Li, Su, Bowman, Howard and Barnard, Philip (2006) *Emotional Modulation of Temporal Attention, An Approach based upon Distributed Control and Formal Methods.* Technical report. UKC

Emotional Modulation of Temporal Attention, an Approach based upon Distributed Control and Concurrency Theory

Li Su and Howard Bowman, Centre for Cognitive Neuroscience and Cognitive
Systems Computing Laboratory, University of Kent

Philip Barnard, MRC Cognition and Brain Sciences Unit, Cambridge

1 Introduction

Numerous studies have confirmed both the goals of the current task and emotion, such as personal salience, can affect the allocation of attention (Shapiro et al., 1997). Moreover, the interaction between cognition and emotion has been the focus of experimental investigation from various perspectives. For example, an ERP study performed by (Flaisch et al., 2007) and a psychophysiological experiment performed by (Phelps et al., 2006) both confirm that emotion affects not only the processing of the current stimulus, but also the following stimuli. In this respect, Barnard et al (2005) have presented a literature review on the (somewhat “mixed”) results of attentional capture by emotional salience. They argue that examining the time course of emotional capture of attention is important to understand the effect of emotion and its interaction with other goal directed cognitive processing. Moreover, they also point out that the state of anxiety has a dramatic influence on the attentional deployment to threat related stimuli (Barnard et al., 2005). Such an influence of anxiety is also observed by others (e.g. Bishop et al., 2004; Koster et al., 2006). Based on this idea, we argue that detailed theories or computational models, which address the information processing in emotion, are critical to understand these mixed experimental findings and complex clinical observations. This is because the timing of each processing stage is made explicit in such models.

A recent empirical study (Barnard et al., 2005) suggests that threat related material may attract attention at different points in time compared to non-threat related stimuli, and the time course is modulated by both state anxiety and semantic similarity (between key-distractors and targets). In particular, they have discovered that emotional processing may shift the blink curve laterally in the AB experiment. In addition, other researchers have also observed similar effects of anxiety on the time course of attentional redirection. For example, (Georgiou et al., 2005; Fox et al., 2001; Yiend and Mathews, 2001) have reported that anxiety has the effect of a delayed disengagement of visual attention away from threatening stimuli. Bishop et al (2004) have shown an interaction between anxiety state and attentional focus on threatening stimuli. Moreover, (Leyman et al., 2006) has reported that patients with major depressive disorders show stronger attention to angry faces when compared to controls.

Our modelling is focused on reproducing the timing effect reflected in lateral shifts of the blink curve due to changes in semantic similarity and state anxiety in the presence of threat-related material. In this report, we show how to extend the previously published model (Su et al. 2007), which models the effect of semantic modulation in Barnard’s key-distractor AB task (Barnard et al., 2004), to reproduce the emotional modulation reported by (Barnard et al., 2005). In the previous model, the main factor was the semantic salience of key-distractors, which changes the depth of the blink. However, in this model, we also need to consider emotion related factors, e.g. state anxiety. Moreover, body-state may also contribute to producing such an effect. So, the model is extended with the body-state subsystem (Barnard, 1985).

The report is organized as follows. We will firstly propose the basic principles underlying the model: processing of multiple streams and serial allocation of attention and two-staged processing of semantic meaning. Then, we will explain how threat is modelled. We also highlight three cognitive biases in anxiety: hyperactive Implic-body loop, slow disengagement from threat, and selective processing in anxiety. Before we show the simulation results, we will also discuss how salience could modulate the speed of salience assignment. Finally, we show two experiments. The first one stresses how emotion competes with the main cognitive task when both task relevant and task irrelevant emotional representations occur at the same time. The second one demonstrates how such competition becomes complicated when multiple streams compete in real-time.

2 Basic Principles of the Model

2.1 Multiple Processing Streams

In our previous model (Su et al., 2007), a pipeline structure was implemented using delay-lines, and was used to model sequential tasks, such as RSVP tasks. This model extends such a simple pipeline structure with additional components and feedback loops. As shown in Figure 1, the additional body-state subsystem encodes features from internal bodily receptors, such as cutaneous pressure, temperature, olfaction, muscle tension, pain, positions of parts of the body, tastes and smells (Barnard, 1985). SOM and VISC connect to the output of Implic. They are somatic and visceral response effectors respectively, which may change the body-state (Barnard, 1985). Another difference between this model and our previous model is that Prop does not only output to Sink, but also sends feedback to Implic. As a result, it can be seen that this model contains two loops, as shown in Figure 1:

- The *Implic-body loop* starts from Implic, runs through SOM and VISC, then the body-state subsystem, and returns to Implic. Signals in this loop could be initiated by emotion-related inputs from source to Implic. The product of this loop is called bodily feedback.
- The *Implic-prop loop* passes from Implic to Prop, and returns to Implic. The product of this loop is called internal thought feedback. We will explain both loops shortly.

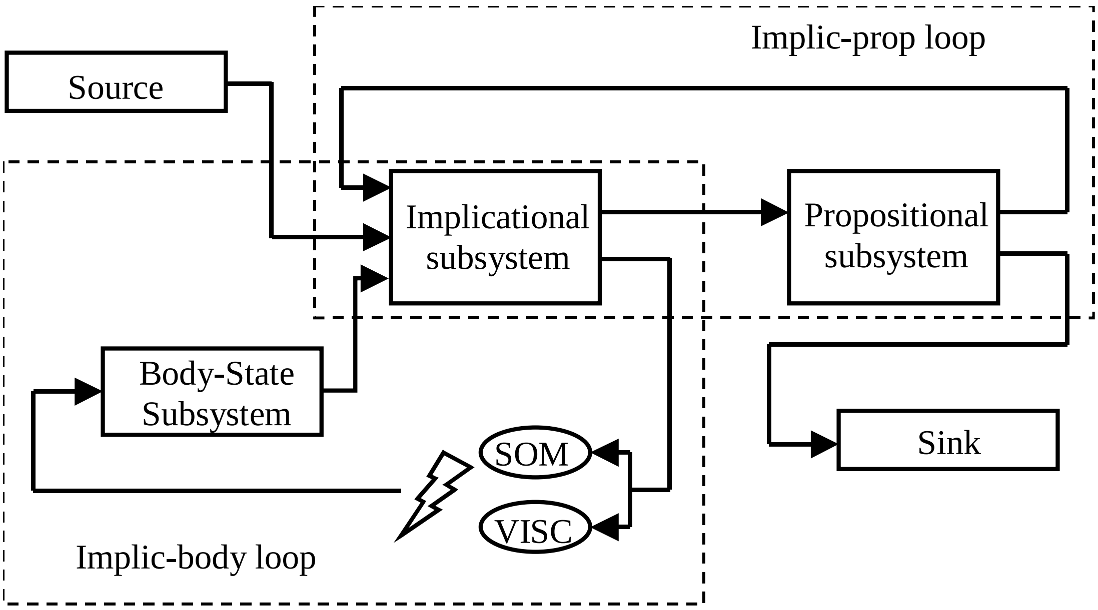

Figure 1 Model of ICS central engine with body-state subsystem.

Similar to (Le Doux, 1996), Implic-body and Implic-prop loops in our model also work at different speeds. Our model is abstract in nature, so it cannot be directly mapped to Le Doux's dual route. However, the Implic-prop loop is similar to Le Doux's "high road" that receives emotional signals from the sensory thalamus, passes it to sensory cortex, and then sends it to the amygdala. We assume that the Implic-prop loop is slow because it is evolutionarily more recent and requires high-level cognitive processing. More importantly, it has limited capacity because both Implic and Prop require the buffer to access semantic meaning, i.e. only one subsystem can access meaning at the same time. To some extent, the Implic-prop loop may also be characterised as a controlled process (Hasher and Zacks, 1979; Shiffrin and Schneider, 1977). The Implic-body loop is similar to Le Doux's "low road" that transmits emotional signals directly from the sensory thalamus to the amygdala, which is believed by Le Doux to be the centre of emotional processing (Le Doux, 1996). We assume that the Implic-body loop is fast because it is evolutionarily (relatively) ancient, and mainly requires low-level processing. In particular, the capacity of this process is not limited, in the sense that the body-state subsystem does not require the buffer to monitor the changes in the body. So, such processes may be characterised as automatic (Hasher and Zacks, 1979; Shiffrin and Schneider, 1977). We argued that propositional processing is relatively slow, since it needs to extract "definitive" referential meaning. This is reflected by the fact that the processing speed in Prop is slower on average and has more variance, thus it may potentially have long processing delays.

Note, our model does not make explicit assumptions on how subsystems are mapped to brain areas. So, it should not be regarded as an implementation of Le Doux's (1996) theory. In fact, subsystems in our model can only be related to such a neural network (Le Doux, 1996) in explaining the specific experimental findings discussed in this report. Another issue regarding Le Doux's theory of emotional networks in the brain is that most evidence is derived from animal studies. Hence, whether or not such a theory is generalisable to humans is an open question.

2.2 Serial Allocation of Attention

The mechanism for attentional engagement in this model is similar to the model described in the previous model (Su et al., 2007). That is, it is only when attention is engaged at a subsystem that it can assess the salience of items passing through it. In the current model, there could be multiple input streams in a subsystem, for example Implic has three inputs: from the visual system, from the body-state subsystem and from Prop. We assume that it is only when attention is engaged at a particular stream of input within a subsystem that the information in that stream can be assessed for salience. Furthermore, we assume that attention can only be engaged at one subsystem and only at one stream of input at a time. Consequently, the system cannot access the salience of a stream while it is accessing the salience of another at the same time. We can see that these constraints are generalised from the previous model, and they will play an important role in generating blinks in this model. As in the previous model, when attention is engaged at a subsystem or a stream, we say that it is buffered (Barnard, 1999). Although items pass concurrently, i.e. all items throughout the system are moved on one place on each time step, the buffer mechanism ensures that central attentional resources are allocated serially. This is because salience assignment can only be performed if the appropriate stream of input within a subsystem is buffered, and only one stream can be buffered at a time.

2.3 Two-stages

A number of theoretical explanations and indeed computational models of the AB have been proposed; see (Bowman and Wyble, 2007) for a review. Like (Chun and Potter, 1995), we have argued elsewhere for a two-stage model (Barnard et al., 2004;

Barnard and Bowman, 2004), but this time recast to focus exclusively on semantic analysis and executive processing. In particular, (Barnard and Bowman, 2004) modelled the key-distractor blink task using a two-stage model. In the context of modelling distributed control, we implemented the two-stage model as a dialogue between two levels of meaning. In the first stage, a generic level of semantic representation is monitored and initially used to determine if an incoming item is salient in the context of the specified task. If it is found to be so, then, in the second stage, the specific referential meaning of the word is subjected to detailed semantic scrutiny. In this stage a word's meaning is actively evaluated in relation to the required referential properties of the target category. If this reveals a match, then the target is encoded for later report. The first of these stages is somewhat akin to first taking a "*glance*" at generic meaning, with the second akin to taking a closer "*look*" at the relationship between the meaning of the incoming item and the target category. These two stages are implemented in two distinct semantic subsystems proposed within a multi-level model for cognition and emotion: the *implicational subsystem* or Implic (which supports the first stage) and the *propositional subsystem* or Prop (which supports the second) (Barnard, 1999), as shown in Figure 1. Note, these two subsystems are components in the central engine of the ICS model (Barnard, 1999).

These two subsystems process qualitatively distinct types of meaning. One, implicational meaning, is holistic, abstract and schematic, and is where affect is represented and experienced (Barnard, 1999). The other is classically "rational", being based upon propositional representation and captures referentially specific semantic properties and relationships. The exchanges between two levels of meaning reflect distributed executive functions rather than central executive control/homunculus. In the context of the task being considered here, these subsystems can be distinguished as follows:

- *Implicational Subsystem*. This performs the broad "categorical" analysis of items, which might be related to Chun and Potter's first stage of processing, by detecting the presence of targets according to their broad categorical features. In the context of this report, we will call the representations built at this subsystem implicational and we will talk in terms of implicationally salient items, i.e. those that "pass the implicational subsystem test". The implicational subsystem implements the idea introduced earlier of a "glance".

- *Propositional Subsystem*. This builds upon the implicational representation generated from the glance in order to construct a full (propositional) identification of the item under consideration, which is sufficient to test whether the meaning of the incoming item meets the task specification and should therefore be reported. We will describe items that "pass the propositional test" as propositionally salient. That is, this more detailed level of semantics is required to test the specific referential meaning of an incoming item against the specification of the target category.

There is significant evidence that a good deal of human semantic processing relies upon propositionally impoverished representations. It is this evidence that gives the clearest justification for the existence of a distinct implicational level of meaning. In particular, semantic errors make clear that sometimes we only have (referentially non-specific) semantic *gist* information available to us, e.g. false memories (Roediger and McDermott, 1995) and the Noah illusion (Erickson and Mattson, 1981). With respect to the latter, when comprehending sentences, participants often miss a semantic inconsistency if it does not dramatically conflict with the gist of the sentence, e.g., in a Noah specific sentence, such as "How many animals of each kind did Moses take on the Ark?" most people respond "two" even though they know, when pressed, that it was Noah, not Moses, who took the animals on the Ark. Substitution of Moses for Noah often fails to be noticed, while substitution with Nixon, or even Adam, is noticed. This is presumably because both Moses and Noah fit the generic (implicational) schema "aged male biblical figure", but Nixon and Adam do not.

In addition, Gaillard et al (2006) recently reported that in a subliminal priming study, semantic gist information was available even when participants failed to correctly name masked emotional words. Specifically, in error, words semantically related to target words were often reported (e.g. target "war", response "danger"; target "bomb", response "death"). This suggests the availability of implicational meaning and the absence of veridical propositional meaning. In addition, deep dyslexia (Coltheart et al, 1987), in which sufferers generate incorrect referents (e.g. reading "lion" as "tiger"), can be regarded as a marker of broadly intact extraction of implicational meaning and significantly impaired attribution of precise propositional meaning.

As outlined earlier, the implicational and propositional subsystems perform their corresponding salience assessments as items pass through them in the pipeline. We will talk in terms of the overall delay-line and subsystem delay-lines. The former of which describes the complete end-to-end pipeline, from the visual to the response subsystems, while the latter is used to describe the portion of the overall pipeline passing through a component subsystem, e.g. the propositional delay-line.

3 Modelling Threat

3.1 Levels of Threat-related Markers

In ICS, Implic is the centre for emotional processing (Barnard, 1999), so it is the key to modelling emotional influences of attention. As previously explained, Implic may have three sources of threat-related markers (corresponding to the three input arrows to Implic in Figure 1), and they can be classified into two levels.

1. The first one is external stimuli, e.g. the threat-related information passed from the visual system (Source) to Implic. We argue that such stimuli contain first order threat-related markers because they are directly extracted from sensory inputs. In general, animals have the ability to extract first order threatening information from the environment, and it has been argued that such ability is hard-wired through evolution. Such information acts as cues of potential danger, so it is important for almost all animals, including humans to survive in a changeable environment. Hence, threatening information needs to be rapidly extracted directly from sensory inputs. However, first order threat-related markers are abstract and holistic compared to the second order markers that are generated from Prop. Taking Le Doux’s famous example, a rope that has the shape of a snake may be interpreted by Implic as a potential threat. However, typically it would not be interpreted by Prop as a potential threat.

   As the first order threat related markers could act as cues of potential danger, animals need to respond to these cues and prepare themselves to handle the potential danger. Whatever they choose, e.g. to escape or defend, it requires some sort of bodily change, as arise from a set of signals sent to the body via SOM and/or VISC. The results of these signals may be fear responses, such as increase in the heart rate, blood pressure and muscle tension or freezing behaviour, so the animal is ready to run or attack when the danger actually arrives. There is evidence that suggests threatening information could be extracted as early as Implic, consequently causing bodily responses. For example, Ohman et al (1994) have shown that, compared to normals, phobics have larger skin conductance responses to masked fear related pictures, such as snakes, even when they were unaware of their presentation.

2. In addition, the body-state subsystem is continuously monitoring changes within the body. Once it has detected changes, it signals these changes to Implic; such a signal has similarities to what is called a somatic marker (Bechara and Damasio, 2004). Body-state feedback via the Implic-body loop may also server as a source of threat. We assume that the strength of signals in this loop increases with both the level of threat and state anxiety. The body-state feedbacks are also first order threat related markers because they are extracted from (bodily) sensory inputs.
3. Prop extracts meaning from the outputs of Implic. Threat-related components can also be interpreted further at propositional level. Then, threat related markers might be fedback to Implic to enhance the interpretation of implicational meaning. This mechanism sets up a context for comprehension of meaning. (Similar mechanisms may also play an important role in normal reading, where the meaning is continuously extracted and refined via this Implic-prop loop (Teasdale and Barnard, 1993). In normal reading though the stimuli arrive at a much slower rate than in RSVP, making it much easier for the context to help the reader to understand the subsequent text.) The propositional feedback is called a second order threat related marker.

Thus, Implic encodes an abstract schematic representation for affect using all three sources, i.e. threat may emerge from first order sensory inputs, body-state changes and second order internal thoughts.

The distinction between first and second order threat related markers could be compared with Bechara and Damasio's (2004) notion of primary and secondary inducers. "Primary inducers are innate or learned stimuli, which exist in the environment or are learnt from experience. Secondary inducers, on the other hand, are generated by the recall of memories or thoughts about the primary inducers." They further argued that the primary inducers could be triggered by activation of the amygdala, but the ventromedial prefrontal cortex is necessary for generating the secondary inducers. Although Bechara and Damasio have different definitions from us (in particular, we do not make detailed assumptions about which brain areas are responsible for generating these markers), it can be seen that both definitions distinguish two levels of threat markers by the degree of processing. In their definition, the ventromedial prefrontal cortex is necessary for generating the secondary inducers. In our definition, Prop is necessary for producing second order threat-related markers, although it does not necessarily suggest that Prop can be mapped to ventromedial prefrontal cortex and Implic can be mapped to the amygdala.

3.2 Measurement of Threat-related Information

As in our previous model (Su et al., 2007), semantic similarity is measured using Latent Semantic Analysis (LSA) (Landauer and Dumais, 1997) in the current model. Moreover, we use LSA to measure threat-relatedness, because such an approach was also used in Barnard's emotional AB experiments (Barnard et al, 2005). That is, a word is seen as high threat if its distance to a set of generic threatening words in LSA space is less than a predefined threshold. Otherwise, it is seen as low threat.

4 Cognitive Bias in Anxiety

4.1 Hyperactive Implic-body Loop

In our model, we assume that only high state anxious individuals produce significant body-state feedbacks that can interfere with attentional focus when they encounter highly threatening stimuli. Thus, anxiety could be modelled as a hyperactive Implic-body loop. That is, we assume that only in the case of highly anxious individuals, the first order emotional markers from the visual system generate an increased activation at the Implic-body loop. However, such stimuli are not sufficient to trigger activation in the Implic-body loop in the case of low anxious individuals. Moreover, it is only when the stimuli are attended (i.e. being propositionally processed in our model) that the second order markers could be generated by Prop, and then both high and low anxious individuals may have increased activation in the Implic-prop loop. Such assumptions are supported by neurophysiological findings (fMRI, Bishop et al., 2004), which has shown that anxiety may interact with attention to threat related stimuli. In their experiment, both high and low anxious people showed increased amygdala activation for fearful faces vs. neutral faces when the faces were attended. However, only high anxious people showed increased amygdala activation for fearful faces vs. neutral faces when the faces were unattended.

4.2 Slow Disengament from Threat

In our previous model (Su et al., 2007), the delay of buffer movement does not change systematically according to the salience level of items. (Although the buffer movement delay in our previous model may vary, its distribution remains the same for all different key-distractor and target combinations.) This is because there was no significant difference in the time course of the blink curves, and indeed, only blink depth was modulated. However, it is necessary to consider the effects of anxiety on the delay of buffer movement in this model, since the main effect of emotion and anxiety state is on the time course of the blink curves.

A large number of studies have reported that anxious individuals may fail to or delay disengaging from threat-related material. For example, anxious people take longer to disengage their attention from threat-related facial expressions (Fox et al, 2001; Georgiou et al, 2005) or pictures (Yiend and Mathews, 2001) compared to neutral or happy stimuli. However, low anxious people showed no such effect. Thus, for anxious individuals, we assume that the buffer, as a moving focus of attention, is slower at disengaging away from a subsystem if that subsystem is processing threat words. This is achieved by shifting the mean delay of buffer movement. We assume that it takes 1.3 times longer for high anxious people than low anxious people to switch the buffer in both directions.

4.3 Selective Processing in Anxiety

How we prioritise our attention to difference stimuli lies at the heart of any model of attention and emotion. In the context of this report, it is most important to model how task relevant processes compete with emotional processes. Previous work by (Wyble et al., 2005; Wyble et al., in press) has modelled the emotional Stroop task. In their model, emotional processing and cognitive processing compete through winner-take-all inhibition. The result of such competition is emotional interference on the main task of colour naming.

Our model takes a similar approach, with the competition occurring between different input streams (at Implic). That is, task demand orients the model to detect the semantic salience of words. In this respect, high saliency would enhance task relevant processing, i.e. the input stream from the visual system may be more likely to be buffered. However, threat related markers might also attract attention, e.g. when anxiety enhances the activity in the Implic-body loop, generating threat-related markers at Implic. Consequently, the input stream from the body-state subsystem may be more likely to be buffered. The second order markers from Prop would have a similar effect as the first order markers. However, it will become clear that in the model, the actual interaction between task relevant (semantic) processing and emotional processing is more complicated, since information is passed concurrently in multiple streams and with feedbacks. We assume that items are processed on a first-come-first-served basis. Moreover, when the system is committed to an item, it cannot process the subsequent items until it finishes processing the previous item. Thus, relative timing in each stream is critical for items to capture attention.

5 Salience Assignment and Buffer Movement

As we have explained previously, anxiety may affect the disengagement of attention. This is reflected by slow buffer movement for high anxious people in our model. Another factor that may influence the delay of buffer movement is the semantic salience of words. This has been supported by a number of studies. For example, Chun and Potter (1995) have shown that increasing the discriminability of T2 (by masking T2 by a symbol instead of a digit) may increase T2 performance, but increasing the discriminability of T1 (in the same way) may reduce the duration of the blink. They have argued that easily discriminating T1 could speed up the initiation of the second stage, and the second stage could also complete sooner. Thus, blinks will be shorter. A related effect has been shown by Wyble et al (2005), who have shown that a strong T1 results in an earlier and shorter blink, but a weak T1 results in a later and longer blink. Easy and hard T1s are determined by their recognition rate. Short blink durations may be due to the rapid recovery from the processing of a strong T1.

We argue that salience of words may influence the blink in a similar fashion as the discriminability of T1 in Chun and Potter’s 2-stage model, or the strength of T1 in Bowman and Wyble’s STST model (Bowman and Wyble, 2007). That is, we assume that the buffer moves quicker when the key-distractor is high salience and slower when it is low salience. Such assumptions allow the model to produce a similar effect as that observed by (Chun and Potter, 1995; Bowman and Wyble, 2007), i.e. a short and earlier blink for high salience words and a long and later blink for low salience words. (But see also for contradictory findings: Shapiro et al., 1997.)

The intuitions behind our assumptions are as follows: high salience words may be implicationally interpreted faster than low salience words, because Implic classifies words into different categories based on how close these words are to the centre of a word category. High salient words will have advantages because they are close to the centre, thus it takes less time to decide which category the word belongs to. By the same token, low salient words may take longer to be processed at Implic. However, Prop works differently from Implic, i.e. it maintains a collection of semantic referents for words. In order to assign propositional salience, Prop has to search for sufficient referents before a decision can be made. High salient words will again have advantages, because they are close to the target template and their semantic referents are clearly “signposted” (Barnard et al, 2005). As a result, Prop may take less time to decide whether a word is a target or not for the high salient words. However, low salient words are distant from the target template and lack ready semantic referents. Thus, Prop will take longer to find sufficient referents. In this model, we assume that the buffer moves quicker by 0.8 times in the high semantic salient condition than in the low semantic salient condition.

6 Simulation Results

6.1 Experiment 1

This section shows how the model reproduces Experiment 1 of (Barnard et al., 2005), in which targets are job words, background items are nature words, and the key-distractors can be one of three sorts:

1. The same category as the background items,
2. Neurtal words that are different category from background and target items,
3. Physical threat words belonging to a different category from background and target items.

Note, in this experiment, key-distractors are not semantically related to targets, so they are task irrelevant. (Please refer to (Barnard et al., 2005) for detailed description of the experimental procedure.) The experimental results show that threat-related words only briefly capture the attention of high state anxious individuals, at around lag-4, as shown in Figure 2 (b). However, Figure 2 (a&c) shows that threat-related words do not capture attention for low anxious individuals[1] when the stimuli are task irrelevant.

When comparing the blink caused by emotion with the standard AB, we can find that the typical AB has consistent lag-1 sparing followed by a blink at lag-2, 3, and 4 (Raymond et al., 1992). However, the blink caused by emotion shows a somewhat different pattern, i.e. the blink is later (around lag-4) and narrower, as shown in Figure 2 (b). According to the model, the later blink may suggest that the physical threat words are not implicationally salient, and not being propositionally evaluated, as in the standard AB tasks, because the physical threat words used in this experiment share little semantic properties with targets. Moreover, the weakness of physical threat words[2] without semantic relevance to the task may not be sufficient to capture attention as seen in the cocktail party effect. So, the model explains the later blink by threat markers that arrive at Implic at later stages.

---

[1] In this report, low anxious refers to low state anxious since trait anxiety has no effect in these experiments (Barnard et al., 2005).

[2] A single exposure of a threat word is a relatively weak threat compared to, for example, one’s life being threatened by a gunman.

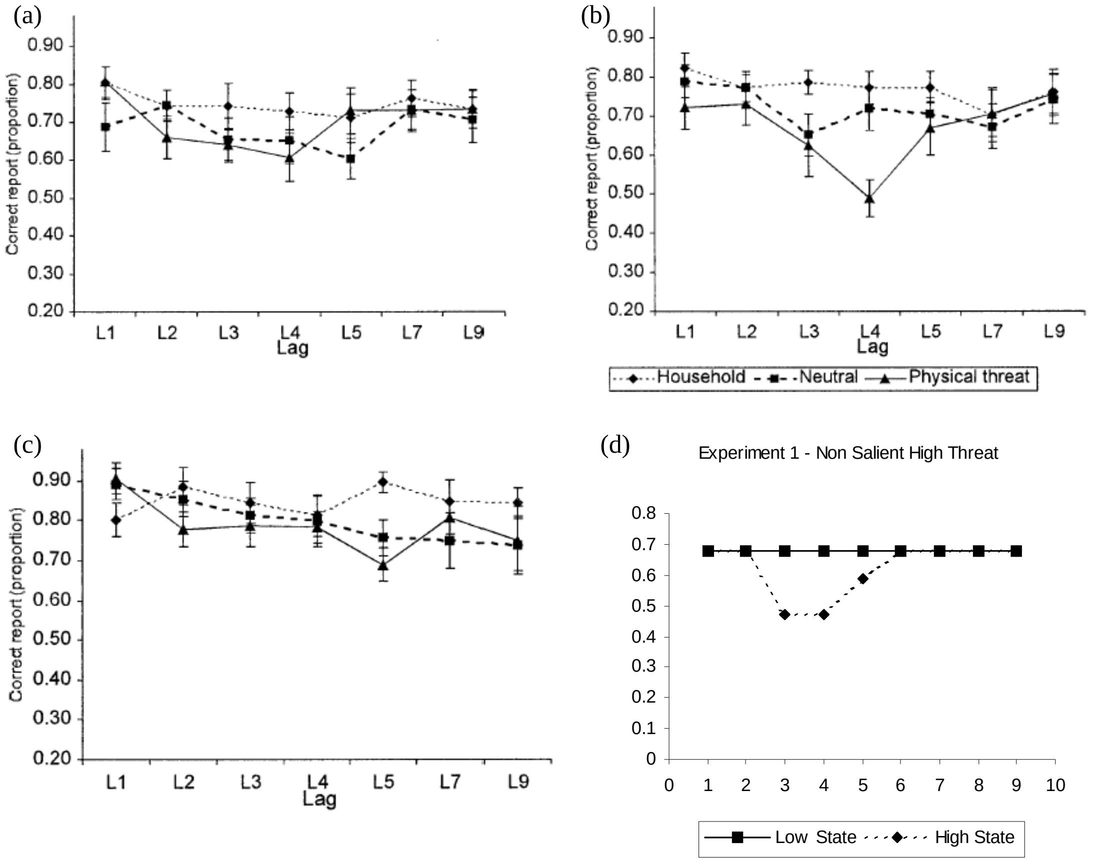

Figure 2 Target report accuracy by serial position in the following conditions: (a) Human - Low trait low state anxious; (b) Human - High trait high state anxious; (c) Human - High trait low state anxious; (a,b and c adapted from Barnard et al., 2005) (d) Simulation results - High and low state anxious, high threat related stimuli.

As we have discussed, blinks observed in the high state condition could not be caused by the buffer moving to Prop, because the time course would not match. So, we argue that the blink (if it occurs) could only be due to emotional processing triggered by threat related markers. In order to distinguish the sort of blink shown in Figure 2 (b) and other blinks, we call this type of blink an *emotional blink* and call the blink considered in the previous model a *semantic blink* (Su et al., 2007). As discussed previously, there are three sources of threat-related information. The first order threat markers from the visual system do not produce blinks because they do not cause an attention switch to other subsystems or other input streams. So, only the body-state feedback and the second order threat markers from Prop could produce emotional blinks. As previously discussed, in this experiment, words are not propositionally processed, so the emotional blink can only be caused by body-state feedback. Moreover, it is assumed that only high state anxious people produce significant body-state feedback for the sort of weak threatening materials considered here resulting in an interference with attentional focus. Hence, the simulation result shows that the emotional blinks can only be found in high state individuals at around lag-4, as shown in Figure 2 (d). The model produces such emotional blinks as follows:

1. A threat related key-distractor passes from the visual system (Source) to Implic.
2. Threat-related information (first order threat markers) is extracted at Implic. For (and only for) high state anxious people, sufficient SOM and VISC signals are initiated to generate body-state processing.
3. When the changes in the body are detected by the body-state subsystem, feedback (containing first order threat markers) will be sent to Implic. We assume that such feedback occurs at around 100-120ms after the onset of the key-distractor and remains for no longer than 100ms.
4. Implic detects the body-state feedback and switches the buffer from monitoring the visual system input stream to checking the event at the body-state input stream. Hence, targets arriving from the visual input stream might be missed and emotional blinks would occur.
5. When the buffer returns to the visual input stream after a brief check of body-state, the blink recovers. Note, we assume that switching of the buffer within a single subsystem takes less time than between two different subsystems. This is why emotional blinks in this experiment are narrower.
6. Less anxious people do not show blinks due to the insensitivity of the Implic-body loop as explained previously.

In summary, when weak threat is competing with the main task, the buffer in less anxious individuals tends to stay at the input stream of the main task, i.e. the visual system. However, anxiety may enhance the Implic-body loop shifting attention to the input of emotional markers from the body-state subsystem. In the next experiment, the semantic salience of the key-distractor is increased. We can predict that when salience has reached a certain level, even high anxious individuals could overcome the emotional interference. Moreover, the extensive semantic processing may also introduce a second order threat marker, which may cause interference with the main task at a later stage via the Prop-implic loop.

6.2 Experiment 2

Experiment 2 in (Barnard et al., 2005) is similar to Experiment 1 explained previously, but it uses four types of key-distractors:

- High salient high threat
- Low salient high threat
- High salient low threat
- Low salient low threat

All key-distractors are human related words, thus even low salient key-distractors may be salient enough to capture attention. So, most key-distractors would be both implicationally and propositionally processed and would produce normal semantic blinks if the emotional interference is ignored. We are interested in how semantic processing interacts with emotional processing over time and whether emotional and semantic blinks could co-occur. It has been reported that the most significant lateral shift of the blink curve occurs only in the high threat condition (Barnard et al., 2005). As shown in Figure 3 (a&c), the dynamic of attentional capture is a function of both anxiety states and semantic salience.

We argue that emotional processing and goal directed semantic (cognitive) processing might compete for limited attentional resources. In this setting, the goal directed processing might be dominant, since the key-distractors are all high salient human related words. Both high and low state anxious individuals would see key-distractors as implicationally salient and process them propositionally. On detecting a salient key-distractor, the buffer will be committed to moving to Prop at 60ms from the onset of the key-distractor. Thus, from this point of time, Implic cannot respond to the threat feedback from body-state (if there is any) for both high and low anxious individuals when such feedback arrives at Implic. So, emotional blinks could not occur at this point.

However, human data has shown a potential late secondary blink that might follow the first semantic blink, as shown in Figure 3 (a&c). We argue that in our model, such secondary blinks could only be caused by the threat-related feedback from Prop. As we have previously explained, such propositional feedback is generated by the slow Implic-prop loop, thus it arrives much later than body-state feedback, which is generated by the fast Implic-body loop. In this model, the propositional feedback could occur from around 400ms to 560ms after the onset of high-threat key-distractors. A secondary emotional blink may occur if Implic responds to propositional feedback, the depth of the blink is modulated by the probability of Implic catching such feedback, which we will discuss now.

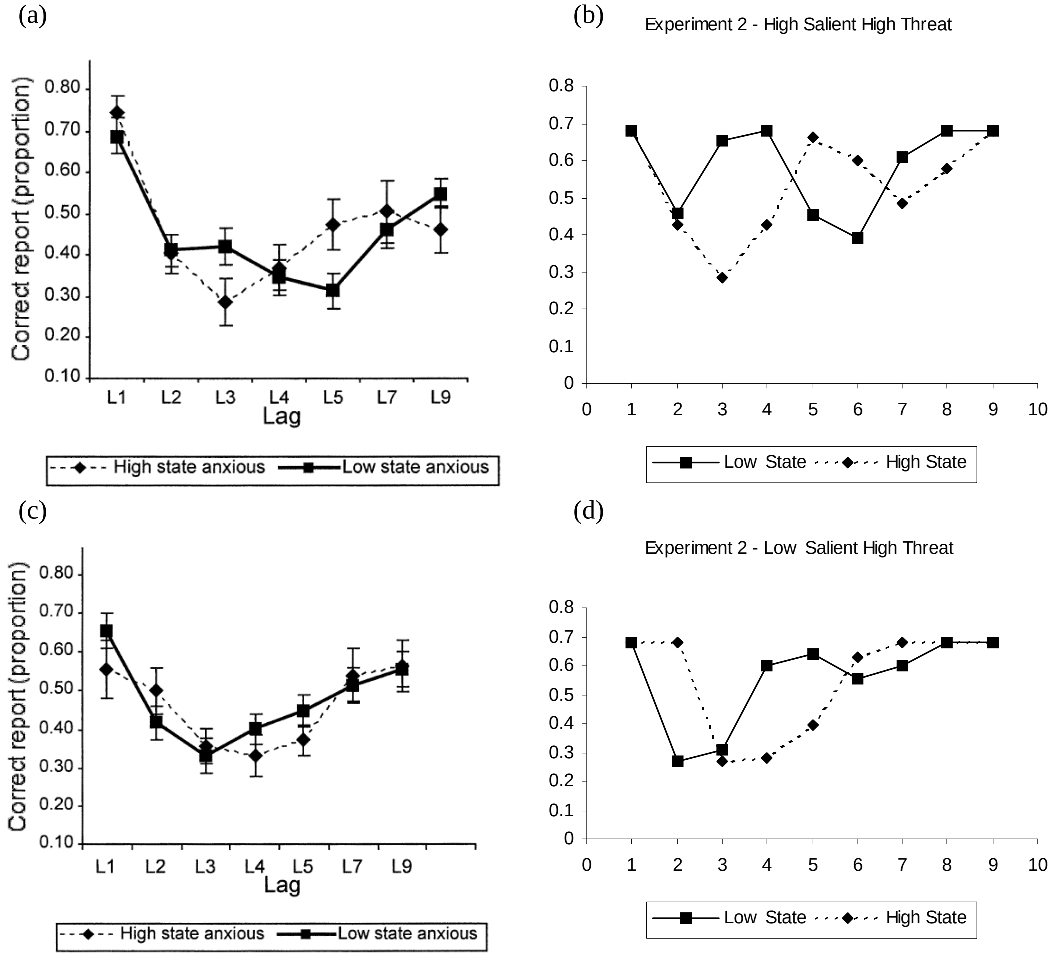

Figure 3 (a) Human - high salient condition; (b) Simulation - high salient condition; (c) Human - low salient condition; (d) Simulation - low salient condition.

We explain how the model blinks in the following four different conditions.

- For the low state anxious individuals and high semantically salient key-distractor condition, shown as a solid line in Figure 3 (a), the curve starts with a brief initial semantic blink. Then, it is followed by a longer second blink. As previously discussed, the high salient key-distractor should be processed at Prop, so we can identify that the second blink must be caused by the threat-related propositional feedback. The emotional blink in this condition is more pronounced than in the other three conditions. The reason is that high semantic salience enables a rapid switch of the buffer between subsystems, as we have discussed in the previous sections. So, the first semantic blink is brief, and the buffer returns to Implic in time to capture the threat-related feedback from Prop.

- For the high state anxious individuals and high semantically salient key-distractor condition, shown as a dotted line in Figure 3 (a), the curve starts with a sharp and long initial semantic blink. There is a small second blink at later lags. This is because of the slow disengagement of attention from threat by highly anxious individuals, i.e. the buffer stays in Implic and Prop for a longer time and their first blinks are longer than those for less anxious people. In other words, the blink is incidentally extended by threat and high state anxiety. As a result, they are more likely to miss the threat-related feedback from Prop. So, in our model the second blink is much reduced. We can see that the second blink is almost invisible in the human data. We argue that such shallow blinks in late lags are more difficult to be discovered by the current experimental setup, since noise in the system increases as the lag increases. That is, the key-distractor initiates the blink; therefore the blink onset is accurately timed locked to the key-distractor. But, as time progresses from this time locked onset, temporal noise increases.
- For the low state anxious people and low semantically salient key-distractor condition, shown as a solid line in Figure 3 (b), the curve is similar to the standard AB curves except that the model shows a very shallow secondary blink. This is because the buffer moves slightly slower for low salient key-distractors. And, low anxious people do not generate sufficient body-state feedback to interfere with the on-going task. Thus, the buffer moves to Prop, and stays there for an extended period to evaluate the propositional meaning as we have explained in Section 5. Similar to the previous condition, the blink is incidentally extended, and propositional feedback is likely to be missed at Implic. Hence, such a shallow and late blink is embedded in noise and difficult to find in human data.

- For the high state anxious people and low semantically salient key-distractor condition, shown as a dotted line in Figure 3 (b), the curve starts with a slow onset and long initial semantic blink. There is also no significant second blink at later lags. This is because of the slow disengagement of attention for highly anxious individuals and low semantic similarity. In this condition, the buffer moves much slowly than in the other three conditions. So, the model produces both lag-1 and lag-2 sparing. The blink also has a very long duration. The propositional feedback is likely to be missed in this condition, so no clear second blink was found up to lag-10 in both simulation and human data.

7 Comparison between Other Theories

There are several well-known theories that address the information processing of emotion and anxiety. In comparison with our model, we now consider these existing models, e.g. the somatic marker theory (Damasio, 1994), the Evaluative Map Network or EMNET (Mathews et al., 1997; Mathews and Machintosh, 1998), a connectionist model of the emotional Stroop task (Wyble et al., in press), and neuroscience findings on the amygdala (Le Doux, 1996).

The somatic marker hypothesis argues for the notions of “body loop” and “as if body loop”. These loops differ from each other by whether or not the body is engaged in the emotional processing. Our model also reflects such distinctions, i.e. the Implic-body loop contains the body-state subsystem while the Implic-prop loop does not. In this respect, the threat marker from the Implic-body loop could be seen as a somatic marker. The threat marker from the Implic-prop loop reflects internal thought. In the context of this report, we stress the ability of such markers in directing attention, i.e. both kinds of markers could potentially cause the buffer to move away from the main task. Hence, the cognitive task (recalling job words) is competing with emotional processing for limited attentional resources.

Another well-known theory for emotion-cognition competition is EMNET, which also influenced us. The main components in EMNET are a pair of competing modules. One is processing target relevant representations, and the other is processing emotional distractor representations. These two modules inhibit each other in a competition for limited attentional resources. Attending to targets facilitates the performance of the main task, but attending to distractors interferes with the main task. They have argued that effortful task demand could enhance the target representations and make it win the competition. Thus, attention is captured by target representations. However, anxiety may increase the tendency of automatic and unconscious processing of emotional meaning. Consequently, attention may also be captured by distractor representations. Our model extends EMNET by considering two levels of meaning, and attention to be distributed between them. Perhaps, the most significant difference between our model and EMNET is the fact that we have modelled richer feedbacks between body-state and two levels of meaning. As a result, more complex interaction would occur when stimuli and threat markers are synchronised by the feedback loops. Moreover, Implic-body and Implic-prop loops in our model have different delays. Hence, our model predicts that the relative competitive power between semanticly salient stimuli and emotional markers rely not only on their absolute strength but also their time courses.

Wyble et al (in press) have proposed a neural network model of the emotional Stroop task, in which emotional words slow the responses to subsequent neutral words in the next trial. This finding is consistent with our model in terms of the generally slowed effect of emotion. Moreover, they (Wyble et al., in press) modelled the competition between cognition and emotion in the form of inhibitory competition between cognitive and emotional parts of the anterior cingulate cortex (ACC). Such an approach is also similar to our model in respect of different input streams competing for the buffer at Implic.

Regarding the time course of emotional stimuli, Le Doux (1996) has argued for a two-pathways model of fear conditioning. In his model, information about threatening stimuli (either conditioned or unconditioned) can be fed into the amygdala via two routes. Importantly, these two routes work at different speeds, i.e.

- The “low road” is subcortical, that is, sensory inputs go through the thalamus and project to the amygdala directly. It was argued that this pathway is fast but it only supports crude representations of the stimulus. Thus, it can only extract representations that roughly encode which category the stimulus belongs to.
- In the “high road”, sensory inputs are first processed at the thalamus, and then continue to sensory cortex, where a more complete analysis is performed.

> Finally, the results are fedback to the amygdala. This route is relatively slow, but provides more complete and sophisticated representations of the stimulus.

Note, pathways described by (Le Doux, 1996) were identified from animals, thus whether the same pathways exist in humans remains hotly debated. Now ,we discuss the relationship between Le Doux's model and our Implic-body and Implic-prop loops. We have argued that they are consistent in handling two routes that differ in speeds, but there is no accurate mapping between brain areas identified in Le Doux's model and our ICS model. However, neuroimaging (LaBar et al., 1998; Buchel et al., 1998) and studies on either amygdala or hippocampus lesion patients (Bechara et al., 1995; LaBar et al., 1995) have suggested possible neural substrates for such separate pathways in humans.

8 Conclusion

Our model reproduces the human data in Experiment 1, but the fit is not very accurate in Experiment 2, i.e. we only capture the general time course of the data but not the detailed performance. Nonetheless, the model is valuable because it allows both semantic and emotional processing to be expressed in a single framework, and their interaction to be investigated in the context of AB experiments. Although, in the current form, a number of assumptions made in this model are not fully justified by experimental findings, it remains an interesting hypothesis for the potential mechanism underlying the emotional AB. For example, we have assumed that the speed of processing for high salient stimuli is faster than that for low salient stimuli. However, to our knowledge, there is no direct evidence that supports such an assumption. The current model is based on some indirect findings (e.g. Chun and Potter, 1995; Wyble et al., 2005), which suggests that more visually salient T1s generate a reduced blink. We think a potential method to validate (or falsify) our assumptions is to relate our model to electrophysiological data, which may give us more accurate timing constraints.

With respect to the interaction between emotion and cognition, the general effect of emotion on the AB has been extensively studied, but related computational theories of the emotional AB are not readily available in the literature. Some successful computational models of emotion rely on learning algorithms discovered by neuroscientists, e.g. reinforcement learning (Montague et al., 1996; Schultz et al., 1997). Others argue for competition between emotion and cognitive processing (Wyble et al., in press; Mathews et al., 1997; Mathews and Machintosh, 1998). Our model is closer to the latter, and argues for competition between cognition and emotion, i.e. emotional salience can attract the buffer, and thereby impairing (cognitive) task oriented processing. Like many other models, the distribution of attention also depends on the relative strength of task relavent stimuli and emotional interference. For example, as previously explained, when highly salient (task relevant) stimuli arrive at Implic, they can capture attention only if weak emotional markers are present from the body-state subsystem. However, our model differs from others, since stimuli also compete in time. This is achieved by the buffer movement dynamic. That is, when a weak emotional marker triggers the buffer to move, any following highly salient stimuli may be missed, since the buffer has been engaged to switch. In this respect, the interaction between cognitive and emotional processing is much richer in our model, allowing temporal properties of mental processes to affect the allocation of attention. This provides a new perspective and reevaluation of the relationship between cognition and emotion.

In summary, although our model of the emotional AB only partially reproduces the human data (Barnard et al., 2005), it provides an initial step towards integrating semantic and emotional processing in a unified computational framework. We believe that it may be refined in the future to accurately account for emotional AB phenomena.

9 Reference

Barnard, P. (1985). Interacting Cognitive Subsystems: A Psycholinguistic Approach to Short-term Memory. In A. Ellis (Ed.), Progress in the Psychology of Language, Vol. 2 (pp. 197-258). Hove, UK: Lawrence Erlbaum Associates Ltd.

Barnard, P. J. (1999). Interacting Cognitive Subsystems: Modelling Working Memory Phenomena with a Multi-processor Architecture. In A. Miyake and P. Shah (Eds.), Models of Working Memory (pp. 298-339). Cambridge, UK: Cambridge University Press.

Barnard, P. J., Ramponi, C., Battye, G., and Mackintosh, B. (2005). Anxiety and the Deployment of Visual Attention over Time. Visual Cognition, 12(1), 181-211.

Barnard, P. J., Scott, S., Taylor, J., May, J., and Knightley, W. (2004). Paying attention to meaning. Psychol Sci, 15(3), 179-186.

Bechara A. and Damasio, A.R. (2004). The somatic marker hypothesis: a neural theory of economic decision. Games and Economic Behavior, 52, 336-372.

Bechara, A., Tranel, D., Damasio, H., Adolphs, R., Rochland, C., and Damasio, A.R. (1995). Double dissociation of conditioning and declarative knowledge relative to the amygdala and hippocampus in humans. Science 269, 1115-1118.

Bishop, S.J., Duncan, J., and Lawrence, A.D. (2004). State anxiety modulation of the amygdala response to unattended threat-related stimuli. The Journal of neuroscience, 24(46): 10364-10368.

Bowman, H., Su L., and Barnard, P.J. (2006). Semantic modulation of temporal attention: Distributed control and levels of abstraction in computational modelling. Technical Report 9-06, Computing Lab, University of Kent at Canterbury.

Bowman, H., and Wyble, B. (2007). The Simultaneous Type, Serial Token Model of Temporal Attention and Working Memory. Psychological Review, 114(1), 38-70.

Buchel, C., Morris, J., Dolan, R.J., and Friston, K.J. (1998). Brain systems mediating aversive conditioning: an event related fMRI study. Neuron 20, 947-957.

Chun, M. M., and Potter, M. C. (1995). A Two-Stage Model for Multiple Target Detection in Rapid Serial Visual Presentation. Journal of Experimental Psychology: Human Perception and Performance, 21(1), 109-127.

Coltheart M., Patterson, K., Marshall J.C. (1987). (eds) Deep Dyslexia, Routledge, London, pp 23-43.

Damasio, A. (1994). Descartes' Error. G.P. Putnam's Sons, New York.

Erickson, T. D., and Mattson, M. E. (1981). From words to meaning: a semantic illusion. Journal of Verbal Learning and Verbal Behavior, 20, 540-551.

Flaisch, T. LAISCH, Junghofer, M., Bradley, M.M., Schupp H.T. and Lang P.J. (2007). Rapid picture processing: Affective primes and targets, Psychophysiology, 44.

Fox, E., Russo, R., Bowles, R. J., and Dutton, K. (2001). Do threatening stimuli draw or hold visual attention in sub-clinical anxiety? Journal of Experimental Psychology: General, 130, 681-700.

Gaillard R., A. del Cul, L. Naccache, F. Vinckier, L. Cohen, S. Dehaene (2006). Nonconscious Semantic Processing of Emotional Words Modulates Conscious

Access, Proceedings of National Academy of Sciences USA,103(19), 7524-7529.

Georgiou, G. A., Bleakly, C., Hayward, J., Russo, R., Dutton, K., Eltiti S., and Fox, E., (2005). Focusing on fear: Attentional disengagement from emotional faces. Visual Cognition 12(1):145-158.

Hasher, L., and Zacks, R.T. (1979). Automatic and effortful processes in memory. Journal of Experimental Psychology: General, 108, 356-388.

Koster, E.H.W., Crombez, G., Verschuere, B. and De Houwer J. (2006). Attention to Threat in Anxiety-prone Individuals: Mechanisms Underlying Attentional Bias, Cogn Ther Res, 30, 635–643.

LaBar, K.S., and Phelps, E.A. (1998). Arousal-mediated memory consolidation: role of the medial temporal lobe in humans. Psychological Science, 9, 490-493.

LaBar, K.S., Le Doux, J.E., Spencer, D.D., and Phelps, E.A. (1995). Impaired fear conditioning following unilateral temporal lobectomy in humans. Journal of neuroscience, 15, 6846-6855.

Landauer, T. K., and Dumais, S. T. (1997). A Solution to Plato's Problem: The Latent Semantic Analysis Theory of the Acquisition, Induction and Representation of Knowledge. Psychological Review, 104, 211-240.

Leyman, L., De Raedt, R., Schacht, R. and Koster, E.H.W. (2006) Attentional biases for angry faces in unipolar depression, Psychological Medicine.

Le Doux, J.E. (1996). The Emotional Brain. New York: Simon and Schuster.

Mathews, A. and Machintosh, B. (1998). A cognitive model of selective processing in anxiety. Cognitive therapy and research, 22(6): 539-560.

Mathews, A., Machinotosh, B., and Fulcher, E.P. (1997). Cognitive biases in anxiety and attention to threat. Trends in cognitive sciences, 1(9): 340-345.

Montague, P. R., Dayan, P., and Sejnowski, T. J. (1996). A framework for mesencephalic dopamine systems based on predictive hebbian learning. Journal of Neuroscience, 16, 1936-1947.

Phelps, E A., Ling, S. and Carrasco, M. (2006). Emotion Facilitates Perception and Potentiates the Perceptual Benefits of Attention, Psychol Sci., 17(4), 292–299.

Raymond, J. E., Shapiro, K. L., and Arnell, K. M. (1992). Temporary Suppression of Visual Processing in an RSVP Task: An Attentional Blink. Journal of Experimental Psychology: Human Perception and Performance, 18(3), 849-860.

Roediger, H. L., and McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. Journal of Experimental Psychology: Learning, Memory and Cognition, 21, 803-814.

Schultz, W., Dayan, P., and Montague, P. R. (1997). A neural substrate of prediction and reward. Science, 275:1593-1598.

Shapiro, K. L., Caldwell, J. I., and Sorensen, R. E. (1997). Personal names and the attentional blink: The cocktail party revisited. Journal of Experimental Psychology: Human Perception and Performance, 23, 504-514.

Shiffrin, R.M and Schneider, W. (1977). Controlled and automatic human processing: (2) Perceptual learning, automatic attending, and a general theory. Psychological Review, 84, 127-190.

Su, L., Bowman, H. and Barnard P. J. (2007). Attentional Capture by Meaning, a Multi-level Modelling Study, Proceedings of 29th Annual Meeting of the Congitive Science Society, Nashville Tennesse, 1521-1526.

Teasdale, J. D., and Barnard, P. J. (1993). Affect, Cognition and Change: re-modelling depressive thought. Hove: Lawrence Erlbaum Associates.

Wyble, B, Sharma D, and Bowman H. (2005). Modelling the Slow Emotional Stroop Effect: Suppression of Cognitive Control. In Angelo Cangelosi, Guido Bugmann, and Roman Borisyuk, editors, Proceedings of the Neural Computation and Psychology Workshop.

Wyble, B., Sharma, D. and Bowman H. (in press). Strategic regulation of cognitive control by emotional salience: A neural network model. Cognition & Emotion.

Yiend, J., and Mathews, A. (2001). Anxiety and attention to threatening pictures. Quarterly Journal of Experimental Psychology, 54A, 665-681.