1. Introduction

Previous research has shown that emotional cues have an effect on cognitive processing, such as decision making (Bechara et al., 2003), attention (Ohman et al., 2001) and working memory (Gray et al., 2002). These executive functions rely on particular areas of the prefrontal cortex, where direct pathways exist to and from the 'emotion-processing' areas of the brain, such as the amygdala (Ghashghaei and Barbas, 2002). However, the nature of this effect is unclear, as emotions have been shown to advantageously modify cognitive processing and behaviour (Bechara et al., 1997), but also cause irrational cognitions and behaviour, as seen in some mental illnesses (Davis and Whalen, 2001; Rosen and Schulkin, 1998). Emotional interference can be measured in terms of salience and valence, both of which cause differing outcomes. The former concerns emotional versus neutral stimuli, the latter relates to positive and negative emotional stimuli. Masked emotional stimuli are used in studies so that automatic processing is targeted and separated from deliberative influences dependent on awareness (Esteves & Ohman, 1993).

Backward masking is a method used to present stimuli as subliminal, as opposed to conscious or supraliminal presentation, so that the complications of conscious control mechanisms and desirability biases are eliminated (Esteves & Ohman, 1993). In visual backward masking, a target stimulus is presented for a brief period of time, less than 50ms. The target stimulus is followed by a mask, which acts to interrupt the onset of conscious processing but not automatic processing (Imanaka et al., 2002). The effectiveness of the mask is determined by factors such as the 'stimulus onset asynchrony' (SOA), which is the time period between the start of the stimulus and the onset of the mask (Francis, 2003).

1.1. Emotional Processing

Emotions set the tone of our experience, giving life its vitality and, like motives, they are internal factors which can energise, direct and sustain behaviour (Rubin & McNeil, 1983). Emotions have also been viewed by some as influential, but ‘brute, disorganising and stuporous’ (Sartre, 1948). Commonsense belief suggests that conscious cognitive processes determine the nature of emotional experiences, e.g. perceiving a positive event subsequently makes us feel happy. However, psychologists such as William James and Walter Cannon, during the late nineteenth and early twentieth centuries, criticised the commonsense view of emotion. They postulated the importance of physiological arousal and feedback mechanisms in the experiences of emotion. Following this view, James and Lange put forward a theory (James, 1890) arguing that physiological changes following an event lead to an emotional experience. The notion that physiological input to the cortex is the basis of emotional experience has been incorporated into most contemporary theories of emotion. Arnold (1960) suggests that an emotion is caused by an unconscious evaluation of the physiological response to a beneficial or harmful situation, whereas feeling is the conscious recollection of this evaluation. Damasio (1999) and Tranel (2002) believe that emotions are stories constructed by the cortex in a particular context, to explain bodily arousal; a view reflected in their Somatic Marker Hypothesis.

Considering the neuroanatomy of emotion, the limbic brain (e.g. the extended amygdala, insula) is no longer solely referred to as the emotional centre (MacLean, 1949). Neuroimaging and electrical stimulation for example, suggest that the amygdala communicates with cortical areas concerned with conscious feeling (the cingulate, parahippocampal and prefrontal cortices) and regions associated with the somatic expression of emotion (the hypothalamus and brain stem nuclei) (Kandel et al, 2000).

It is widely accepted that the hypothalamus regulates the autonomic nervous system (ANS) via connections with the brainstem. This was initially demonstrated by Ranson (1934), using stereotaxic equipment to precisely stimulate areas of the hypothalamus. In this way, Ranson was able to evoke a selection of autonomic reactions, such as changes in heart rate, blood pressure and erection of hairs. Hess (1954) extended this technique to examine anaesthetised cats, and showed that electrical stimulation to the lateral hypothalamus and connecting fibres produced physiological responses associated with anger, such as the raising of body hair, papillary contraction and arching of the back.

Connections between the prefrontal cortex and amygdala have been implicated in emotional processes such as the fear response (Bechara et al., 2000, Wright et al., 2000, Calder et al., 2001). Damage to the amygdala has been shown to reduce behavioural responses to fearful emotional stimuli (Adolphs et al., 2002). Synaptic connections between the amygdala and thalamus seem to play a role in negative memories associated with bodily sensations (Bauer et al., 2002). Right amygdala activity has been specifically implicated in the role of learned fearfulness (Morris et al., 1999, Furmark et al., 1997, Garavan et al., 2001).

Studies have also shown that the amygdala, ventro-medial prefrontal cortex and the orbitofrontal cortex are parts of a neural circuit critical for more complex executive functions, such as judgement and decision making. Lesions to the ventro-medial prefrontal cortex impair both peripheral nervous system responses, and the ability to make advantageous decisions in social and financial circumstances. (Bechara, Damasio & Damasio, 2000). Lesion studies of the medial prefrontal cortex have also illustrated an attenuation of the fear response (Shah and Treit, 2003). Direct connections exist between the anterior cingulate, ventral prefrontal cortices and the amygdala (Nauta & Feirtag, 1986). The orbitofrontal areas issue inhibitory connections to the central nucleus of the amygdala (Ghashghaei and Barbas, 2002). It has been suggested that this 'ventral-medial-orbital' system is activated, perhaps in response to physiological arousal, during decisions based on 'intuition' when there is no clear correct answer (Faw, 2003).

Another issue in emotional processing is lateralisation. Processing of emotional stimuli, particularly of an aversive nature has been associated with right hemispheric activation (Davidson et al., 1990). Emotional stimuli have been shown to adversely affect performance by prolonging response times to stimuli in the left visual field (Hartikainen et al., 2000). Patients with specific right-hemisphere damage seem to perform significantly worse on tasks involving facial and vocal affect perception in comparison to patients with left-hemisphere damage or healthy controls (Kucharska-Pietura et al, 2002). Unlike aversive emotional stimuli, pleasant or neutral stimuli are hypothesised to activate left-hemisphere systems (Heller et al., 1998).

It is likely that both the cortical and subcortical circuits described above play an important role in human mental diseases. For example, in some anxiety disorders there is a hypothesised link between inappropriate processing of bodily sensations and an irrational fear response stemming from the amygdala (Davis & Whalen, 2001; Rosen & Schulkin, 1998).

1.2. Subliminal versus Supraliminal Stimuli

Subliminal presentation of stimuli involves paradigms that prevent conscious processing of the stimulus material, whereas supraliminal methods enable conscious recollection of stimuli. Often during supraliminal presentation of stimuli, deliberate responses occur, based on complex metacognitions (Fazio and Olson, 2003). For example, a patient diagnosed with a psychiatric disorder may purposely respond to disease-specific stimuli, in a manner perceived as being desirable. This desirability bias often applies to subjective reporting in questionnaires, where participants will answer according to their perception or knowledge of the desired outcome (Pauls et al., in press). Examining automatic processing eliminates these complications, and allows for measurement of the underlying default mechanisms that are employed when conscious control is relaxed (Mesulam, 2002).

Presentation of masked subliminal stimuli has been shown to effect perception (Greenwald et al., 1998) and behaviour (Klapp et al., 2002), and increase amygdala activation (Sheline et al., 2001, Whalen, Rauch et al., 1998). Subliminal priming has been demonstrated to have greater effect when it is contextually relevant (Greenwald et al., 2003) and is particularly effective when using stimuli that elicit a conditioned fear response (Mineka and Ohman, 2001). In neuroanatomical terms, the difference between subliminal and supraliminal loosely refers to cortical and subcortical areas respectively. The subcortical amygdala seems to direct subconscious processing of emotional stimuli. Neocortical areas, such as the prefrontal cortex seem to modulate subsequent conscious processing in connection with previous subcortical processing (Faw et al., 2003).

1.3. Cognitive Processing

Individual differences in frontal lobe function are associated with thinking style, and may predispose to mental illness (Goldberg et al., 1994, Mesulam et al., 2002). The prefrontal cortices, found in the more rostral areas of the frontal lobes, are implicated in executive functions concerning control, inhibition and attention (Braver et al., 2002). Specifically, these executive functions include working memory (i.e. rehearsing a telephone number whilst locating a telephone), decision-making, cognitive flexibility (i.e. responding to changing cues) and inhibition (i.e. prevention of responding to changing cues) (Fuster, 2002). Although it is known that areas of the prefrontal cortex work simultaneously in a widely distributed network, like an 'executive committee' (Faw, 2003), it is possible to devise tasks that focus on individual functional areas (Stuss et al., 2002). For example, in neuroimaging studies utilising tests of working memory (e.g. the n-back task), activity in the dorsal lateral prefrontal cortex (Braver et al., 1997) is apparent. Similarly, in tests of cognitive inhibition (e.g. go/no go task) activation of the inferior lateral cortex (Watanabe et al., 2002, Aron et al., 2003) is shown.

1.4. Cognitive-Emotion Interface

Many studies have demonstrated that an emotional experience can modify subsequent information processing. In the Emotional Stroop task (Williams et al., 1996) emotional, or disease-specific words are used to interfere with the naming of the colour of ink in which the words are written. Others have shown that positive and negative mood inducement can subsequently help or hinder performance during specific cognitive tasks (Gray et al., 2002). Negative mood seems to enhance working memory performance for spatial and non-verbal material, but impairs performance for verbal stimuli; positive mood seems to have the opposite effect (Gray 2001, Gray et al., 2002). Studies have also highlighted that emotional stimuli can disrupt attention to spatial targets (Hartikainen et al., 2000), and influence decision-making during an evaluation of profit and loss (Bechara et al., 1997).

Other demonstrations of the emotion-cognition interaction examine the valence effect (whether emotional stimuli are positive or negative). ‘Affective priming’ has been shown, where valance-specific stimuli act to influence valence judgements (Murphy and Zajonc, 1993). Positive stimuli are thought to facilitate an ‘approach-state’ motivation, and negative stimuli to induce a ‘withdrawal-state’ motivation (Rolls, 1999). Therefore, the valence effect of emotional stimuli could be investigated by observing the type of motivational errors caused. Omission errors (failing to respond when necessary) may be caused by a withdrawal state, which is present in an attempt to avoid negative stimuli. Conversely, commission errors (responding when not necessary) may be caused by an approach state, catalysed by the presence of positive, desirable stimuli. The difference between emotional and neutral stimuli is referred to as salience. It is likely that emotional rather than neutral stimuli affect cognitive processing in terms of accuracy (time and number of errors) and response time, based on the collective results of studies described above.

Neuroimaging studies into the neural correlates of cognitive-emotion interaction have shown that the anterior cingulate is activated by emotional interference in the Emotional Stroop task (Whalen et al., 1998). Another study has demonstrated that activity of the dorsal lateral prefrontal cortex is associated with cognitive-mood interference (Gray et al., 2002). However, activation of the different regions could be attributed to the tasks used. The Stroop task is associated with the anterior cingulate cortex even in its non-emotional variant (Whalen et al., 1998) whereas in the latter study (Gray 2002), a working memory task was used, which is known to rely on the dorsal lateral prefrontal cortex (Braver et al., 1997; Faw, 2003). The ventromedial frontal cortex, orbitofrontal cortex and amygdala are systems that supposedly work in conjunction to aid decision-making and judgement (Damasio, 1999, Tranel, 2002).

In addition to normal emotional processing and decision making, the ventromedial prefrontal cortex has been implicated in a range of mental disorders, including obsessive-compulsive disorder (OCD), addictions and eating disorders (Uher et al., 2003). Therefore, it is possible that stimuli relevant to a particular psychiatric disorder interfere more with decision-making (e.g. two-choice task) than with other cognitive functions. However, the interaction between tasks dependant on specific brain regions, and type of emotional/ disease specific stimuli has not yet been examined. Also, the neural mechanisms underlying cognitive-emotion interaction has not yet been determined. Overall, previous research suggests that emotional stimuli occupy neural processing capacity, which is then unavailable for the processing of emotion-irrelevant cognitive tasks (Hartikainen, Ogawa & Knight, 2000; LeDoux, 2000). If tasks that are more demanding require the recruitment of more cortical systems, it follows that they are more susceptible to emotional interference. This idea, which has not been formally examined, could be deemed *competitive interference*. The notion of competitive interference will be addressed during the present study using tasks of varying difficulty, and will be supported if performance is impaired by emotional stimuli during the more difficult tasks.

2.1. Aims

The aim of the present study is to examine whether emotional stimuli interfere with cognitive processing despite the absence of awareness. Also, an exploration into whether cognitive-emotion interaction is task specific will be conducted. Finally, the mechanisms of cognitive-emotion interaction will be investigated by determining the role of task difficulty, and the type of errors caused by the interference.

2.2. Hypotheses

1) Emotional stimuli interfere with cognitive processes despite the absence of awareness.

2) Interference by emotional stimuli is dependant on specific cognitive tasks of varying difficulty.

3) Valence of emotional stimuli will affect the type of motivational errors made.

3. Method

3.1 Participants

A sample of 31 participants (18 female, 13 male) was obtained through public advertisement. Participants were paid £10 for their involvement. Exclusion was based on: presence of axis I mental disorder (DSM-IV; SCID-NP, First 2001), neurological disease, previous head injury and current use of psychotropic medication. The mean age of participants was 25.4 years (S.D. 8.7; range 17-55), and the mean IQ as measured by National Adult Reading Test (NART, Nelson and Willison, 1991) was 114 (S.D. 8.9; range 91-127). Participants were native English speakers and had varied professional and educational circumstances; the mean number of years in formal education was 15.4 years (S.D. 2.3; range 10-20). Four participants were left-handed. Participants were informed that vivid emotional images would be used, but the presence of these images during the cognitive tasks was not disclosed. Participants gave written consent following explanation of the procedures. The Ethics Committee at the Institute of Psychiatry, King's College, London, approved the study.

3.2 Procedure

Following a screening interview, volunteers completed two cognitive tasks on a laptop computer, positioned at eye level and 50cm away. The order of presentation of the two tasks, known as 'n-back' and 'go/no go', was counterbalanced between participants. During both of the tasks, masked emotional and neutral pictures were inserted. Afterwards, a forced-choice test was used to ensure that the pictures were presented subliminally (Eimer & Schlaghecken, 2002; Esteves & Ohman, 1993). At the beginning of the experiment all participants were given a short training consisting of twenty cards, for both tasks. Before the commencement of formal testing, a pilot study was carried out to determine suitable timings for the presentation of the emotional stimuli and presentation of the experimental protocol.

3.2.1 The N-back Task

The n-back task is a test of working memory, which has shown in neuroimaging studies to be associated with dorsal lateral prefrontal cortex function (Braver et al., 1997). Participants pressed a mouse button when the letter on the screen was the same as one letter before (known as 1-back), or alternatively when the letter on the screen was the same as two before (known as 2-back), a more demanding variation of the n-back task. One-back and two-back tasks were alternated using twelve blocks of twenty letters (half were lower case), each consisting of four possible correct responses (twenty percent target). There was a brief pause of four seconds before the commencement of the next block. A red rectangle on the left of the screen indicated an incorrect response; a green rectangle on the right indicated a correct response. At the top of the screen, participants were told whether the task was one-back or two-back. The whole n-back task lasted for six minutes.

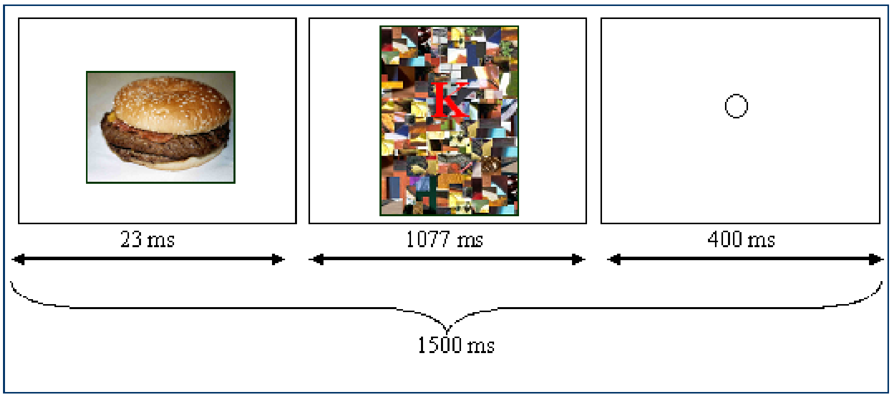
Directly before the presentation of each letter, either an emotional or neutral picture was shown for 23 milliseconds. Letters were presented on a mosaic tile (made up of small, unrecognisable segments of the pictures) for 1077 milliseconds which caused the pictures to be masked and prevented the participants from consciously processing them. Letters were 2.4cm high and written in red ink. There were eight different mosaics used randomly. Emotional pictures consisted of food items (positive) and aversive scenes of violence, threat or injury (negative). Neutral pictures comprised of everyday objects or scenes (see Appendix for all the images used). The order of picture presentation was also counterbalanced between participants; there were six possible combinations (NFA, NAF, FAN, FNA, AFN, ANF, A=Aversive, F=Food, N=Neutral). Both one-back and two-back tasks utilised a block of twenty pictures from the same category (food, neutral, aversive) twice, but the order of the pictures within each block was randomised. After presentation of the mosaic, a blank screen, with a circle to illustrate the position of the next letter was shown for 400 milliseconds. Each individual run lasted for 1500 milliseconds, and was repeated for 240 runs.

Figure 1:

a) An example of an individual run, demonstrating the initial picture presentation, followed by the letter K on a mosaic to cause a backward-masking effect. Finally, a blank screen is presented to prepare the participant for the next run.

b) An illustration of the block design used for n-back, alternating between twenty blocks of neutral (n), food (f) and aversive (a) pictures (i.e. this participant was exposed to the NFA sequence). In each block of twenty cards, task difficulty was also alternated, between one-back and two-back. Order of task difficulty and combination of pictures were counterbalanced between participants.

a)



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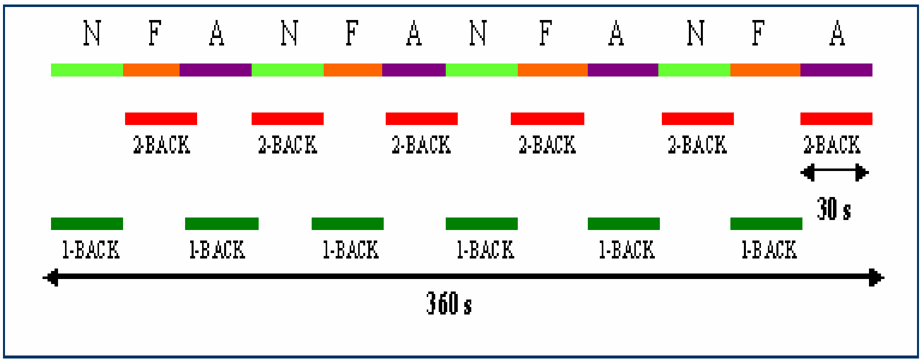


3.2.2. The Go/No-Go Task

The go/no-go task is a test of cognitive inhibition associated with the inferior lateral prefrontal cortex (Aron et al., 2003; Rubia et al., 2001). In this task, presentation of letters was the same as for n-back, but participants responded to every letter with the mouse button, unless the letter was a 'no-go' letter (D, K or X). Again, there were 240 runs, but no pauses because there were no changes in task difficulty. The same counterbalancing and randomising procedures that were used for the n-back task were administered during this task.

3.2.3. The Forced Choice Task

Upon completion of the two tasks, participants were asked if they had seen any images. If they answered "yes", participants were asked to state what images they had seen. If the images reported corresponded with images used in the experiment the participant was excluded from analysis. Following questioning, participants were told that pictures were present during the tasks. They were then asked to choose which picture had been used during any of the tasks, from a series of screens on the computer, showing two pictures. The pictures (size 12 x 8cm) were presented alongside each other. One of the pictures had been used during the tasks (primed), the other, although in the same category (food, neutral, aversive) had not been used (novel). There were 60 screens in total containing the 20 primed pictures from each category alongside 20 novel pictures. The position of the primed picture (i.e. left or right) was randomised. Participants simply responded by clicking the mouse button on the picture they thought was primed; if unsure participants were instructed to make a guess.

3.3 Materials

Tasks were conducted on a 15” LCD monitor with a processing capacity of 1.5GHz on a Pentium 4 laptop computer. The Stimulus Onset Asynchrony (SOA) used was 23 milliseconds and the screen refreshment time was 15 milliseconds. A standard mouse was used to record responses.

3.3.1. Stimuli

Before the presentation of a target letter in each cognitive task, picture stimuli (12cm x 8cm) were presented for 23ms. The selection of food, neutral and aversive pictures was based on 56 colour photographs taken from the International Affective Picture System (IAPS, Lang, 1996) and 126 colour photographs created by those involved in the experiment (see acknowledgements and Appendix). Initial selection was conducted on the basis of diversity within each type of picture (i.e. no repetition of foodstuffs) and between each type of picture (i.e. no food-related images in the neutral category). Although the pictures were presented subliminally during the experiment, selection was based on clarity and recognisability of content so that differences in processing could be attributed to picture type.

The final selection of 20 pictures per condition (food, neutral, aversive) was based on ratings given to the 182 pictures by volunteers. Ratings were on a scale of 0 - 100 for pleasantness, aversion, salience, visual complexity and recognisability. Volunteers’ responses were recorded on a computerised scale. The 60 pictures were chosen based on maximum recognisability, maximum aversion (unpleasantness), and maximum pleasantness of food. All categories were matched for similar visual complexity and colour (i.e. aversive pictures were not all red in nature, but similar in colour and visual content to neutral and food pictures).

Aversive stimuli (all selected from IAPS) included colour photographs of violence, injury, illness etc that would cause a withdrawal - motivated state. Average ratings by the volunteers for these pictures (maximum = 100) were; salience 75 (S.D. 17), pleasantness 30 (S.D. 19), aversion 68 (S.D. 8), complexity 48 (S.D. 23) and recognisability 73 (S.D. 15). Food stimuli (selected from IAPS and additional pictures created by those involved in the experiment) included colour photographs of sweet foods, (i.e. cakes, chocolate etc) and savoury foods (i.e. hamburgers, potatoes, baked beans, pasta etc). It has been suggested that food creates a positive, approach - motivated state (Rolls, 1999). Average ratings given to these pictures were; salience 61 (S.D. 13), pleasantness 71 (S.D. 10), aversion 19 (S.D. 11), complexity 34 (S.D. 17) and recognisability 82 (S.D. 11). Neutral pictures (created by those involved in the experiment) included colour photographs of inanimate objects such as office equipment, buildings, bridges, outdoor scenes etc. Average ratings of these pictures were; salience 43 (S.D. 23), pleasantness 56 (S.D. 9), aversion 24 (S.D. 9), complexity 35 (S.D. 17) and recognisability 85 (S.D. 11). Therefore, the final choice of 20 pictures per category was decided on the basis of the highest average score for each relevant rating (i.e. aversive rating for negative pictures etc.).

3.4 Design

3.4.1. Block design

The order of tasks (n-back, go/no-go) was counterbalanced between participants. The order of task difficulty in the n-back task was also counterbalanced (one-back and two-back). Stimuli belonging to one category (food, neutral, aversive) were subliminally presented in blocks of 20, along with individual letters shown on a mosaic to act as a backward mask. The order of stimulus presentation was alternated, and repeated four times (i.e. F,N,A,F,N,A,F,N,A,F,N,A where F=food, N=neutral, A=aversive, see figure one). There were six possibilities for the order of stimulus presentation (i.e. FNA, FAN, NFA, NAF, ANF, AFN), which were counterbalanced between participants (i.e. one of these six possible combinations would be used for each participant). The appearance of the target letters (there were always 4) in each block of twenty letters was randomised between conditions.

3.4.2. Backward masking

Target letters were presented on a mosaic-effect comprised of small, unrecognisable sections of picture stimuli of all types (see figure one). The mosaic acted as a backward mask to prevent picture stimuli from being consciously processed. A pilot study demonstrated that a stimulus onset asynchrony (SOA) of 23 milliseconds in the presence of the mask enabled the picture to be presented wholly but subliminally. In the absence of the mask the stimuli were clearly visible. However, since the refreshment time of the computer screen was 15ms, timings are only approximate.

3.4.3. Measures

Food, neutral and aversive picture presentation during each of the cognitive tasks formed the three conditions of the experiment. Task difficulty was also taken into account (go/no-go, one-back and two-back). Performance of participants during these tasks and between the conditions was measured based on response time and accuracy (errors made). There were two types of errors possible; commission whereby participants responded when it was not required and omission whereby participants failed to respond when expected. Since there was an unequal number of trials between the tasks (120 in go/no-go and 240 in both variations of n-back), errors were weighted to give relative error rates per 100 trials. Relative error rates are presented in the results, rather than absolute values. A 3x3x2 Analysis of Variance (ANOVA) was used to examine the main effects of the factors condition (food, neutral, aversive), task (go/no-go, one-back, and two-back) and type of errors (commission, omission). ANOVA was used for both reaction times and accuracy (error rates). The interaction between these factors was also explored. Pearson correlations were used for the different tasks and stimuli. All p-values given indicate a two-tailed level of significance.

4. Results

4.1. The Forced Choice Task

Following completion of the cognitive tasks, participants were asked whether they had seen any images during the tasks. Out of thirty-one participants, eleven answered "yes" to this question. When asked to describe the pictures they had seen, five out of the eleven participants reported seeing images that did not match stimuli used during the experiment. For example, some reported seeing actors, monsters, famous pop groups etc. However, the remaining six participants described one or a number of the images that had been used during the experiment. They also indicated in the forced choice task which primed pictures they had seen. As a result, these participants (four female, two male) were considered to be aware of the images and so were excluded from the experimental analysis. The remaining twenty-five participants performed at chance level in the forced choice task, identifying on average 29.96 (S.D. 4.5) of primed and 30.04 (S.D. 4.5) of novel stimuli.

4.2. Effects of subliminal stimuli on accuracy

To determine whether subliminal emotional stimuli has an effect on accuracy (error rate), a 3x3x2 ANOVA was used to analyse the results from all tasks. The within-subject factors were; condition (aversive, food, neutral), task (go/no-go, one-back, two-back) and error type (commission, omission). ANOVA illustrated the main effects of task ($F\,[2,23]=18.90$, $p<0.001$), and type of error ($F\,[1,24]=14.4$, $p<0.001$). There was no significant main effect of condition upon accuracy, demonstrated by ANOVA ($F\,[2,23]=1.85$, $p>0.1$). The analysis highlighted significant interactions between task and condition ($F[4,21]=2.89$, $p<0.05$) – *see figure 2*, and between error type and condition ($F\,[2,24]=4.20$, $p<0.05$) – *see figure 3*.

Figure 2:

The graph below shows the interaction between type of task and condition. A higher percentage of errors occurred during the two-back task. Both aversive and food conditions together caused more errors in the easier tasks (go/no-go and one-back), than in the more demanding two-back task, where the effect of condition was not significant.

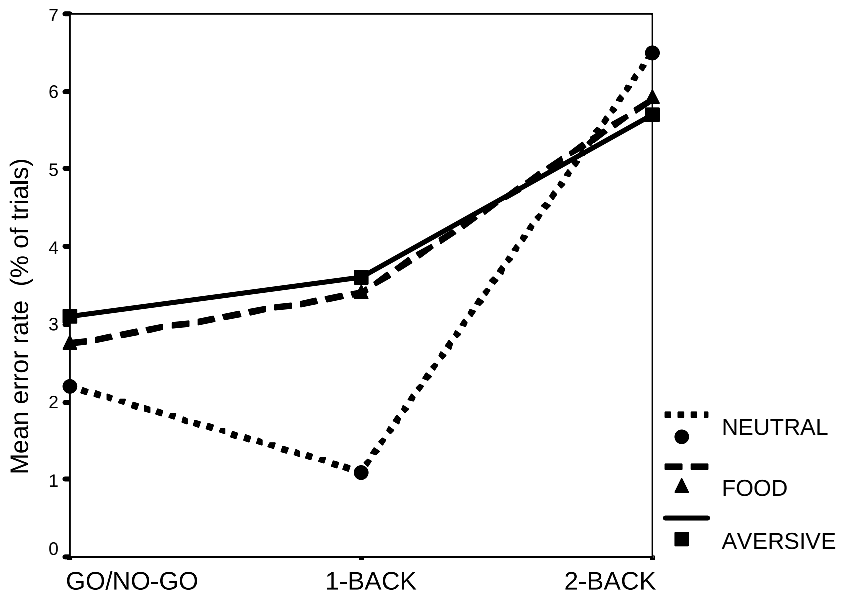
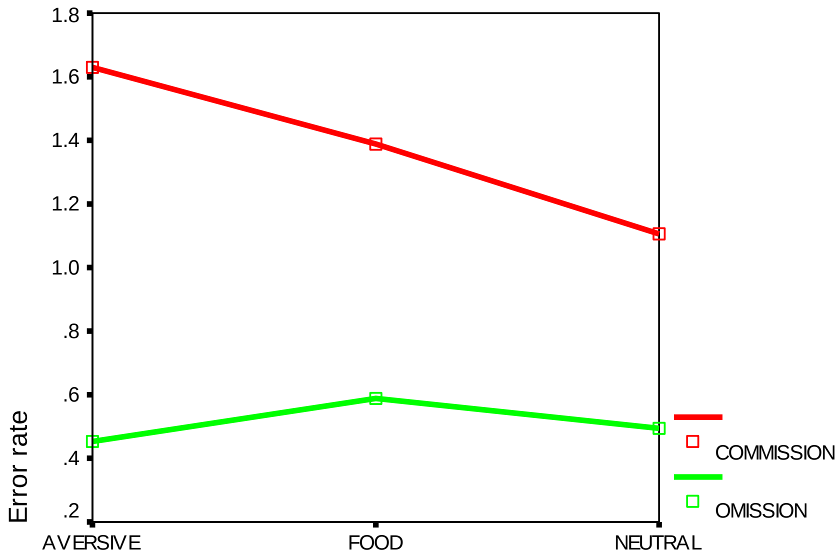


Figure 3:

The graph below shows the interaction between error type and condition during all cognitive tasks. The interactions occur between food versus neutral, and between aversive versus neutral (where neutral images cause less commission errors in comparison to both food and aversive).



Further analysis was necessary to specify the main effects found, as two of the factors have three levels (condition and task). The main effect of task was caused by a higher error rate in two-back in comparison to one-back (F [1,24] =30.14, p<0.001) and go/no-go (F [1,24] = 21.22, p<0.001). The main effect of error rate was due to there being more commission than omission errors across all three tasks.

There were significant interactions found between task and condition, specifically in food versus neutral, which interacted with one-back versus two-back tasks (F[1,24] = 5.97, p<0.05) – *see figure 4*. Aversive versus neutral conditions interacted with one-back versus two-back tasks (F[1,24] = 5.2, p<0.05) – *see figure 5.* Aversive versus neutral conditions also interacted with two-back versus go/no-go tasks (F[1,24] = 4.55, p<0.05) – *see figure 6.*

Figure 4:

The graph below demonstrates the interaction between food and neutral conditions and one-back versus two-back tasks where, during the food condition there were more errors in the one-back task compared with the neutral condition (difference in two-back not significant).

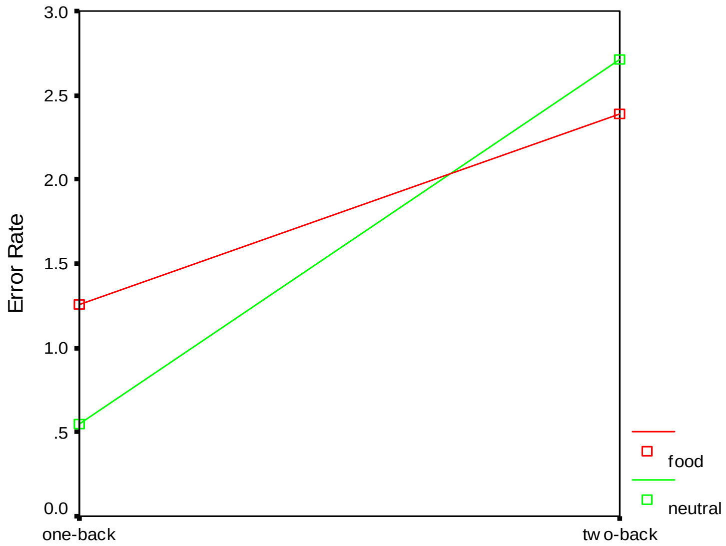


Figure 5:

The graph below highlights the interaction between aversive and neutral conditions and one-back versus two-back tasks. There were more errors in the aversive condition during one-back, in comparison to two-back (not significant).

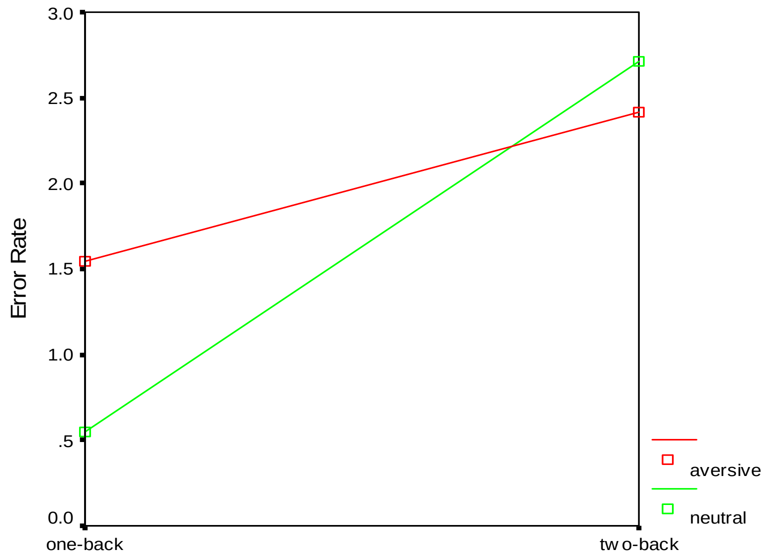
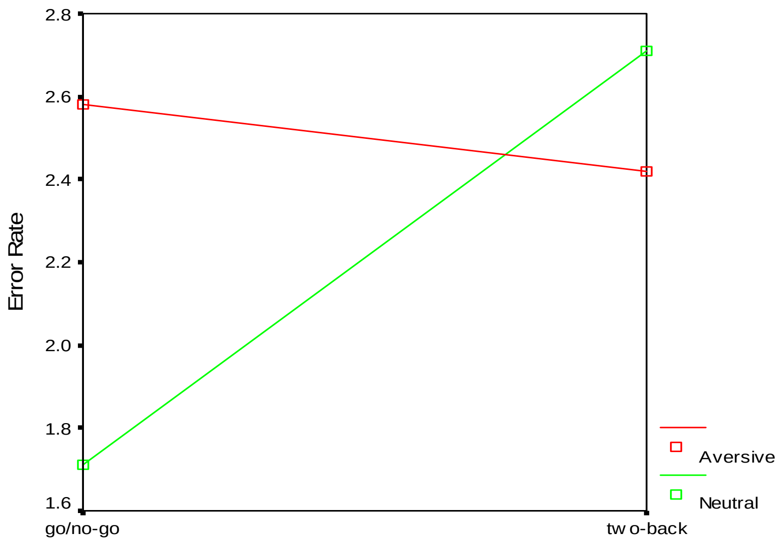


Figure 6:

The graph below illustrates the interaction between aversive and neutral conditions in go/no-go versus two-back tasks. There were more errors during aversive than neutral stimuli in the go/no-go task, whereas there were fewer errors during aversive than neutral stimuli in the two-back task (not significant).



The analysis highlighted that there was no significant difference between aversive and food stimuli in their effects upon accuracy during the cognitive tasks. There was, however, a three-way interaction that approached significance, between condition (aversive, food), task (one-back, go/no-go) and error type (commission, omission) ($F[1,24] = 3.61$, $p=0.08$) – *see figure 2.*

The second interaction between error type and condition occurred specifically in the neutral versus aversive conditions ($F[1,24] = 9.02$, $p<0.01$) and neutral versus food conditions ($F[1,24] = 7.04$, $p<0.05$) – *see figure 3*. To determine the direction of these interactions, post-hoc paired samples t-tests were conducted. In the one-back and go/no-go tasks, there were more errors made in the aversive condition than in the neutral condition. The subliminal presentation of all types of stimuli had no significant effect on error rates in the two-back task. In the one-back task, both types of error (commission and omission) were increased during the aversive condition, whereas in go/no-go it was commission errors that specifically increased during aversive image presentation. However, there was a significant increase in commission errors during the aversive as opposed to the neutral condition in both one-back ($t[24] = 2.43$, $p<0.05$; $d=0.49$) and go/no-go tasks ($t[24] = 2.99$, $p<0.01$; $d=0.60$). Food stimuli in comparison to neutral significantly increased the amount of commission errors during the one-back task ($t[24] =3.48$, $p<0.01$; $d=0.70$), but did not significantly affect commission error rate during the go/no-go task. During the one-back task, aversive subliminal images significantly increased omission errors ($t[24] = 2.30$, $p<0.05$; $d=0.46$). All data are presented in Table 1.

4.3. Effects of subliminal stimuli on response time

To examine whether subliminal emotional stimuli has an effect on response times, a 3x3 ANOVA was used to analyse the results during all tasks. The within-subject factors were again; condition (aversive, food, neutral) and task (go/no-go, one-back, two-back). The only significant main effect found was of task ($F [2, 23] = 7.62$, p,0.01). This was due to response times being longer in two-back, compared to one-back and go/no-go tasks (*see figure 7*).

Figure 7:

The graph below shows the mean response times across the three different conditions (aversive, food, neutral) for the three cognitive tasks (go/no-go, one-back, two-back). Participants took significantly longer to respond in the two-back task, compared to go/no-go and one-back – probably since two-back is cognitively more demanding. There was no significant main effect between conditions.

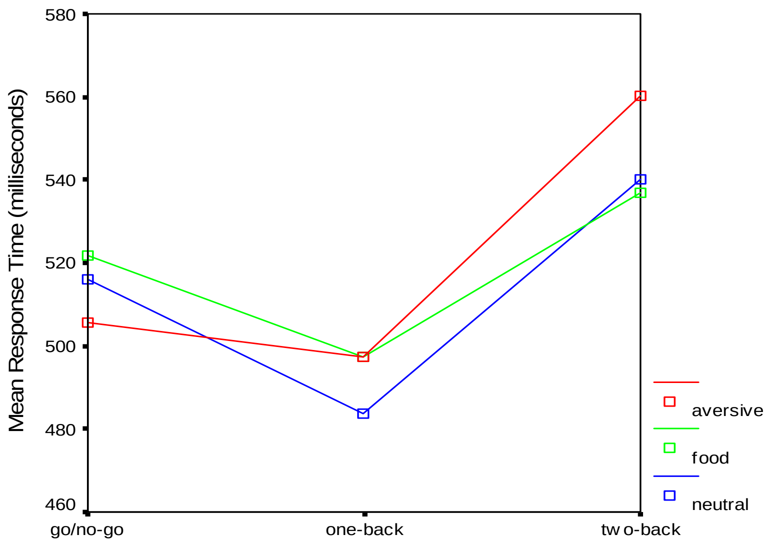


Table 1: Accuracy and response times in the go/no go and n-back tasks.

	Errors Total	Commission Errors	Omission Errors	Response Time (ms)
GO/NO GO				
Aversive	**3.1 ± 2.9***	**2.9 ± 2.6****	0.3 ± 1.0	500 ± 124
Food	2.8 ± 2.8	2.2 ± 2.3	0.6 ± 1.2	524 ± 95
Neutral	2.2 ± 2.5	1.8 ± 1.8	0.4 ± 1.1	519 ± 87
1-BACK				
Aversive	**3.6 ± 4.7****	**2.9 ± 4.1***	**0.7 ± 1.4***	509 ± 94
Food	**3.4 ± 4.7****	**2.9 ± 4.3****	0.5 ± 1.3	506 ± 70
Neutral	1.1 ± 2.3	1.0 ± 2.2	0.1 ± 0.5	492 ± 57
2-BACK				
Aversive	5.7 ± 5.7	3.6 ± 4.7	2.2 ± 2.5	572 ± 101
Food	5.9 ± 6.1	3.2 ± 4.1	2.7 ± 4.0	559 ± 95
Neutral	6.5 ± 5.2	3.7 ± 3.7	2.8 ± 2.7	547 ± 126

Relative error rates per 100 trials given. Significant differences from the neutral condition are marked (*p<0.05; **p<0.01)

4.4 Correlations between tasks

Previous analysis highlighted that subliminal emotional stimuli had an affect on the accuracy of performance in two of the tasks (one-back and go/no-go). Further exploration was undertaken to determine whether there was a correlation of interference between the different tasks and stimuli. Pearson correlation coefficients are given in Table 2. Overall, food and aversive stimuli interference were positively correlated for each task. However, the correlations of these coefficients were weak between the two tasks.

Table 2: Correlations between interference coefficients.

	Aversive 1-back	Aversive 2-back	Food go/no go	Food 1-back	Food 2-back
Aversive go/no go	0.324	.033	0.199	.085	0.118
Aversive 1-back		.040	-0.110	**0.490***	0.170
Aversive 2-back			-0.026	-0.082	**0.642****
Food go/no go				0.243	0.192
Food 1-back					0.269

Significant differences from the neutral condition are marked (*p<0.05; **p<0.01).

4.5 Correlations between interference and individual differences

Age, gender and intelligence variables were selected to examine their influence upon any of the correlations found. However, the interference coefficients measured in both aversive and food conditions were not altered by gender or age, and neither by verbal intelligence, as measured by NART.

5. Discussion

5.1. Explanation of Findings

The main aim of this study was to examine whether subliminal emotional stimuli affect cognitive processing. The hypothesis is supported: emotional stimuli interfere with cognitive processing despite participants being unaware of the presence of stimuli. Moreover, this interference is specific to less demanding cognitive tasks caused equally by emotional images of both positive and negative valence. The effect was observed in the less cognitively demanding go/no-go and one-back tasks, but was not found in the more challenging two-back task. There was no significant interference to participant response times caused by the emotional versus neutral stimuli. The more demanding two-back task naturally caused response times to be slower.

Participants made more errors in the presence of masked emotional versus neutral stimuli during both go/no-go and one-back tasks. Stimuli were visually similar and differed only in terms of their emotional content; therefore errors must be caused by processing of subliminal emotional information. Specific interactions were discovered when examining emotional stimuli against neutral stimuli. Subliminal images of food caused significantly more errors than neutral in the one-back task, but this effect was absent during the two-back task. A similar interaction emerged during examination of aversive versus neutral stimuli.

Comparing the effect of food and neutral images during one-back and go/no-go tasks, food images caused significantly more errors during one-back than go/no-go. Aversive stimuli also increased the error rate during one-back and less so in go/no-go, although this interaction was only marginally significant. The interaction between aversive and neutral stimuli during go/no-go and two-back tasks illustrated that aversive stimuli caused more errors in go/no-go. Finally, in one-back versus go/no-go tasks there was no significant interaction between subliminal aversive and food stimuli. However, the direction of the interaction indicated that slightly more errors were caused by aversive stimuli during one-back.

Participants performed at chance level during the forced choice task, which is regarded as a valid way of establishing that stimuli are subliminal. Therefore, participants were unaware of the stimulus presentation during unrelated cognitive tasks, yet the accuracy of their performance was impaired by emotional images.

5.2. Limitations and Modifications

One of the main limitations of this experiment was that accurate timings for the presentation of stimuli could not be assured when using a laptop computer screen. A laptop was used so that travelling to participants to conduct the experiment would not pose a problem. However, this advantage was overshadowed by the probability that screen refreshment might not be consistent, or be rather slow. Attempts were made to control the effectiveness of stimulus presentation. For example, when the stimuli were presented for the same length of time but without a mask in a pilot study, it was apparent that a SOA of 23 milliseconds was sufficient for the images to be clearly visible on the screen. Assuming that the stimuli were being presented clearly, the other problem was to ensure subliminal presentation, as individual differences in the threshold of subliminal processing are difficult to measure. Nevertheless, this was tackled by the objective forced-choice task, which is a widely used measure to imply participants' lack of awareness of the stimuli (Esteves & Ohman, 1993; Hermans et al., 2003). However, as this task was conducted at the end of the experiment, participants may have forgotten many of the pictures they perceived during the trials – which may account for 'chance performance'. Nevertheless, previous research has emphasised that backward masking is an effective technique to prevent previously-presented pictures from entering awareness (Eliot & Dolan, 1998). Therefore, assumptions can be confidently made that stimuli presented here were in fact subliminal.

Another issue with this experiment is that the pictures used to represent the different categories (i.e. food, neutral, aversive) were quite similar – both between pictures and within pictures in some circumstances. For example, it could be argued that some of the food pictures lacked distinctiveness, and may have been confused with neutral or even aversive pictures (perhaps in the case of 'red' foods). This would certainly hinder the interfering effect of condition upon cognitive processing, yet could be rectified by choosing more distinct pictures per category.

Finally, subliminal emotional stimuli had no significant effect on participant response times during the cognitive tasks. This may be due to individual differences, as the variation of response times was large. However, participants were given less than 1.5 seconds to respond before the commencement of the next letter. This time constraint meant that participants were under pressure to respond quickly, regardless of the emotional interference. It has been suggested, however, that time constraints over 3 seconds would prevent the detection of a differential effect caused by emotional interference (Gray, 2001). Future experiments using this paradigm might increase the time available for participants to respond, without exceeding 3 seconds.

5.3. Relationship to Previous Research

During this experiment, emotional stimuli, regardless of valence were shown to affect accuracy during cognitive processing, even though participants were unaware that the stimuli existed. This result is in accord with previous research, suggesting that we constantly evaluate environmental cues in an automatic manner, in order to modify our thinking and subsequent behaviour (Bechara et al., 1997; Hermans et al., 2003; Winkielman & Berridge, 2003). As with previous research (Dalgleish et al., 2003; de Jong et al., 2003), this study demonstrated that the valence of emotional content is not important; the cognitive-emotion interface is more task than stimulus-specific. Research using mood inducement prior to cognitive testing however, has illustrated that negative affect improves visuospatial performance and positive affect improves verbal performance (Gray 2001, Gray et al., 2002). However, the cognitive tasks used in the present study were neither visuospatial nor verbal, which may account for the lack of valence affect. Results regarding valence effect during mood inducement were not available during the planning of this study.

In this experiment, it was found that subliminal emotional stimuli has a significant affect upon accuracy and not response times – unlike other studies (e.g. Hartikainen et al., 2000; Hermans et al., 2003). It has been suggested that positive stimuli promote approach-state motivation, whereas aversive stimuli promote withdrawal-state motivation (Rolls, 1999). It could be argued that positive emotional stimuli produce commission errors, whereby a participant is over-stimulated to act, whereas aversive stimuli produce omission errors, where action is inhibited. However, the current study did not support this suggestion and found no significant main effect of condition (food, neutral, aversive) on type of errors made.

Finally, previous research hints at the idea that emotional stimuli compete for processing resources (Hartikainen et al., 2000; LeDoux, 2000); an idea which could be deemed *competitive interference theory* for the purpose of this thesis. If this theory was supported here, subliminal emotional stimuli would significantly impair performance during more demanding tasks (i.e. the two-back task). However, it was the less demanding tasks (i.e. go/no-go and one-back) that were significantly affected by the presence of subliminal emotional stimuli. Consequently, an *insertion model* of cognitive-emotion interference is proposed.

5.4. Implications and Further Research

Based on the current findings, it is suggested that an insertion model would more adequately explain cognitive-emotion interaction. According to this model, emotional stimuli are processed by lower level systems in the brain, such as the amygdala. However, emotional stimuli would not influence higher processing in areas such as the prefrontal cortex if there were no neural capacity available. Neural capacity would reach its limit in cortical areas during tasks demanding more attention; therefore it would be difficult for emotional stimuli to impose on such areas. However, in less demanding tasks there would be more cortical space available for emotional processing to occupy and affect cognitive processing. The insertion model seems to have implications for real-life when trying to concentrate whilst ignoring unnecessary information.

The insertion model of cognitive-emotion interface may be determined by emotional stimuli presented at a low-level (i.e. subliminally), with the cognitive task at the centre of attention. It would be interesting to alter the level in which emotional stimuli are processed, and examine how they interact with tasks of varying difficulties. Although many previous studies have presented emotional stimuli so that participants were conscious of it (Hartikainen et al., 2000; Gray 2001; Gray et al., 2002), no studies seem to have compared different levels of stimulus presentation. It may also be useful to include a forced-choice task after each task in future studies, to ensure subliminal presentation and prevent the possibility of forgetting. It could also be interesting to compare subliminal stimuli that lead to a different outcome than supraliminal stimuli, so that the influence of subliminal stimuli is easier to measure. In this study, both subliminal and supraliminal emotional stimulus presentation had the same affect on cognitive performance. Tests that compare arousal during the experiment when presenting subliminal and supraliminal stimuli might highlight level of perception (Kubota et al., 2000).

Finally, it seems that this study is the first to show that subliminally-presented emotional stimuli impair accuracy during valence-unrelated cognitive tasks. The effect size for emotional stimuli upon accuracy was particularly large (df = 0.4 to 0.7). Therefore, a paradigm using subliminal stimulus presentation during unrelated tasks could be used to gauge the presence of psychiatric illness, or even to examine social attitudes (Dalgleish et al., 2003; Fazio & Olson, 2002). It would be interesting to examine whether subliminal mood inducement is possible, and whether it alters opinions previously held. It could also be used to determine the effectiveness of treatment following a psychiatric disorder. For example, an eating disordered patient, having followed a course of therapy, may no longer be affected by the subliminal presentation of food stimuli during a cognitive task. Such a paradigm may have important implications for testing the effectiveness of varying treatments and in relation to many different psychiatric disorders.

6. Conclusion

This study has demonstrated that emotional stimuli presented subliminally are able to impair accuracy of performance during unrelated cognitive tasks. This interference is more likely to occur when the cognitive task is less demanding. Furthermore, it seems that interference is caused, regardless of whether the emotional information is positive or negative. Further research is necessary to determine the exact mechanisms of cognitive-emotion interaction. Comparing conscious to unconscious emotional processing during tasks of varying difficulties may shed more light on this complex relationship.

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9. Appendix

List of images

Food Pictures


fo3


fo6


fo1


fo16


fo31


fo7


fo41


fo60


fo14


fo49


fo52


fo12


fo8

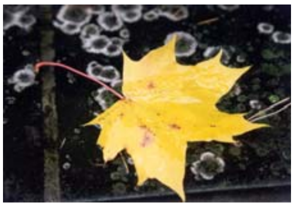

fo53


fo20

 fo45  fo76  fo68

 fo70  fo75

Neutral Pictures

 ne2  ne16  ne19

 ne27  ne44  ne40

 ne49  ne36  ne32

 ne61  ne54  ne66


ne21

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Aversive Pictures


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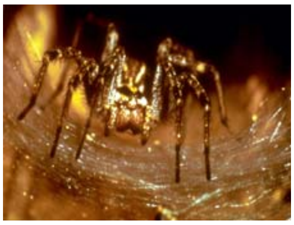
 av40  av42  av9

 av34  av38  av4

 av14  av24  av16

 av12  av3