with psychopathy might show impairment in both broad classes of system.

In Chapter Two, I described the development of a new paradigm of executive control: The Number Stroop task. The purpose of this development was twofold. First, so that I would have a more sensitive measure of the regulation of behaviour according to affect-neutral task demands in individuals with psychopathy. Secondly, so that I could examine the implications of findings obtained with this measure for theories of the Stroop effect. In particular, the relative speed of processing account (Morton and Chambers 1973; Posner 1978; Schooler, Neumann et al. 1997), the automaticity account (Shiffrin and Schneider 1977; Hasher and
Zacks 1979; MacLeod and Hodder 1998), and the *task context module model* (Cohen, Dunbar et al. 1990; Cohen, Botvinick et al. 2000). I concluded that: First, the Number Stroop did provide a more sensitive, parametric measure of the regulation of behaviour according to affect-neutral task demands that would be useful for work with individuals with psychopathy. Secondly, that the findings from the Number Stroop paradigm, particularly those from Experiment 3, posed difficulties for all current models of the Stroop effect. I attributed these difficulties to a failure of these models to consider in depth the semantic relationship of the targets and distractors in such paradigms. To attempt to account for the data, I developed a preliminary version of an extension of Cohen's (Cohen, Dunbar et al. 1990; Cohen, Botvinick et al. 2000) task context module model where numerical semantic information, as conceptualized by Dehaene (Dehaene, Bossini et al. 1993) and others, influenced the level of interference.

In Chapter Three, the Number Stroop paradigm developed in Chapter Two was applied to individuals with psychopathy in the context of two other measures of executive functioning: the Object Alternation (OA) task, and the Spatial Alternation (SA) tasks. Together these provided a broad assessment of executive functioning in individuals with psychopathy. The Stroop task is most strongly associated with medial frontal regions, while the OA and SA tasks are primarily associated with the OFC and DLFPC, respectively. Moreover, while performance on the Number Stroop task can be considered relatively affect neutral, performance on both the OA and SA task requires the processing of reinforcement contingency. In the OA task, the individual must associate a particular object with reward/punishment and learn the rule concerning the transition of the rewarding/punishment status of that object. In the SA task, the individuals must associate a particular spatial location with reward/punishment and learn the rule concerning the transition of the rewarding/punishment status of that object. Performance on the OA task is known to recruit orbital frontal cortex whilst performance on the SA task is known to recruit dorso-lateral prefrontal cortex. Interestingly, individuals with psychopathy showed no impairment on either the Number Stroop task or the SA task. They did, in contrast, show striking impairment on the OA task. This suggests at least two major conclusions: First, that individuals with psychopathy show impairment on tasks known to recruit OFC. Secondly, and more fundamentally, they suggest that a cognitive level specification of executive functioning/ the functions of the frontal lobes is long past due. The Number Stroop, OA and SA tasks could all be described as "inhibition" tasks. The OA and SA tasks both involve the assignation and re-assignation of contingency information to stimuli. Yet individuals with psychopathy only presented with impairment on one of the three. While an account of the
Stroop effect can be developed from previous positions (see Chapter Two), as yet no formal model has been developed of the OA and SA tasks. All that can be stated is that the systems the assignation and re-assignation of contingency information to objects are separable from those mediating this form of processing with respect to spatial locations.

In Chapter Four, I developed a novel paradigm specifically to investigate the ability of individuals with psychopathy to evaluate objects with respect to reward/ punishment information associated with these objects: the Differential Reward/ Punishment Learning Task. In the task, participants had to choose between different objects that they learnt progressively through the experiment could be associated with greater or lesser degrees of reward or punishment. If, as was suggested in the context of the results from Chapter Three, individuals with psychopathy show particular difficulties for tasks which involve the assignation of contingency information to objects, we might predict that they would show difficulty with this task. Moreover, and importantly, it allowed an evaluation of whether individuals with psychopathy show difficulty when associating both reward and punishment information with objects or only when associating punishment information with objects. The results strongly indicated that individuals with psychopathy do show particular difficulties for tasks which involve the assignation of contingency information to objects. Moreover, while individuals may have difficulty with forming and processing stimulus-reward information as well as stimulus-punishment information, their impairment for stimulus-punishment information is significantly more pronounced. These results have considerable significance for emotion-based theories of psychopathy. They contrast with suggestions that individuals with psychopathy may actually be hypersensitive for reward (Fowles 1988; Levenston, Patrick et al. 1996); the individuals with psychopathy did show impairment forming/ processing stimulus-reward association information. However, they do show that the impairment shown by individuals with psychopathy is more pronounced when forming/ processing stimulus-punishment association information. General emotion learning positions, such as the original amygdala dysfunction position (Blair 2001) have difficulty with such data. These positions would predict comparable impairment in stimulus-reward and stimulus-punishment association/ processing.

In Chapter Five, I examined the ability of individuals with psychopathy to use prior stimulus-reward and stimulus-punishment associations that were not learnt in the experimental context, through the use of a novel paradigm developed from the priming literature. Specifically, the suggestion was that in healthy individuals emotion facilitation occurs if the prime word primes the same valence representation, and in turn output response, as the target word. Thus, if the target word ‘happy’ is preceded by the prime word ‘love’ the ‘positive’
valence representation is already primed by the word ‘love’ and thus the output response is more ready to be activated by the target word ‘happy’. In contrast, if the target word ‘happy’ is preceded by the prime word ‘hate’, the ‘negative’ valence representation will have been primed up by the word ‘hate’. Thus, not only will the ‘positive’ valence representation not have been primed but there will be response competition between the ‘positive’ and ‘negative’ valence representations. By examining the facilitation conditions in particular, it was possible to show, that individuals with psychopathy showed no significant affective priming for either positive or negative word targets. This result, of course, contrasts the result found in Chapter Four. I suggested that this discrepancy could be due to either the effects of task sensitivity or alternatively processing reasons for the effects across tasks.

Finally, in Chapter Six, I examined the interaction of cognitive systems which regulate our behaviour according to task demands or goals that are frequently affect-neutral and systems that regulates our behaviour according to reinforcement history and allows decision making on the basis of likely rewards and punishments for particular behavioural choices in particular situations. I did this through the development of an emotional Number Stroop paradigm. In this paradigm, I manipulated ‘cognitive load’; Number Stroop trials could be either congruent/incongruent or not present (the view condition). In addition, I manipulated the presence/absence of emotional stimuli whilst the participant was performing the Number Stroop paradigm. This paradigm allowed an assessment not only of emotional stimuli on the performance of affect-neutral task processing but also an assessment of affect-neutral processing on the processing of emotional stimuli. In addition, I examined whether the impact of emotional material was equivalent whether this material was positive or negative. Interestingly, I observed modulation of Number Stroop processing by both positive and negative emotional information. This was in contrast to suggestions by other authors that only negative, and in particular threatening stimuli can ‘grab’ bottom-up attention and interfere with cognitive processing. Instead, it is likely that the extent to which emotional stimuli ‘grab’ attention is a product of their strength (i.e., the degree to which they are a CS) rather than their valence. In addition, I observed, that affect-neutral processing did impact on the processing of emotional stimuli (or at least the neural responses to emotional stimuli).

In short, I believe the main conclusions that can be drawn from this thesis are: First, models of performance on Stroop tasks need to take greater account of the semantic features of the target/distractors. Specifically, models of Stroop performance which fail to specify the role to semantic information are likely to be incomplete models of the phenomenon. Secondly, individuals with psychopathy show particular difficulties making/re-evaluating reward/
punishment associations when these are formed with objects but not when they are formed with spatial locations. Moreover, their impairment is far more marked for stimulus-punishment associations than stimulus-reward associations. Thirdly, positive as well as negative emotional material can interfere with affect neutral processing. Fourthly, the degree to which affect-neutral processing commands attentional resources influences the processing of emotional material.

7.3.: Future Directions

My aim is to take the empirical and theoretical work of this thesis forward in three main ways. Each of these three main ways will be discussed in turn.

7.3.1.: Further Specification of the Reward/ Punishment Deficit in Psychopathy

The work reported in Chapters Four and Five demonstrated that individuals with psychopathy showed impaired processing of reward-related but, particularly, punishment-related stimuli. The Differential Reward/ Punishment Learning Task described in Chapter Four indicated that individuals with psychopathy showed impaired formation, and processing, of stimulus-reward but especially stimulus-punishment associations. It is plausible to suggest that this may reflect reduced sensitivity to punishment information in particular in individuals with psychopathy. To test this hypothesis, I have recently developed the Subjective Value Task. This task was developed from the theory of subjective value developed by Tversky and Kahneman (Tversky and Kahneman 1981). Tversky and Kahneman theorized that the subjective perception of values is S-shaped, concave above the (0) reference point (i.e., for reward signals) and convex below it (i.e., for punishment signals); see Figure 7.1. In other words, small differences in low levels of reward are relatively less salient than small differences in low levels of punishment.

In my new Subjective Value Task, each trial involves the participant choosing between one of two objects presented on the computer screen. There are eight different pairs of objects. Four pairs are associated with an overall loss, and four pairs are associated with an overall gain. Over ten trials, the choice of one of the objects will always gain/lose the participant 10 more points than the choice of the other. However, the object pairs differ in the mean that can be won/lost for them. Thus, for object pair One+, consistent choice of stimulus A will average 10-point gains but consistent choice of stimulus B will average 20-point gains. In contrast, for object pair four+, consistent choice of stimulus C will average 120-point gains but consistent choice of stimulus B will average 130-point gains. Reversely, for object pair One-, consistent
choice of A averages 10-points loses and consistent choice of B averages 20-points losses, while for object pair Four-, consistent choice of A averages 120-point losses, and consistent choice of B averages 130-point losses. If my interpretation of the subjective value position is correct, healthy participants should learn to differentiate between token pair One+ faster than token pair Four+, and also between token pair Four- than token One-. Moreover, healthy participants should be faster to differentiate between token pair One- than token pair One+ though there may be less of a difference between token pair Four- and token pair Four+.

Figure 7.1.: The predicted data pattern for healthy individuals as well as one of the predicted data patterns for individuals with psychopathy on the Subjective Value Task.

Preliminary work with healthy individuals is providing some support for these predictions. The predictions for individuals with psychopathy on this task are more complicated. Thus, assuming that they functionally simply operate at a lower level of sensitivity to reward, and even lower level of sensitivity to punishment, they should show the same S-shaped function as healthy individuals, only at a lower level (see Figure 7.1.). However, if they have a differential way of processing reward (and possibly punishment) they might not only take longer to learn the task overall, but also will not show the concave shape. Upcoming studies will test these predictions.
The affective priming data presented in Chapter Five indicated that individuals with psychopathy also operated on the basis of semantic information that was more weakly associated with affective information than comparison individuals. A second way that I would like to investigate this issue is by assessing the degree to which such individuals might show Optimistic Bias. Optimistic Bias (OB) is the tendency to consider oneself invulnerable (or less likely compared to other individuals) to experience negative life events. It is found across cultures and age groups and is believed to exist in about 90% of the general population. OB is typically measured by questionnaires where people are asked to consider what the likelihood is of experiencing a negative life event (e.g., diabetes) compared to other individuals of their age. There are two main accounts of OB. First, that OB is the product of a cognitive defense mechanism to high levels of anxiety (Baker and Chapman 1962). If this position is correct, and given the reduced levels of anxiety in individuals with psychopathy (Patrick 1994; Frick, Lilienfeld et al. 1999; Verona, Patrick et al. 2001) we must predict that individuals with psychopathy will not show OB. Secondly, OB is the product of 'cognitive errors'; an individual's lack of experience with the problem makes it difficult to imagine how it might affect themselves (Weinstein 1980; Weinstein 1982; Weinstein 1987). If OB simply reflects poor risk assessment then individuals with psychopathy may show appropriate levels of OB.

I have developed an assessment of OB based on the work of Weinstein (Weinstein 1980; Weinstein 1982; Weinstein 1987). In this paradigm, participants are presented with a questionnaire consisting of 20 negative life events (e.g., tooth decay, diabetes, becoming a murder victim) and asked to consider their likelihood of experiencing each of these negative life events. In addition, the participants are presented with a questionnaire consisting of 20 positive life events (e.g., winning the lottery). Finally, because OB is considered by some to be the product of a lack of experience with a given event, I have administrated a questionnaire concerning their experience of life events included in the first two questionnaires.

Finally, in Chapter Six, positive and negative picture content was found to interfere with the incongruent condition in a Number Stroop paradigm. The suggestion was made that the emotional material interfered with the numerical processing. This, of course, allows the prediction regarding individuals with psychopathy, that they will show superior performance (i.e., experience no interference and so respond faster), relative to comparison individuals, on these incongruent trials when they are presented together with emotional material.
7.3.2. Examination of Reward/ Punishment Processing in Other Psychiatric Disorders

In Chapter One I described how many other mood and anxiety disorders, in addition to psychopathy, have been linked to reward/ punishment processing abnormalities. Thus, Major Depressive Disorder (MDD) has been linked to a heightened sensitivity to negative information (Murphy, Sahakian et al. 1999), or alternatively attenuated sensitivity to positive information (Henriques, Glowacki et al. 1994). Generalized Anxiety Disorder (GAD) has also been linked to over-sensitivity to threat-related negative stimuli (Kagan and Snidman 1999). In contrast, Mania has been linked to an affective bias to positive stimuli (Murphy, Sahakian et al. 1999). However, although there have been speculations that these populations have such imbalance, relatively little empirical work has been conducted with these populations regarding reward and punishment processing. The tasks developed in this thesis, the Differential Reward/ Punishment Learning Task, the Affective Priming task, and the Affective Stroop task are all currently being applied to children and adults with GAD, adults with PTSD and children with Bipolar Disorder. Recent results with respect to the Affective Stroop paradigm and PTSD suggests increased interference on the incongruent conditions when these are presented together with negative, threat related material but not when presented together with positive material. In other words, as would be expected clinically, individuals with PTSD may indeed show a heightened sensitivity to threat. Other preliminary results with children with Bipolar Disorder and the Differential Reward/ Punishment Learning Task suggest generalized impairment relative to comparison individuals. In short, these children show no specific impairments for reward or punishment related processing but rather a generalized impairment in evaluating objects associated with different levels of reward/ punishment. On the basis of the IES model, described in Chapter One, I have suggested that this is most likely to be due to dysfunction in the hypothesized medial orbital frontal cortical units allowing response selection.

I myself will be applying these tasks to patients with Major Depressive Disorder (MDD), which is probably the most exciting population for investigation as they might present the inverse of psychopaths. Thus, MDD has been linked to both a heightened sensitivity to negative information (Murphy, Sahakian et al. 1999) as well as attenuated sensitivity to positive information (Henriques, Glowacki et al. 1994). The predictions of both these positions with respect to the tasks described in this thesis (as well as those briefly outlined above) are clear. For example, if patients with MDD have a heightened sensitivity to negative information they should show superior performance for discriminating objects associated with different levels of punishment on the Differential Reward/ Punishment Learning Task as well as superior facilitation by negative, relative to neutral, primes for negative targets in the Affective Priming
If patients with MDD have a attenuated sensitivity to positive information, their performance should be impaired on tasks involving the discrimination of objects associated with different levels of reward. In addition, they should show reduced facilitation by positive primes, relative to neutral primes, for negative targets in the affective priming task.

7.3.3.: Specification of the Neuro-Chemical Basis of Reward/ Punishment Processing

On the basis of the work presented in this thesis, I would argue that positions suggesting global dysfunction in specific neural systems in individuals with psychopathy need to be reconsidered. Positions suggesting amygdala dysfunction (Patrick 1994; Blair, Morris et al. 1999; Blair 2001), orbital frontal cortex dysfunction (Damasio 1994; LaPierre, Braun et al. 1995) or even anterior cingulate dysfunction (Kiehl, Smith et al. 2001) all face the difficulty that these systems process both reward and punishment related information. None of them provide a convincing explanation for why the impairment seen in individuals with psychopathy should be more marked for the processing of stimuli associated with punishment rather than stimuli associated with reward. I have argued that the data I have collected in this thesis suggests that a neuro-chemical account of psychopathy may be more appropriate. This is not to deny that individuals with psychopathy suffer from amygdala dysfunction. It is however to suggest that this position must be constrained; i.e., individuals with psychopathy may have particular problems with those functions of the amygdala that require neurotransmitter X.

If the above argument is correct it suggests that it would be useful to determine which neurotransmitters may be involved in the mediation of the paradigms developed in the current thesis. In particular, it would be useful to know which neurotransmitter systems, when modulated, give rise to effects that are more pronounced for the processing of punishment-related material.

Recent data by Rogers et al. suggests that the non-specific beta-adrenoceptor blocker, propranolol, attenuated discrimination between the magnitude of possible losses in situations where the probability of winning was relatively low and the probability of suffering losses was relatively high (Rogers, Lancaster et al. submitted). That is, their data suggested that noradrenaline (NA) is involved in mediating the impact of aversive cues in human choice (Rogers, Lancaster et al. submitted). One exciting possibility is therefore that NA function is compromised in individuals with psychopathy, leading to impaired processing of aversive cues. Further support for this suggestion comes from studies linking NA abnormalities to antisocial behaviour/ Conduct Disorder (Rogeness, Cepeda et al. 1990; Rogeness, Javors et al. 1990; Raine 1993). In this regard it is interesting to note that NA function appears to be increased in
a range of anxiety disorders (Charney, Heninger et al. 1984); i.e., in populations that are hypothesized to show a very different pattern of result to that of individuals with psychopathy on reward/punishment processing paradigms. Studies have shown that the α-2A adrenoceptor, which functions primarily as an autoreceptor, is abundant in the amygdala and orbitofrontal cortex (MacDonald and Scheinin 1995). In rodents, dense labelling of α-1A and 1B adrenoceptor mRNA in nuclei of the amygdala and throughout the cerebral cortex has also been demonstrated (Pieribone, Nicholas et al. 1994). There is evidence that this is the case in humans also (Zilles, Qu et al. 1993; Ferry, Roozendaal et al. 1999).

A further future direction for my work therefore is to explore the impact of manipulations of NA functioning on performance of the tasks presented in this thesis.

7.4.: Summary

This thesis started off considering Garry who plunged to his death demonstrating the strength of the windows on the 24th floor of his building. I suggested that most people are not nominated for Darwin awards, as they have two types of systems to regulate and help guide their behaviour: One system which regulates behaviour according to task demands or goals, and a second system which regulates behaviour according to reinforcement history. Now, these two systems can be difficult to disentangle. Executive function (EF) and emotion interact in guiding our behaviour. Thus, Garry probably carried out his actions not due to a faulty EF or stimulus-reinforcement mechanism, but due to the (faulty) overriding of a sense of danger in lieu of wanting to impress the visiting law students. The difficulty of teasing apart these two systems is reflected in the fact that just about all major disorders have been proposed to be the consequence of EF or alternatively a punishment insensitivity – or both. The first challenge then of affective neuroscience is to tease out the constituent parts of these two systems. In this thesis I have developed a series of new measures for the indexing of these two systems, and applied them to a disorder which has been associated with a dichotomous EF or fear/punishment problem.

The second challenge of affective neuroscience is to understand the modulatory effects of emotion on EF. This second challenge is of less importance in psychopathy where there is a hypo-active amygdala or emotional input, but it is of immense importance in relation to disorders such as MDD and Posttraumatic Stress Disorder where the strong suggestion is that there is a hyper-active amygdala or emotional input (Drevets 2001; Blair and Charney 2003). In this thesis I have developed an instrument that will allow for an increased understanding of the emotional effects of emotion on EF. It may be too late for Garry, but others can be helped.
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