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Emotional arousal and temporal resolution of the visual system

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Abstract

Emotions influence perceptual processing. An exposure to an emotional stimulus may increase visibility of a neutral target (e.g., Ciesielski *et al* 2010). We tested whether emotional arousal affects temporal resolution in visual domain. Specifically, we expected an increase in temporal resolution since emotional information is transmitted by the magnocellular system, tuned to high temporal frequency. To this aim, critical flicker fusion threshold (CFF) as the measure of capability for temporal resolution was assessed after presentation of short videos with negative (threat, fear inducing) and neutral affective charge, in healthy human subjects. Change in emotional state was verified by measuring skin conductance level. To the contrary to our expectation, critical flicker fusion threshold was not affected positively by induced state of emotional arousal and even seems to be decreased in subjects who manifested high variability in reaction times task performance at basal testing, associated with neuroticism.

Introduction

Emotional feelings are fundamental part of human experience. Understanding the psychological structure of emotions and its underlying brain processes is one of the major challenges of psychology and neuroscience. To this aim, attempts have been made to decompose the complex psycho-physiological states associated with emotional feelings. One well known view is that emotions can be effectively mapped onto two separate axes or dimensions – valence and arousal (Lang *et al* 2005). Emotional valence refers to subjective emotional quality, reflecting pleasantness or unpleasantness of the emotion. Emotional arousal refers to the intensity of emotion and the activation of the central and autonomic nervous system associated with it.

Although emotions are often seen in opposition to cognition, emotional and cognitive processes are firmly related. In particular, evolutionary psychology emphasizes the role of emotions in increasing the chance to survive in dangerous situations (LeDoux 2000). According to this view, emotions serve as labels indicating biological importance of the stimulus and signal the need for processing preference.

Majority of our knowledge on the interaction between emotions and cognition comes from studies of visual perception. This research has convincingly shown that emotional stimuli are more easily attended, detected, identified and remembered. For instance, time needed to detect a threatening object is shorter compared to safe objects (Ohman *et al* 2001). Visually presented positive and negative words are more easily identified than neutral words (Zeelenberg *et al* 2006; Anderson & Phelps 2001).

This orientation of attention and perception towards emotional and especially threatening stimuli can be found to be of greater magnitude in anxious individuals in form of attentional bias. Threat related information is favored and attended to at all stages of information processing more readily and more resources are kept allocated to it for greater amount of time than in nonanxious individuals, for review see Bar-Haim *et al* (2007).

Several studies addressed the mechanisms of emotional information processing within the visual system. The visual systems includes two major processing streams originating in the retina, the parvocellular (P) and the magnocellular (M) system (Desimone & Ungerleider 1989). P retinal ganglion cells project to parvocellular layers of the lateral geniculate nucleus (LGN) that in turn sends projections to layer 4Cb of the primary visual (striate) cortex. M ganglion cells of the retina send projections to magnocellular layers of the LGN, which in turn targets layer 4Ca of the primary visual cortex. Neurons of the P and M system have different properties and process different kind of visual information. P cells have red-green color-opponent receptive fields and are tuned to high spatial and low temporal frequencies. This implies the role of the P system in color vision and fine form vision. M cells, on the other hand, are sensitive to luminance contrast only and are tuned to low spatial and high temporal frequencies. This implies the role of the M system in detection of rapid changes of the visual image, motion perception and fast course form analysis.

Face perception studies suggest that emotional information resulting from facial expression is mostly encoded in low spatial frequencies, implying primary involvement of the M rather than P system (Vuilleumier *et al* 2003; Carretié *et al* 2006). Moreover, it has been found that low rather than high spatial frequencies activate amygdala, a subcortical nucleus importantly involved in emotional processing (Vuilleumier *et al* 2003). It has been proposed that information from the M retinal ganglion cells could be transmitted to amygdala via retinal-collicular-pulvinar pathway bypassing the visual cortex. It has been found that emotionally arousing stimuli are processed more extensively in the visual cortex than neutral stimuli (Vuilleumier *et al* 2001,2004). Lang *et al* (1998) were using functional magnetic resonance techniques in their study and found significantly greater functional activity in occipital cortex during processing emotional (pleasant or unpleasant) pictures than when processing neutral stimuli. Sabatinely *et al* (2007) tested the correlation of functional MRI and event-related potentials (ERP) data using the functional hemodynamic (blood oxygen level-dependent, BOLD) and dense-array EEG to measure slow-wave late positive potential (LPP) during presentation of pleasant, neutral and unpleasant pictures. Signals from both measures were modulated by the rated intensity of picture arousal and suggest an enhanced perceptual sensitivity during emotional picture processing.

Recently, Shackman *et al* (2011) tested the effect of stress and threat on early and late perceptual activity in ERP study. Stress was found to amplify earlier activity consistent with vigilance for threat but disrupted later postperceptual activity and selective attention processes associated with evaluation of task-relevant information.

Relationship between spatial attention and performance in temporal resolution was also examined. Yeshurun and Levy (2003) found that spatial attention degrades temporal resolution, as they argued, possibly by promoting (favoring) parvocellular neurons activity and inhibiting magnocellular activity leading to longer temporal integration. Chica and Cristie (2009) objected to these results as their finding was exactly opposite if control of time window for response and response accuracy (speed-accuracy-tradeoffs, SATs) variables was employed by asking participants to withhold their response until 1 second after the target stimulus appearance. Under these circumstances, overall result was that the spatial attention does improve temporal discrimination.

Bocanegra and Zeelenberg (2011) tested ability of emotion to facilitate vision in order to promote adaptive responses to environment. They have found emotion induced improvement in fast temporal vision at the expense of fine-grained spatial resolution in their experiments using spatial and temporal gap detection technique after presentation of emotional face cues.

In line with these findings, it has been reported earlier, that emotional arousal enhances visual sensitivity. Phelps *et al* (2006) found increased contrast sensitivity for detection of faint grating after exposure to fearful compared to neutral faces. When faces were used as peripheral spatial cues indicating position at which the grating will subsequently appear, a decrease in grating detection threshold was greater after presentation of fearful compared to neutral faces. This indicates that emotional signal could provide additional advantage for information processing the attended location.

These findings suggest that early steps of visual image analysis can be modulated by emotional arousal. However, it remains unclear whether effects of emotional arousal relate specifically to the activity of the segregated processing streams. Given the pivotal role of the M system in transferring the emotional information from the retina to visual cortex it could be expected that the M system is the primary target of emotional influence.

Studies mentioned earlier, addressing the impact of emotions on temporal resolution, were testing the capability for temporal resolution in very short time periods (in scale of milliseconds) after tachystoscopic presentation of emotional stimuli. Toward the longer temporal intervals, Bradley *et al* (1996) were using repetitive processing of pictures with the same affective valence, or mood manipulation, to show that in the order of minutes, no habituation or decrease in affective discrimination occurred, assessed in somatic (corrugator electromyographic [EMG] activity) and visceral (heart rate and skin conductance) systems. Also the responses measured during the picture processing were maintained (with the exception of heart rate) during the interpicture interval and that shows that affective reactions can be sustained during short periods of time in the absence of actual picture content.

In present study we tested the ability of emotions, particularly emotional arousal manipulated by presentation of fear inducing film, to modulate visual temporal resolution capability. Study was designed to gather information on effect of emotions on temporal resolution in longer temporal intervals (in order of several seconds to minutes, rather than milliseconds) after presentation of emotionally salient stimulus. We tried to manipulate capability for temporal resolution by changing the emotional state rather than by employing attentional mechanisms.

Temporal resolution, i.e. the ability to discriminate stimuli presented in rapid succession, is one of the fundamental properties of the visual system and relies on the activity of the M system (Eden & Zeffiro 1998). A well-established method for assessing visual temporal resolution is the measurement of critical flicker fusion (CFF) threshold, the frequency above which flicker is perceived as a constant light. This method has been widely used in psychophysiological research to assess psychomotor functioning, especially the effects of psychoactive substances. In particular, activating drugs (such as amphetamine and caffeine) were found to increase CFF threshold, while sedating drugs (including benzodiazepines, neuroleptics and histamine antagonists) have the opposite effects on CFF (Hindmarch 1980). To modulate emotional arousal we used short video films. The effect of arousing horror movie was compared to neutral non-arousing movie. Induced emotional arousal was quantified by measuring electrodermal activity, an established marker of activation of the autonomic nervous system. Specifically, we expected that CFF will be higher after watching emotionally arousing horror movie than after watching neutral non-arousing movie and will be correlated with EDA (electrodermal activity).

Methods

Subjects

Thirty healthy subjects (20 women; 10 men) participated in our experiment. Most of the participants were undergraduate students. Age span was 18–28 years, mean age was 22.7 years. All test subjects had normal or corrected-to-normal vision and reported no history of neuropsychiatric disorder or drug abuse.

Experimental stimuli

Two short video clips from movies were used as experimental stimuli each lasting about 6 minutes. A horror film was used to induce the emotion of fear. A nature documentary film was used as a comparison stimulus. Capacity of the horror movie to induce emotional arousal, compared to the nature movie, was verified by SCL (skin conductance level) measurement (see Figure 2). All subjects were presented both movies in a counterbalanced manner. Participants were divided into two groups by order of movies presented. The horror movie was presented as first and the neutral movie as second for the first group; the order of films was reversed for the second group.

Experimental setup and procedure

The experiment was conducted in a darkened room. The subject was sitting in a comfortable armchair with a headrest and a response button placed on the armrest. Films were projected from a neighboring room behind the subject through a window. A projection screen with dimensions of 150 × 100 cm was placed 150 centimeters in front of the subject's eyes. A CFF testing board was placed in front and below the projection screen, 70 cm away from the subject so it did not block the clear view of projecting screen. After adaptation to the testing environment subjects were given standardized instructions and they completed a block of training CFF measurements. Next, visual reaction time measurement and baseline CFF assessment were carried out. Thereafter, the first movie was presented followed by a light adaptation procedure. This consisted of reading a standard list of instructions presented on the screen for 30 seconds. This procedure was introduced to ensure adaptation to the same light level after watching each film. This way any possible difference in light adaptation resulting from exposure to different movies was eliminated. Immediately after this, CFF was measured continuously during next 6 minutes. After finishing the CFF measurements the second movie was presented followed by the light adaptation procedure and the last 6 minutes of CFF measurements.

Assessment of subjective levels of emotional arousal and valence

Subjective feelings of emotional arousal and valence during film presentations were quantified using self-assessment manikin scale (Lang *et al* 2005). Ratings were performed at the end of experiment session.

CFF measurement

CFF was tested using a light emitting diode (LED) with diameter of 5 mm placed in the middle of a rectangular board. LED luminance was controlled by a computer and was modulated as a square-wave function of time. During the measurement subjects fixated the LED to yield foveal estimates of the CFF thresholds. The measurement consisted of a series of twelve consecutive trials, in which ascending and descending CFF thresholds (CFFT) were assessed alternatively. Duration of one trial was 30 s, i.e. completion of the measurement series lasted 6 min. For the assessment of ascending CFFT, the LED started to flicker at 13–15 Hz and the frequency of flickering was increased by 1 Hz/s up to

38–42 Hz. The subject instruction was to indicate the moment, in which the LED stopped appear flickering by pressing the answer button. For the assessment of descending CFFT LED start to flicker at 38–42 Hz and the frequency of flickering was decreased by rate of 1 Hz/s down to 13–15 Hz. In this case, the subject indicated the moment, in which the LED started to appear flickering. The variable starting frequencies were introduced to ensure that judgments will not be influenced by the duration to the button press, which, if constant, may yield adoption of an internal rhythm of responses.

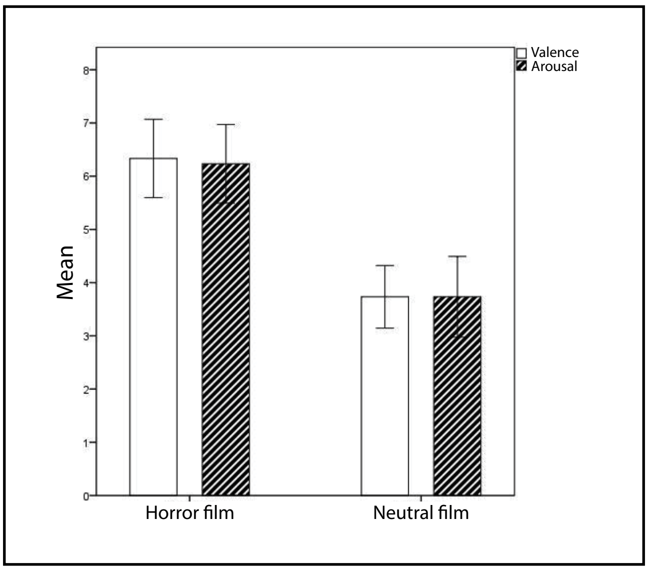

Fig. 1. High score in valence represents strong unpleasant subjective feelings experienced during presentation of horror film. Neutral emotional subjective feeling were experienced during presentation of nature documentary film, represented by score of 4 in self-assessment manikin. Subjective levels of emotional arousal were higher in horror film and lower in documentary film.

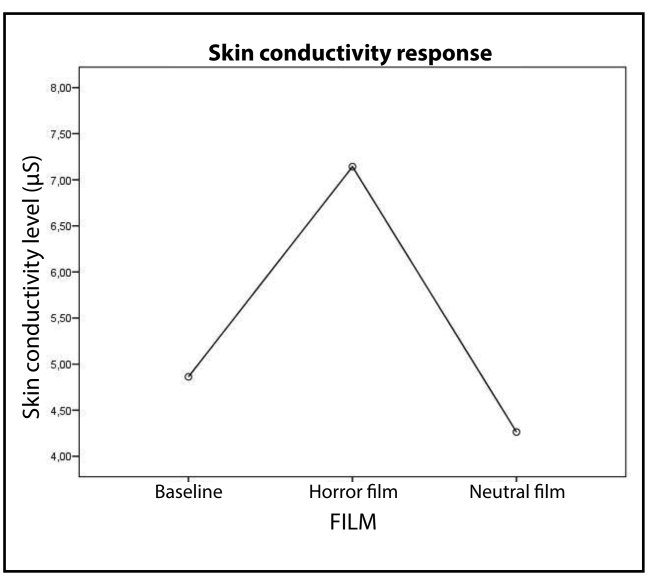

Fig. 2. Objective levels of arousal assessed by measurements of skin conductivity response in normal, horror film and documentary film conditions.

Visual reaction time measurement

Simple visual reaction time (RT) was assessed as a basic measure of psychomotor processing speed and alertness, which are related to CFF (Hindmarch 1994). Subjects had to press a button as soon as possible after a letter X appeared on the screen. Values from 10 trials were averaged. Assessment of RT was carried out before initial CFF measurement. Interquartile range was taken as measure of RT variability that has been associated with neuroticism (Robinson & Tamir 2005; Ode *et al* 2011).

Skin conductance level (SCL) measurement

The change of emotional state induced by horror or documentary movie was verified by measuring skin conductivity level. Measurements were conducted using two Ag/AgCl electrodes fitted to medial phalanges of the index and ring fingers of the left hand. Device used for converting SCL levels into form detectable and recordable by Brainscope EEG apparatus available in the laboratory was using low voltage (1.5 V) alternating voltage 1 Hz pulses sent from one of the electrodes to another. SCL was assessed by measuring of current flowing between two electrodes and represented as the height of edges of these pulses. By using alternating current to assess the SCL we also managed to eliminate all polarization phenomena normally interfering with assessing of SCL.

Data analysis

We analyzed CFF data from last 6 baseline measurement trials (3 ascending and 3 descending trials, 3 min before first movie presentation) and 6 initial measurements after each movie presentation (3 ascending and 3 descending trials, 3 min following movie presentation). These time intervals were chosen based on the dynamics of SCL. SCL was analyzed from the last minute before first movie presentation (baseline measurement) and from the first minute after presentation of each film clip.

Results

Subjective ratings

Subjective ratings of o films were found to be different in both dimensions of valence [t(26)=6.750; $p<0.001$] and arousal as well [t(26)=–5.157; $p<0.001$]. This subjective difference of horror film and neutral film in dimensions of valence and arousal can be seen in Figure 1.

Autonomic arousal evoked by emotional stimuli

The effect of films on SCL was analyzed using repeated measures analysis of variance (ANOVA). Measurement failed due to technical problems in 5 subjects. It was confirmed that autonomic arousal was modulated by the horror film clip presentation. As shown in Figure 2, SCL was increased during presentation of the horror movie, but remained at baseline value for the emotionally neural movie (main effect of Film: $F(2,42)=14.493$, $p<0.001$).

Tab. 1. Repeated measures design ANOVA was used to analyze CFFT data after each of the movies (factor Film), baseline CFF threshold and reaction time interquartile range (RTiqr) were included as covariates. Significant interaction of factor Film and reaction time interquartile range (RTiqr) was found.

Factor	Df1	Df2	F	*p*-value
Film	1	24	1.358	0.255
CFF baseline	1	24	80.001	0.000
RTiqrVariability	1	24	0.046	0.832
Film*RTiqrVariability	1	24	5.680	0.025
Film*CFF baseline	1	24	0.837	0.369

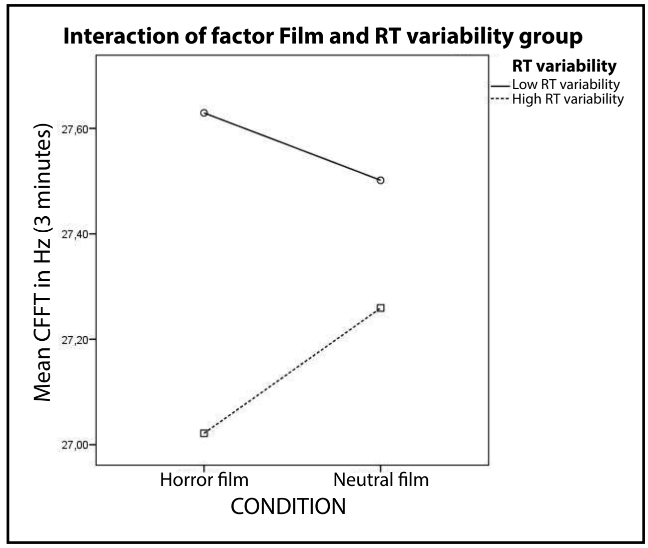

Fig. 3. Study participants with high reaction time variability were not able to differentiate flicker from steady light after watching the horror movie at frequencies they were able to distinguish after watching documentary movie. In contrast, subjects with low reaction time variability even showed some increase in CFF threshold after the horror film compared to the documentary film.

Critical flicker fusion frequency

Two subjects were excluded as outliers since their CFFT values were outside 3 standard deviations from the group mean. In addition, one subject was excluded as outlier in RT.

Mean CFFT values were not significantly different in females and males (27.3 vs. 27.9 Hz, t(25)=0.798; p=0.432). As gender differences were not the aim of this study we did not explore the effects of gender in further analysis of CFFT.

The experimental effects of films on CFFT were assessed using repeated measures design ANOVA. Baseline CFFT and RT interquartile range (RTiqr) were included as covariates. Results of the statistical analysis are presented in Table 1.

CFFT following film presentations were strongly associated with the baseline CFF values (F(1,23)=77.321, p<0.001). We found no significant main effect of Film. However, there was a significant interaction between Film and RTiqr (F(1,23)=6.270; p=0.020). To visualize this interaction subjects were divided into groups with low and high RT variability based on median interquartile range of RT (173.5 ms). Visualization of results is presented in Figure 3. In subjects with high RT variability CFFT was lower after watching the horror movie than after watching the neutral movie. In contrast, subjects with low RT variability showed increase in CFFT after the horror compared to the neutral movie.

Discussion

To the contrary to our original expectation, that the enhancement in capability for temporal resolution in vision should be detected after exposure to emotionally arousal stimuli in participants, no overall effect of emotionally salient film was found.

Our investigation on effects of emotion on temporal resolution in vision revealed no sex difference in men and women in temporal resolution performance. This result is not in line with previous reports that men have higher CFF threshold than women (Hale & Pinninty 1995).

Gender differences could not be explored in our analysis as small test group and unbalanced distribution of men and women test subjects, only one third of men, would not allow for any conclusion.

Physiological levels of emotional arousal were found to be higher after presentation of horror film clip than documentary film clip.

Using CFF we did not find any improvement of temporal resolution capability in visual domain after a horror film presentation and this result was in no relation to levels of subjective emotional arousal and emotional valence reported by participants.

Our study failed to find impairing effect of negative arousing stimuli on overall performance in efficiency of target detection as found by Helton and Russell (2011) who attributed it to resource depletion rather than boredom-mindlessness accounts. Findings of Most *et al* (2007) showed similar effect of positive arousing stimuli that can spontaneously cause emotion-induced deficits in visual processing just as aversive stimuli can.

Ciesielski *et al* (2010) were comparing effect of emotional stimuli with varying valence and presented in varying times before target on visual attentional performance. They report enhancement or impairment of attentional performance depending not on valence of emotional stimuli (fear, disgust, erotic and neutral) but on time passed between presentation of emotional stimulus and target. In contrast to impaired attentional performance at short (200 ms) and intermediate lags (400 ms, 600 ms), enhancement was found in later temporal stages (800 ms).

Effects of emotional arousal on temporal resolution in vision revealed interesting differences between subjects with low and high RT variability (indexed by interquartile range). Subjects with high variability (neuroticism and emotional instability) of reaction times showed decreased temporal resolution as opposed to subjects with low reaction time variability (emotional stability) in condition of induced emotional arousal. Two groups did not differ in ability for temporal resolution in emotionally neutral condition. In our previous work we found decreased performance in CFF in subjects with long RT at basal testing after exposure to emotionally salient film clip (Budac *et al* 2011).

To investigate RT variability related line of results, we found body of literature supporting notion of influence of emotional traits and states (neuroticism, anxiety) on performance in perception tasks. Intra-individual differences in reaction time (RT) attributes in relationship with temperament are discussed in temperament research in general.

Some of the explanations to this effect in emotionally unstable subjects or subjects higher in neuroticism can be delayed disengagement of attention from film clips presented, internalization of attention, thus impairing attention toward light source stimulus used to estimate capability for temporal resolution or attention distribution deficits after presentations of film clips in emotionally unstable subjects. Support for these assumptions can be found in study by Rensink *et al* (1997) on the role of attention in the flicker tasks and more generally, in change blindness phenomenon – observers detected changes to central interest objects more rapidly than marginal interest objects.

Greater tendencies toward RT variability associated with higher levels of neuroticism were proposed to be a result of higher cognitive or mental noise within the individual's information processing system that intervenes between stimulus and response to explain why individuals high in neuroticism are more variable in their behavior and experience (Robinson & Tamir 2005). Later study by same first author (Robinson *et al* 2006) failed to show the correlation of neuroticism trait with reaction time variability but rather it showed the role of RT variability in modeling neuroticism and self-reported emotional distress relation in attention and concentration demanding tasks. More precisely, in group of participants with high variability in cognitive performance, participants high in neuroticism tended to report higher levels of distress. Further investigation was focused on the mental noise hypothesis of neuroticism resulting in cognitive failure also in everyday life as opposed to laboratory test conditions of previous studies was carried out by Flehmig *et al* (2007). Relation of neuroticism and cognitive instability was further supported by this study as high neuroticism individuals reported increased liability for committing lapses of attention and memory failure in everyday life situations due to lower effectivity in regulating the attentional capacity, prospective memory and general behavior as opposed to low neuroticism individuals. More recent study by Ode *et al* (2011) on subject used coefficient of variation in RT as a operalization for mental noise and showed that individuals manifesting higher intra-individual variability in RT tasks exhibited less effective cognitive control, less controlled behavior, and were more prone to negative emotional experiences and depressive symptoms.

Neurophysiological and neuroimaging research evidence brings more information on above notions in terms of linking manifests of neural processing and effects of emotional states and personality traits on this processing with its underlying neuronal structures. Greater frontal and parietal cortex activation was linked with conscious awareness of flicker in single light source stimulus. In contrast fused perception of flickering light source (note that the frequency of light source stimulus was not changed) was associated with greater activation of occipital extrastriate cortex, indicating higher level cortical areas are important awareness of temporally distinct visual events (flicker) (Carmel *et al* 2006). Study by Prado *et al* (2011) is stressing the importance of attentional mechanisms linking variations in response time tasks with variations of functional connectivity between cortex areas responsible for attention control, namely anterior cingulate cortex (ACC), right dorsolateral prefrontal cortex (DLPFC) and bilateral posterior parietal cortex (PPC). Anatomical study on patients with brain lesions found that the stability of cognitive performance is excessively impaired in patients with focal frontal lobes brain lesions resulting in greater intra-individual performance variability in reaction time tasks in comparison to patients with damage to non-frontal cortex areas and healthy control subjects (Stuss *et al* 2003). Availability of attentional and processing resources seems to be another condition determining the ability for detection of temporal pattern as perceptual load modulates perception of flicker. Identical flickering stimuli were perceived as uninterrupted source of light when presented concurrently with peripheral letter search task (high perceptual load task) as opposed to being perceived as flickering when presented with low load perceptual task (Carmel *et al* 2007).

Attentional bias is likely to be another possible explanation for this result. Emotionally unstable subjects higher in levels of anxiety could experience difficulty in disengaging their attention from fear and threat inducing film towards detection of emotionally indifferent rapid changes of light source intensity (Fox *et al* 2005). Along with neuroticism, anxiety and emotional instability may have also played a role in our results. Eysenck and Byrne (1992) found that subjects with high trait anxiety are more liable to be negatively affected by distracting stimuli while performing reaction time tasks than subjects with lower trait anxiety. Furthermore, this higher distractibility among high trait anxiety subjects occurred primarily when distractor words were related to threat. This finding is relevant to us because emotionally salient horror film that was used to induce change in emotional state of participants in our study consisted of fear and threat inducing scenes. Anxiety impairs attentional control and anxious individuals preferentially allocate attentional resources to threat-related stimuli. Comprehensive insight and more reference on role of anxiety and attention in cognitive performance is offered by Eysenck *et al* (2007) in their attentional control theory that is the extension of efficiency theory proposed by Eysenck and Calvo (1992). In addition to the above mentioned possible role of trait anxiety in our results, state anxiety should projected into our results through attention as well. Pacheco-Ungetti *et al* (2010) found that trait anxiety is resulting in deficiency in executive control network (difficulty responding) while state anxiety resulted in over activation of alerting and orienting networks (bottom-up processing).

Neuroticism, in our study derived from reaction time variability measure, was also tested against SCL data, but no correlation suggested by Norris *et al* (2007) was found.

Results of our study suggest that the performance of lower levels of cognitive processing are prone to be affected by state of higher cortical areas. State of emotional arousal induced by audiovisual stimulus impaired the ability of subjects to discriminate rapid changes in visual domain (flicker) only if modulated by neuroticism personality trait, reflecting system noise within the individual's information processing system and attentional mechanisms.

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