Mood Induced Changes in Global or Local Processing of Information Explained by Locus Coeruleus Norepinephrine Patterns of Activity

Yasaman Kazerooni

Graduate Student at University of Michigan

Author Note

This thesis is aimed at fulfilling one of the requirements of the Accelerated Degree Program in Psychology at University of Michigan.

Abstract

Many studies have revealed mood induced changes in the cognitive processing of different tasks. Recent studies show that negative moods lead to a switch in the style of processing while positive moods lead to a continuation of the preferred style of processing. Two of the centers responsible for mood regulations also play a big role in modulating different patterns of locus coeruleus norepinephrine (LC-NE) release and decision making processes. Therefore, we expected to find mood induced changes in performance as well as changes in patterns of LC-NE release specific to each of the induced moods. Our task required our participants to look at congruent and incongruent Navon images and decide whether the bigger letter or the smaller ones were vowels or consonants. Depending on the group each participant was randomly assigned to, either mirth, elevation, sadness or neutral mood was induced in the second half of the experiment. Overall, we found that participants got faster in the task throughout the study. Although, across all of the induced mood categories our participants had a better performance at local blocks before and after mood induction, participants in the sadness condition had the least improvement in their performance on the global blocks. We also found mood induced patterns of NE release specific to each type of mood induction. Moreover, the post mood induction performance of participants on the task was in accordance with what would be expected of participants displaying that specific pattern of LC-NE release.

Keywords: Global or local processing, Adaptive Gain Theory, Pupil, Norepinephrine, Mood

Acknowledgements

This thesis would not have been possible without the guidance and support of my research adviser Dr. Richard Lewis, help and support of Michael Shvartsman and finally my colleague and friend Mehgha Shyam who collaborated with me in conducting this study.

Mood Induced Changes in Global or Local Processing of Information Explained by Locus Coeruleus Norepinephrine Patterns of Activity

Have you ever felt like you are too sad or too excited to perform well on a task? Many studies have demonstrated mood induced changes in people's cognitive abilities and performance on different tasks. In this study, we aimed to take this research a few steps further and see whether mood induced changes in performance can be linked to changes in one's level of arousal and locus coeruleus norepinephrine (LC-NE) patterns of activity. We also examined people's preference for certain aspects of a task and how that may change with mood induction.

Affect Leading to Global or Local Processing

The exact influence of positive or negative moods on cognitive processing of information has been a topic of debate for decades. Originally, it was believed that positive moods induce one to use general knowledge, schemas and stereotypes (Bless, 2001; Bodenhausen, Sausser, & Kramer, 1994), focus on the general aspects of visual stimuli (Gasper & Clore, 2002), and process information in a top-down manner (Fredrickson, 1998); whereas, negative moods induce one to focus on details of a stimulus (Clore, Gasper, & Garvin, 2001) and process information on a bottom-up manner (Gasper et al., 2002; Bless, 2001; Clore, et al., 2001). Hence, according to the Affect-as-Information (AAI) Approach, positive moods induce global processing while negative moods lead to local processing of information.

However, recently Isbell, Lair and Rovenpor (2013) provided strong support for the Cognitive Malleability Approach which states that positive moods lead one to follow through with their preferred method of processing (global or local), whereas negative moods induce one to change such method. According to Cognitive Malleability approach positive affects function as "go" signals which induce one to continue with the style of processing (global or local) that one prefers or is accustomed to, while negative affects function as “stop” signals which trigger a change in the style of processing. For instance, Isbell and colleagues studies (2013) demonstrate that induction of a positive mood following training for focus on local aspects of a visual stimuli will lead one to continue processing the information more locally, whereas induction of a negative mood after such training session will lead one to switch the focus from a local level to a more global level of processing.

Although many studies have shown that induction of positive affects are followed by global processing of information, Isbell and colleagues (2013) attribute this trend to the general preference for global processing of information, regardless of one’s mood. Since participants have a tendency to focus on global aspects of a stimulus, positive affects induce continuation of such style of processing, leading to the strong association of positive moods and global processing of information. Furthermore, induction of a negative mood will lead one to switch from such preferred method of processing and follow a local style of processing of information; hence the observation that local processing follows induction of negative moods.

Preference for Global Processing

Despite the mixed reviews, there is stronger support for prevalence of global processing of information in the literature. As mentioned by Kimichi (1992), the size of the stimuli (Navon & Norman, 1983), exposure duration (Paquet & Merikle, 1984), angle of exposure (Kinchla & Wolfe, 1979), the specific task at hand (Kimchi, 1988; Kimichi & Palmer, 1985) and other factors can influence people’s preference for global processing of stimuli.

Despite the mixed reviews, Navon (1977) provided evidence for prevalence of global processing of information in a task very similar to the one employed in our study. To study the locus of attention’s influence on global or local processing of information, Navon (1977) conducted a study in which an image of a letter made up of smaller letters, also known as Navon images, was flashed for 40 ms. Then, based on the instructions, the participants had to identify either the bigger letter or the smaller ones, and make the appropriate button press response. Navon found that participants not only had a much longer response time when identifying the smaller letters (local stimuli) but also such response times increased substantially when the bigger letters and smaller letters did not match. However, he did not find the same trend when participants were asked to identify the bigger letter. Therefore, the interference caused by the global stimuli was found to be much greater than the interference caused by the local ones. The results show that when asked to focus on the local stimuli, there is a great preference for processing the global stimuli over local ones (as shown in Figure 1).

Although, Navon's study revealed the global-to-local prevalence effect by showing the images for only 40ms, other studies have shown that such effect can be observed by displaying the images for longer durations (Paquet & Merikle, 1988; Pomerantz, 1983). Therefore, we expect to find global to local prevalence in our task in which each stimulus is displayed for 500ms as well.

Summary. So far, we have reviewed the literature on effects of mood on global and local processing of information. We have shown that generally people are better at processing of information globally, and that positive moods facilitate such preferences, while negative moods induce a switch in the style of processing. We expect to find similar results in our study. We hope to find faster and more accurate responses during global processing of information compare to local processing, as well as switches in style of processing due to negative mood induction and continuation of preferred style of processing following positive mood inductions. Now we will review some findings that may link different patterns of locus coeruleus-norepinephrine (LC-NE) release to such mood induced changes in preferred styles of processing.

Locus Coeruleus-Norepinephrine System

Locus Coeruleus. Meaning “the blue spot” in Latin, Locus Coeruleus (LC), is a small nucleus in the dorsorostal pons and the major source of norepinephrine (NE) release in the brain. Studies of rat brains show that LC projections reach the limbic system, olfactory forebrain, frontal neocortex, ventral, cranial nerve motor nuclei in the brainstem and dorsal column of the spinal cord (Jones & Yang, 1985; Cedarbaum & Aghajanian, 1978; Jones & Moore, 1977; Nygren & Olson, 1977). Such extensive projections from pons to the motor nuclei in the forebrain and the spinal cord are evidence of the influence of LC neurons in decision making and behavioral responses.

Norepinephrine. Known primarily as the stress neurotransmitter, NE functions as a neuroregulator in the central nervous system. As mentioned by Aston-Jones and Cohen (2005), depending on the type of post synaptic receptors, norepinephrine plays an important role in regulating neural signals (excitatory in alpha 1 receptors and inhibitory in alpha 2 receptors) and increasing synaptic activity of neurons (Williams, Henderson, & North, 1985; Rogawski & Aghajanian, 1982; Waterhouse & Woodward, 1980).

LC-NE activity in the brain takes the form of phasic and tonic modes, and the transitions between these two modes facilitate reaching optimal performance on a given task.

Adaptive Gain Theory

To reach optimal performance at a complex task, one needs to successfully identify the task-relevant stimuli, block noise, and make the correct decisions and behavioral responses. Such processes require an optimal level of arousal and task engagement. As mentioned by Aston-Jones and Cohen (2005), the inverted U-shape relationship between arousal and performance, known as the Yerks-Dodson curve, is very similar to that of the LC-NE tonic activity and performance. In both cases, lower levels of arousal or LC-NE tonic activity results in drowsiness and lack of alertness, while higher levels of arousal or LC-NE tonic activity lead to distractibility and task disengagement. Thus, only moderate levels of arousal or LC-NE tonic activity can enhance task performance (see Figure 3). Adaptive Gain theory (AGT) explains how the frontal cortex regulation of LC-NE phasic and tonic activity modulates one's arousal levels and helps to maintain an optimal performance on a task.

LC-NE Phasic Mode. According to Aston-Jones and Cohen (2005), LC-NE phasic mode of activity consists of lower baseline levels of NE, and higher stimulus induced peaks in NE release (LC-NE phasic responses). Such NE peaks momentarily increase the neural gain and responsiveness of the system only to the task relevant stimuli while inhibiting the task irrelevant stimuli. (Servan-Schreiber, Printz, & Cohen, 1990; Aston-Jones, et al., 2005). During LC-NE phasic mode of activity, the high task related peaks of NE release and inhibition of noise leads to improved performance on the task. The low NE baseline levels result in lower responsiveness of the neural connections and reduced receptivity for exploration of other strategies or stimuli, leading to exploitation of the resources at hand.

LC-NE Phasic Response. Such task related LC-NE phasic responses depend heavily on presence of a behavioral response. When performing a series of signal detection tasks, monkeys were found to show the highest LC phasic responses after detecting the stimuli and before execution of a behavioral response or receiving a reward. If a behavioral response was not required for the task, the LC phasic response was almost nonexistent (Aston-Jones, Rajkowski, Kubiak, & Alexinsky, 1994).The LC phasic response usually occurs about 100 ms after stimulus detection and about 200 ms before the behavioral response. With 60-70 ms of conduction time between the LC neurons and the motor nuclei of the brain, the LC phasic response occurs just in time for making correct behavioral responses (Aston-Jones, Foote, & Segal, 1985; as cited in Aston-Jones & Cohen, 2005, p. 411).

LC-NE Tonic Mode. Contrary to LC-NE phasic mode, during LC-NE tonic mode of activity there is an increase in the baseline levels of NE accompanied by less pronounced stimulus induced peaks in NE release. Such increase in baseline NE levels is accompanied by an overall increase in gain (responsiveness) of neural connections and a decrease in the threshold for detection of both task relevant and task irrelevant stimuli. This may explain the lack of task specific NE peaks in this mode. During LC-NE tonic mode of activity there is an increased probability of detection of noise (false alarms) and poorer performance on the task at hand. However, the increased responsiveness to different stimuli can help the system to explore other options for enhancing performance. Consequently, when the current strategies do not result in optimal performance, or when faced with a novel task or environment, LC-NE tonic mode leads to exploration of other strategies and leads to a more optimal performance by increasing the receptivity of the system.

Cortical Regulation of LC

The widespread projections of anterior cingulate cortex (ACC) and orbitofrontal cortex (OFC) to LC is suggestive of the important role of such entities in regulation of LC-NE modes of activity and therefore optimization of performance (Aston-Jones, et al., 2002; Rajkowski, Lu, Zhu, Cohen, & Aston-Jones, 2000; Zhu, Iba, Rajkowski, & Aston-Jones, 2004).

OFC. One of the main centers of reward evaluation in the prefrontal cortex with projections to the LC neurons is the orbitofrontal cortex. OFC activation has been observed in response to abstract reward and punishment (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001) as well as anticipation of reward (O'Doherty, 2004; O'Doherty, Deichmann, Critchley, & Dolan, 2002). Moreover, not only does the magnitude of OFC activation depend on the reward value, but OFC activation also decreases as the subject no longer finds the stimulus rewarding or when satiety is reached (Critchley & Rolls, 1996; Rolls, Critchley, Mason, & Wakeman, 1989). More recent studies provide evidence for the role of OFC in increasing a system's flexibility as well as integration of reward history and predicting future reward outcomes (Riceberg & Shapiro, 2012; Schoenbaum, Roesch, Stalnaker, & Takahashi, 2009). Such findings bring to light the important role of OFC in anticipation and integration of reward and increasing a system's adaptability to environments with changing reward contingencies.

ACC. Part of the limbic system, anterior cingulate cortex is another important center for decision making and evaluation of cost. ACC activation occurs in response to detection of pain (Lei, Sun, Gao, Zhao, & Zhang, 2004), learned aversions (Johansen & Field, 2004), or prediction of conflicts and future costs. Moreover, according to the conflict monitoring models, ACC activation is linked to conservative and risk aversive decision making (Frank, Woroch, & Curran, 2005; Hewig et al., 2007; Kim, Shimojo, & O'Doherty, 2006). Thus, ACC may be linked to decreased flexibility and responsiveness of the system. Additionally, the *error-likelihood* hypothesis states that the amplitude of the ACC activation not only depends on error prediction, but also on the magnitude of the cost following an error (Braver & Brown, 2005, 2007). Overall, these findings point to the important role of ACC in cost prediction and adapting the system for making optimal decisions.

Regulation of LC-NE Tonic and Phasic Modes. According to the Adaptive Gain Theory (Aston-Jones & Cohen, 2005), OFC and ACC regulate the transitions between the LC-

NE phasic and tonic modes of activity through calculation of the short-term and long-term utility (reward) associated with exploitation versus exploration of different strategies. ACC activity can result in conservative decision making and signals potential cost, while OFC predicts future reward and increases a system's flexibility. Therefore, when ACC and OFC detect temporarily suboptimal performance (short-term decrease in utility) through higher ACC activity and/or perhaps lack of OFC activity (lack of signals for increasing flexibility of the system), LC-NE phasic mode of activity is triggered. LC-NE phasic mode, associated with lower responsiveness to task-irrelevant stimuli and focus on the task at hand, persists until exploitation of the current strategy results in improvements in the performance. Thus, OFC and ACC detect short-term decreases in performance and signal LC-NE phasic activity, which in return improves the performance through increasing the focus on the task at hand.

If the ACC and OFC detect a long-term decrease in performance which could not be compensated using the strategy at hand, LC tonic mode of activity will be triggered. Higher OFC activity increases the flexibility of the system, signals potential reward associated with exploration of other strategies, and signals LC-NE tonic mode of activity. As mentioned earlier, LC-NE tonic mode of activity results in exploration of various options until one of them leads to optimal performance on the task. However, such exploration and increased responsiveness to task irrelevant stimuli may initially decrease task performance. Therefore, after a more optimal strategy is found, a switch to LC phasic activity will help the system to compensate for the lost utility. Since LC phasic activity is associated with more task engagement, as mentioned by Aston-Jones and Cohen (2005), transitions between LC phasic and tonic activity can be summarized via Equation 1.

Engagement in current task = [1 – logistic (short term utility)] ∗ [logistic (long-term utility)]   (1)

In this equation, logistic is the $1 / (1 + e^{-\text{utility}})$, where higher levels of task engagement leads to LC phasic mode and lower levels of the task engagement lead to LC tonic mode of activity.

Pupil Size Change Reflect LC Mode of Activity

Although LC activity in humans cannot be directly measured, animal studies show that LC-NE modes of activity are accurately reflected in pupil dilation patterns. Measuring the pupil size and LC-NE activity of monkeys performing a visual detection task, Rajkowski, Kubiak and Aston-Jones (1993) found a very strong positive correlation between the monkeys' pupil dilation patterns and their LC-NE tonic activity (see Figure 3). LC-NE tonic activity was associated with higher pupil baseline and lower task related dilations, while LC-NE phasic mode of activity was linked to lower pupil baseline and higher task related dilations. Relying on those findings, many researchers have employed pupil dilation patterns as a measure of LC-NE activity in humans. As expected, in all the studies pupil dilation patterns accurately matched the AGT predicted LC-NE activity (Eldar, Niv & Cohen, 2013; Gilzenrat, Cohen, Rajkowski & Aston-Jones, 2003; Gilzenrat, Nieuwenhuis, Jepma & Cohen, 2010; Jepma & Nieuwenhuis, 2011). For instance, during times of low performance and high distractibility, when LC-NE tonic mode of activity is expected to occur, higher pupil baseline and lower task related dilations were observed.

Furthermore, many studies have provided support for the occurrence of task related pupil dilations in response to cognitive load and detection of task relevant stimuli, further supporting Rajkowski and colleagues' findings. Early pupilometry studies revealed the occurrence of task related pupil dilations associated with the degree of task difficulty and cognitive load (Ahern & Beatty, 1979; Beatty, 1982; Kahneman & Beatty, 1966). In more recent studies, similar task related pupil dilation patterns have been observed during cognitively difficult processes such as auditory detection task (O'Neill & Zimmerman, 2000; Steinhauer, Siegle, Condray & Pless, 2004), visual detection task (Privetera, Renninger, Carney, Klein & Aguilar, 2010), visual backward masking task (Verney, Granholm & Marshall, 2004), speech planning task (Papesh & Goldinger, 2012), Stroop task (Siegle, Steinhauer & Thase, 2004) and the lexical decision task (Kuchinke, Võ, Hofmann & Jacobs, 2007).

These observed task related pupil dilations are in accordance with the expected pupil dilation patterns associated with the LC-NE phasic mode of activity. When performing difficult cognitive tasks which require higher degrees of attention and task engagement, LC-NE phasic mode of activity is expected to occur to reach optimal performance. As mentioned before, LC-NE phasic activity is linked to higher task related pupil dilations, such as the ones observed in the aforementioned studies.

In regards to potential ceiling effects prohibiting pupil dilations to occur, Gilzenrat and colleagues (2010) showed that task related pupil dilation patterns continue to occur even in less illuminated ambiences where pupils are already dilated. Moreover, the magnitude of such pupil dilations were found to be highly correlated with the degree of expected cost or reward.

Recent Findings

More recent findings by Eldar, Cohan and Niv (2013) show that high performance on tasks that one has a preference for are linked to LC-NE tonic mode of activity, while high performance on tasks that one does not prefer are linked to LC-NE phasic mode of activity. Eldar and colleagues (2013) further specify the predictions made by the Adaptive Gain Theory based on one's preferred method of performance. Although, they provided extensive neuroimaging and pupilometery evidence supporting the idea that performing well on a preferred task is associated with higher levels of LC-NE tonic mode of activity and increased gain in the system, their findings remain to be replicated. In our task, participants will have the opportunity to show their preference for a specific aspect of a task, therefore we investigated whether participants' performance on their preferred tasks follow the predictions made by Eldar and colleagues (2013).

Effects of Mood on ACC and OFC

Many studies provide evidence for the role ACC and OFC in creating a link between emotion regulation and decision making processes. In their review of brain imaging studies pertaining to ACC function, Bush, Luu and Posner (2000) provided evidence for the involvement of dorsal sections of ACC in decision making and ventral areas in mood regulation. Moreover, Bechara, Damasio, and Damasio (2000) provided evidence for the role of OFC in decision making based on the emotions caused by previous decision outcomes. Furthermore, clinical cases of brain lesions and mood disorders support the role of ACC and OFC in mood regulation. Altered ACC activation as well as reduction in volume of OFC has been observed in patients suffering from mood disorders such as depression (Auer, et al., 2000; Bremner, et al., 2002; Lane, et al., 2013; Miguel-Hidalgo, et al., 2014). Additionally, dysregulation of conscious emotions has been observed in patients with lesions to their OFC (Beer, Heerey, Keltner, Scabini, & Knight, 2003). Moreover, negative moods and stimuli such as imagining angry faces or sad situations, seem to elicit a change in activity of ACC and OFC (Baker, Frith, & Dolan, 1997; Dougherty, et al., 1991; Luu, Collins, & Tucker, 2000). These studies provide evidence for the influence of emotionally salient stimuli on activity of OFC and ACC. Given the important role of these centers in evaluation of potential cost and reward as well as regulation of LC-NE modes of activity, OFC and ACC can be counted as two of the important centers for occurrence of mood induced changes in performance.

Predictions

In our study we expect to find, first, higher initial preference for global processing of information than local processing of information. We would expect our participants to have faster and more accurate responses on trials in global blocks compared to those in local blocks. Second, we expect to find mood induced changes in the preferred style of processing after induction of sad moods and no switch in preferred style of processing after induction of positive moods. In participants who receive either the mirth or elevation mood induction we expect to find a continuation of faster and more accurate responses on whichever type of block the participant have a better performance at prior to the first mood induction. For participants who receive sad mood induction we expect to find a switch from better performance on global (local) blocks to a better performance on local (global) blocks following mood induction. Third, we expect to find mood induced changes in pupil size (reflecting LC-NE modes of activity) specific to the induced mood. We also expect to find changes in pupil size and task performance in accordance with the Adaptive Gain Theory: association of optimally too high or too low levels of LC-NE tonic activity with lower performance and association of moderate levels of LC-NE tonic activity and higher LC-NE phasic activity with a more optimal performance.

Methods

Participants

Participants for this study were recruited from the Psychology Department's Paid Subject Pool at the University of Michigan through email invitations. As mentioned in the email invitations, only right-handed individuals with good eye sight without glasses (or willing to wear contact lenses), no history of psychiatric disorder, and native English speakers were eligible to participate in the study. 81 individuals between the ages of 18 to 29 ($M = 20.48$, $SD = 2.15$) participated in the study. Of the participants, 60 (74.07%) identified their gender as female and the rest as male. Due to calibration errors, equipment malfunctions, and failure to finish the experiment the data obtained from 12 participants were not considered for the analysis ($N = 69$). Prior to start of the study, participants each signed a consent form, which briefly explained the procedure, risks and benefits of participating in the study. Upon completion of the study, the participants were debriefed about the study and received $10 for their participation. However, if the participants were unable to finish the study due to complications with the device or calibration, they received $5 as compensation for their time.

Stimuli

As seen in Figure 4, a Navon image consisting of a big letter made up of smaller letters was presented in each trial. Each Navon image consisted of a combination of either one of the vowels (A, E, I, O and U) and one the five most commonly used consonants in the English language (R, S, T, L, and N), or a combination of just the vowels, or a combination of just the aforementioned consonants, or a combination of the same letter. Each of the vowels or consonants had the potential to serve as the bigger image or the smaller ones. Therefore, in each trial the image was randomly picked from a pool of 100 images. Trials that included an image of a combination of vowels and consonants were called *incongruent trials*. Those made up of a combination of only vowels or only consonants were called *congruent trials*, and trials made up of the same letter were called *identical trials*. Due to our participants' complaints regarding the similarity of the capital letter "I" to the small letter "l" in our images, the trials including the letter "I" were not included in our analysis.

Distance, size and brightness. The stimuli were presented on a computer screen 64 cm away from the eyetracker, where participant's head was positioned. Depending on the shape of the bigger letter, the Navon images were 23 cm tall and ranged from 13 to 20.5 cm wide (letter "O" being the widest). The letters were displayed in white on a black background on a NEC MultiSync FP2141SB monitor with 9% illumination.

Mood Induction

To study the effects of different positive (mirth and elevation) and negative (sadness) moods on cognitive processing, participants were instructed to listen to audio clips of the same type three times throughout the study. Clips designed to induce mirth, elevation or no change in one's mood (neutral) were selected from a series of previously normed clips in a study by Strohminger, Lewis and Mayer (2011). Audio clips of stand-up comedians were designed to induce mirth, audio clips of a tragic story with an inspiring ending were designed to induce elevation, and audio clips of scientific lectures were used as the control condition (neutral mood). The audio clips for inducing sadness were not previously normed; however, they were created by removing the inspiring ending of the elevation audio clips and leaving only the sad beginning. To keep the length of each of the sadness audio clips consistent, more sad narrations were added to each clip using excerpts from stories in the *Chicken Soup for the Soul* series. Moreover, to maintain the consistency of the mood induction, all of the audio clips were about 3.5 min long.

Procedure

Each participant was randomly assigned to one of the mirth, elevation, sadness and neutral conditions in regards to the type of the audio clips he or she was instructed to listen to. To get a better understanding of each participant's baseline performance on the task, participants were asked to finish ten blocks of ten trials of the task prior to the first mood induction. Upon completion of the 9th, 12th and the 15th block, participants were instructed to listen to an audio clip. Right after each clip, participants were asked to rate how the audio clip made them feel on a five point likert scale. (See Appendix A for more information regarding the post mood induction questionnaire.) After completing the questionnaire, participants could start another block of the task. Throughout the study, participants could see their performance (response time and accuracy) at the end of each trial and each block. Participants were also encouraged to take a break any time throughout the study, especially at the end of every block. After completing the task, participants were asked to complete a questionnaire regarding their concerns or general thoughts about the study.

The blocks and the trials. In this task, participants were told to make a decision about whether either the bigger image (global blocks/ Task A) or the smaller images (local blocks/ Task B) are vowels or consonants. The study consisted of alternating nine global and nine local blocks, adding up the total number of trials to 180. Each block consisted of two incongruent (one with a vowel as the bigger letter and the other with a consonant as the bigger letter), two congruent trials (one made up of vowels and the other of consonants), and two identical trials positioned randomly throughout each block. Before the start of each block participants were instructed to either make a response regarding the bigger letter or the smaller ones for all the trials in that block. Each trial was preceded by a drift correction trial start, which required the participants to fixate on the fixation dot appearing in the middle of the screen. Upon fixating on the dot, the trial would start and one of the Navon images would appear on the screen for 500 ms, and was replaced by a black screen. Considering the type of the block, participants had to press either the green button (the “F” button on a keyboard) if the letter of focus was a vowel, and the red button (the “J” button on a keyboard) if it was a consonant. With the participants’ button press response, each trial ended and a feedback screen with the participants' points and response time for that trial would appear. Bonus points for each trial depended on both the accuracy and speed of responses. Participants were informed that they would receive 6.7 points for every second their response time was less than 5 seconds and lose 50 points if their response was inaccurate.

Throughout each trial, participants' right eye movements and pupil size was measured every 1 ms using an EyeLink 1000 desktop mount, with 32 × 25 degree tracking range and 1000 Hz frequency.

Results

The data for 5 more participants was not included in the analysis due to the participants' sleepiness or failure to successfully finish the task, bringing up the total number of our participants to $N = 65$. The remaining participants had an acceptable performance on the task with a mean response time of $M = 705.64$ ms, $SD = 394.25$, and an average of 92% accuracy on the responses. With 93.75% accuracy, participants in the Neutral condition had the highest percentage of accurate responses, followed by participants in the Mirth condition (92.69%), Elevation condition (92.15%), and finally the Sadness condition (89.09%). Overall, 14 (21.54%) of our participants were in the Mirth condition, 18 (27.7%) in the Elevation, 18 (27.7%) in the Neutral, and 15 (23.09%) in the Sadness condition. Moreover, data from participants' performance on the practice block may be used for visualization of participants' initial performance, but will not be included in the statistical analysis.

Congruency Effect

A two-way analysis of variance (ANOVA) was conducted to see whether participants' response time (ms) for each trial depended on the congruency of the image displayed in the trial (congruent or incongruent) and the block type (local or global) the trial belongs to. In trials with accurate responses, there was no main effect of block type on participants' response times ($p > .90$), and participants responded to trials in both global and local blocks with the same speed. However, in trials with inaccurate responses, participants were significantly faster in responding to trials in the local blocks ($F(1, 731) = 3.90$, $p = .049$).

Moreover, in trials with accurate responses, there was a significant main effect of trial congruency on participants' response time for a given trial ($F(1, 8878) = 16.88$, $p < .001$). Participants were significantly faster in accurately responding to congruent trials ($M = 666.70$, $SD = 4.21$) than incongruent trials ($M = 694.93$, $SD = 5.43$). The main effect of congruency on participants' response time was also significant for trials in which inaccurate responses were given ($F(1, 850) = 5.55$, $p = .019$), but in this case participants were faster in responding to incongruent ($M = 624.63$, $SD = 21.27$) trials than congruent trials ($M = 703.60$, $SD = 25.89$) . This indicates that the congruency effect of our stimuli was present only when the participants accurately identified the stimuli. Participants' response time as a factor of block type and congruency of the images are shown in Figure 5. Also, the interaction between the block type and trial congruency on participant's response time was insignificant ($p > .05$).

To further examine the congruency effect of the stimuli, another two way ANOVA was conducted to examine the effects of trial congruency and block type on the bonus points earned for each trial. With an F ratio of $F(1, 8878) = 17.44$, $p < .001$) the results of the ANOVA further support the congruency effect of the stimuli as participants received significantly more bonus points on congruent trials ($M = 28.89$, $SD = 0.03$) than on incongruent trials ($M = 28.71$, $SD = 0.03$). Neither the main effect of block type (global or local) nor the interaction between block type and congruency on the earned bonus points was significant ($p > .05$).

Global or Local Preference

To further investigate participants' general preference for local or global processing of information, we calculated a global/local preference score for each participant based on his/her initial performance on the task. Each participant's preference score was conceptualized as the difference in normalized (*Z* score) response time of the participants on incongruent trials belonging to the first two local blocks and the incongruent trials belonging to first two global blocks (including the practice block). More positive differences in Z_{RT} are indicative of preference for global processing (because the participant took longer to respond to incongruent local blocks compared to incongruent global blocks). Negative differences in Z_{RT} are indicative of preference for local processing of information. With an average preference score of ($M = 0.14$, $SD = 0.42$) our participants showed an initial slight preference for global processing of information.

Mood Induction Efficacy

Participants' self-reports of their feelings about the audio clips they listened to show that the clips successfully induced the desired mood in each participant. Table 1 shows the average rating for each question on the post-mood induction questionnaire. As seen in the table, on average, funny audio clips were rated the funniest (questions 6, 7 & 8), the elevation inducing clips were rated the most inspiring with the most positive message (questions 3, 4 & 5). Moreover, on average, the funny audio clips induced the strongest positive feelings followed by the inspiring audio clips, neutral and sad clips (question 1).

Mood-Induced Performance Changes

Changes in participants' performance due to mood induction was analyzed by comparing the participants' response times and bonus points gained on trials before and after the mood induction. First, we looked at the mood induced changes in performance on global and local blocks. A three-way ANOVA was conducted to see whether participants' response time (ms) for trials in global or local blocks changed before and after mood induction and whether such changes are unique to each mood induction. The results show that the main effect of block type (global or local) on participants' response time was almost significant ($F(1, 9601) = 3.64$, $p = .056$). Pairwise comparison of means indicate that overall participants were faster in responding to trials in local blocks ($M = 666.91$, $SD = 4.72$) than trials in global blocks ($M = 679.69$, $SD = 4.74$).

Moreover, the main effect of mood induction on response time was significant ($F(1, 9601) = 65.51$, $p < .001$).The pairwise comparison of response times before and after mood induction indicates that participants, on average, got $M = 52.90$ ms, $SD = 6.69$ faster in the task after the initial mood induction ($p < .05$). However, there was not a significant interaction between mood induction and block type on participants' response time for each trial. Participants were generally faster at responding to local blocks both before and after receiving mood induction.

Furthermore, the effect of type of mood induction on response time was also significant ($F(3, 9601) = 12.68$, $p < .001$). Post hoc Tukey analysis indicates that participants who listened to funny audio clips had the fastest responses ($p < .05$), followed by participants who listened to the sad audio clips ($p < .05$) followed by participants who listened to neutral and those who listened to the elevating audio clips. The difference in mean response time of participants belonging to the elevation and neutral mood induction categories was not significant. Moreover, although there was not a significant interaction between the type of the induced mood and the block type on participants' response time, as seen in Figure 6, after the first mood induction, participants who listened to the sad audio clips got significantly faster in responding to trials in local blocks compared to trials in global blocks. Also, participants who listened to inspiring audio clips, got faster to the same rate in responding to both global and local blocks.

To further investigate the changes in participants' performance, a three way ANOVA was conducted to examine the effects of block type, mood induction and the type of mood induction on the bonus points earned on each trial. With an *F* ratio of ($F(1, 9601) = 6.09$, $p = .01$) there was a significant main effect of mood induction on the bonus points received. Comparison of means indicate that participants received significantly more points post mood induction compared to before receiving the mood induction ($p < .05$). Furthermore, there was a main effect of type of the induced mood on participants' bonus points ($F(3, 9601) = 11.71$, $p < .001$). A post hoc Tukey analysis show that participants who listened to the funny audio clips ($M = 25.69$, $SD = .30$), participants who listened to inspiring audio clips ($M = 25.09$, $SD = .26$) and those received neutral mood induction ($M = 25.62$, $SD = .26$) scored significantly more points than participants who listened to sad ($M = 23.61$, $SD = .28$) audio clips. There was no significant interaction between any of the aforementioned variables. The post mood induction reduction in response time and increase in the earned bonus points between each mood induction category (regardless of the block type) are shown in figure 7.

Practice Induced Changes in Performance

Since the mood inductions occurred after the participants had successfully finished at least 10 blocks of the experiment (including an initial practice block) it is important to differentiate practice induced changes from mood induced changes in one's performance. As seen in Figure 8, participants got much faster on the task even in the blocks preceding the first mood induction, and the mood inductions only led to a greater variance in participants' response times in the blocks following each induction. As seen in the figure, participants in the sad, mirth and neutral conditions showed a shift in response time in the blocks immediately following each mood induction (mood inductions occurred after participants finished the 9^{th}, 12^{th} and 15^{th} block). For participants in the elevation condition, the shift in response time did not occur until the very last mood induction.

Changes in Pupil Size and Performance

The next step in our analysis was to examine the changes in pupil size and whether mood induction can influence such changes. We conceptualized pupil baseline of a given participant in a trial as the average pupil size of the participant for the first 100 ms of the trial. We also conceptualized pupil dilation for a given trial as the positive maximum deviation of the pupil size from the pupil baseline for a given trial. Next, to account for the physiological variances in pupil size among individuals we used standardized *Z* scores of the pupil baseline and pupil dilation for each individual.

A bivariate correlation analysis between participants' response time, bonus points, standardized pupil baseline and pupil dilations was performed. Our analysis showed that for trials with correct responses, pupil baseline on a trial is slightly correlated with participants' response time (r = 0.11, p < .001) and the bonus points earned on that trial (r = -0.11, p < .001) meaning that increases in pupil baseline were associated with increases in response time and consequently decreases in bonus points earned. Moreover, there was a moderate but significant negative correlation between pupil baseline and pupil dilation (r = -0.17, p < .001), showing that the increases in pupil baseline co-occurred with decreases in pupil dilation. Additionally, magnitude of the pupil dilation for correct trials were slightly correlated with response time (r = 0.07, p < .001) and bonus points earned (r = -0.07, p < .001). This indicated that the increases in pupil dilations co-occur with increases in response time and consequently decreases in bonus points earned.

Pupil Size Changes and Mood Induction,

We started our analysis of effects of mood induction on changes in pupil size by examining the effects of mood induction and the type of the induced mood on pupil base line and the magnitude of pupil dilations. The results of a two-way ANOVA examining the effects of mood induction and the type of mood induction showed that there was no significant main effect of the type of the induced mood on changes in magnitude of pupil dilations. However, there was a significant main effect of mood induction on participants' pupil dilation ($F(1,8874) = 3.91$, $p = .048$). Pairwise comparison of means showed that there was a significant decrease in mean pupil dilation post mood induction ($M = -.047$, $SD = .014$) relative to pupil dilation pre mood induction ($M = -.007$, $SD = .014$). Moreover, there was a significant interaction between mood induction and the type of the induced mood on magnitude of pupil dilation ($F(3,8874) = 3.03$, $p = .028$). As seen in Figure 9, for participants who listened to either inspiring or neutral audio clips, mood induction led to an increase in magnitude of pupil dilations. Whereas, for participants who listened to either sad or funny audio clips mood induction led to a decrease in pupil dilations.

Furthermore, a two-way ANOVA examining the effect of mood induction and type of the induced mood on pupil baseline in trials with accurate responses showed an almost significant main effect of the type of the induced mood ($F(3,8874) = 2.4$, $p = .062$) and a significant main effect of mood induction ($F(1,8874) = 1636.97$, $p < .001$). Pairwise analysis of means shows that there was a significant decrease in participants' pupil baseline post mood induction ($M = -0.48$, $SD = .01$) relative to their pupil size in trials before the mood induction ($M = .28$, $SD = .01$).

Furthermore, the interaction of type of the induced mood and mood induction on pupil baseline was significant ($F(3,8874) = 12.15$, $p < .001$). Comparison of pupil baseline means between each mood condition and mood induction showed that despite the post mood induction decrease in pupil baseline seen across the different mood conditions, on average, participants in the mirth condition showed the least amount of decrease in their pupil baseline. On average, in the pre-mood induction blocks participants in the mirth condition had the smallest pupil baseline while after the mood induction they had the largest pupil baseline compared to participants belonging to other mood conditions. Overall, it seems that although all participants showed a decrease in pupil baseline after mood induction, this decrease seemed to affect participants in the mirth condition the least. The changes in pupil baseline and pupil dilation for each mood are shown in Figure 9.

Changes in Pupil Size throughout the Experiment

As seen in Figure 10, the average pupil baseline of participants in each of the mood categories vary throughout the experiment. However, participants who listened to either sad, funny or inspiring audio clips showed a significant increase in pupil baseline in the blocks immediately following the first ($M = .30$, $SD = .051$, $p < .001$) and the third mood induction ($M = .33$, $SD = .051$, $p = .001$). This trend was not as pronounced for participants who listened to emotionally neutral audio clips.

Changes in magnitude of pupil dilations throughout the experiment for participants in each of the mood categories did not follow a specific pattern. As seen in Figure 11, there was a great deal of variance in the participants' mean pupil dilation of each block that was not associated with the timing of the mood inductions. However, as mentioned previously, participants in the neutral categories showed a general increase in the magnitude of their pupil dilations, while participants in the mirth and sadness categories showed a general decrease in the magnitude of their pupil dilation. Participants in the elevation category tend to have a general decrease in their pupil dilation in most of the blocks following the first mood induction, however, they also show a large but not significant increase in their pupil dilation during the very last block.

Regression Analysis of Mood, Pupil Size and Performance

In our next step of analysis, we examined the effects of the degree of mood induction on one's performance and pupil size changes. Instead of categorizing participants based on the type of audio clips they listened to, we ran a hierarchical regression analysis to see how well participants' responses for each of the post-mood induction questionnaire items predicted their pupil baseline, magnitude of pupil dilation, and response time.

Results of the regression analysis for responses to the post mood induction questionnaire items as predictors for pupil baseline are shown in Table 2. As seen in the table, ratings on the valence or the message of audio clips, how uplifting the clip was and the degree it made the participant laugh were all significant predictors of one's pupil baseline. It appears that funnier and more uplifting audio clips which induce more laughter in the participants lead to an increase in participant's pupil baseline.

Another hierarchical regression analysis of participants' responses to the post mood induction questionnaire's items as predictors for the magnitude of their pupil dilation was performed. As seen in Table 3, pupil dilation magnitude could very slightly be predicted by the responses to the questionnaire items. Only responses to questions regarding the valence of the clip, how funny it is and how much it made the participant smile were significant predictors of one's pupil dilation magnitude. Funnier audio clips with a more negative valence which made the participants smile more (but not laugh) lead to larger pupil dilations.

The final hierarchical regression analysis examined participants' responses to the questionnaire items as predictors for their response time on the trials. As seen in Table 4, only responses to questions regarding the message and valence of the audio clip were not significant predictors of the participant's response time. Funnier, more interesting, uplifting and engaging audio clips which made the participants laugh more (and smile less) lead to faster response times.

Discussion

In this experiment, we examined the effect of mood induction on global or local processing of stimuli as well as a potential link between mood induced changes in LC-NE activity and performance. Effects of mood induction on performance were present across all of the induced mood categories. Moreover, our analysis showed that specific moods are associated with specific patterns of changes in pupil size. Although the association between changes in pupil size and performance was slight, we may be able to link patterns of LC-NE activity to mood induced changes in performance.

Congruency Effect and Global or Local Processing

The analysis of participants' performance (as measured by their response time and bonus points) show that participants were generally faster in responding to congruent trials compared to incongruent ones. Faster responses to incongruent trials were associated with inaccurate responses. This shows that our stimuli successfully induced a congruency effect on participants' performance.

Moreover, our analysis of participants' initial preference for global or local processing of information demonstrated an initial slight tendency towards faster global processing of information. However, with more practice, participants got faster and received more points on trials belonging to the local blocks compared to global blocks. This finding is rather contradictory to the findings of Navon (1977) which supported people's tendency towards global processing of information. However, as mentioned previously, the general preference for global processing of information depends on many factors such as the size and angle of the stimuli. Since in our study, each trial started as soon as the participants stared at the drift correction dot, a point in the middle of the screen, it is possible that with more practice participants got better in shifting their attention from the drift correction dot in the middle of the screen to the smaller letters next to it (or even replacing it) when the trial started. In this way, participants will be much faster in making decisions regarding the smaller letters (in local blocks) than the bigger letter (in global blocks), especially since making judgments about the nature of the bigger letter required participants to retract their attention from the point in the middle and then focus it on the bigger letter.

Mood Induced Changes in Performance

Analysis of the influence of mood induction on participants' performance was rather mixed. Our initial analysis showed that regardless of the type of the induced mood participants got faster in the task after the initial mood induction. However, later analysis of participants' average response time for each block throughout the experiment showed that participants got much faster in the task even in the blocks preceding the mood induction. This leads us to believe, that the improvement in participants' performance was due to practice rather than mood induction.

Additionally, in our study mood induction did not cause a switch in participants' preference for global or local processing of information. Although participants generally got faster in responding to trials in both global and local blocks, they continued to have faster and more accurate responses to local blocks even after mood induction. Moreover, relative to participants in the other mood categories, participants who received the sadness mood induction had the least improvement in their response times for the trials in global blocks. In this way, we neither found a switch in processing of information (Cognitive Malleability Approach) nor encouragement of local processing of information (Affect-As-Information approach) caused by negative mood induction. Instead we found a mood induced inhibition of global processing of information unique to the negative mood induction. Moreover, participants who received the mirth or elevation mood inductions had an equal decrease in their response times for both global and local blocks after the mood induction. This may provide some support for Isbell and colleagues (2013) notion that positive moods do not cause a switch in the style of processing. Overall, instead of providing full support for either the Affect-As-Information approach or the Cognitive Malleability approach, we found evidence supporting some aspects of both of those approaches.

Mood Induced Changes in Pupil Size

Across all conditions, mood induction led to changes in both the magnitude of pupil dilations and the pupil baseline of participants.

Pupil dilation. Our results indicate that for participants who listened to either sad or very funny audio clips, mood induction led to decreases in pupil dilation. This reflects a decrease in LC-NE phasic activity caused by such emotionally valiant types of audio clips. However, for participants who listened to neutral or inspiring audio clips, mood induction led to an increase in pupil dilation. This may reflect a mood induced increase in LC-NE phasic activity and levels of task engagement.

Pupil baseline. Participants who listened to emotionally salient audio clips (mirth, elevation and sadness) showed an increase in their pupil baseline in the block immediately following the first and third mood induction. Since this trend was not as pronounced in participants who listened to neutral audio clips, we can conclude that this immediate increase in pupil baseline can be caused by emotional arousal. Moreover, in the blocks in between each mood induction there was a decrease in pupil size baseline across all mood conditions. Furthermore, our analysis of average pupil baseline in the blocks preceding or following the mood inductions indicated that participants had a general decease in their pupil baseline in the blocks following the mood inductions. However, for participants who listened to funny audio clips, the change in pupil baseline was less than that of participants in other mood conditions. This may reflect that listening to the emotionally salient audio clips led to an initial increase in distractibility and arousal followed by an increase in task engagement across all mood conditions.

Moreover, regression analysis of participants' self-report of their moods shows that higher amounts of laughter and emotional valiance were associated with a larger pupil baseline among participants. However, only funny audio clips which made the participant smile (and not laugh) predicted increased pupil dilation. This may be the differentiating factor between mood induced neurological changes between the two different positive moods, mirth and elevation. Decreases in pupil baseline in both conditions reflects that listening to audio clips may have increased engagement in the experiment overall. However, the additional decrease in pupil dilations among participants who listened to funny audio clips can be indicative of mirth induced higher levels of LC-NE tonic activity but not to the point of increased distractibility. On the other hand, as seen in the increase in pupil dilations and decrease in pupil baseline, listening to inspiring audio clips increased LC-NE phasic mode of activity and task engagement. Moreover, self-report of negative feelings caused by the audio clips were associated with lower pupil baseline. Such a decrease in pupil baseline, as well as decrease in pupil dilation seen among participants who listened to sad audio clips, may be indicative of lower than optimal levels of LC-NE tonic activity. Such low levels of LC-NE tonic activity among participants of this condition is also reflected in their higher response time and response error rate relative to participants of other mood conditions. Overall, each mood induction was associated with a specific pattern of changes in pupil size and performance. Mirth is linked to increased constructive LC-NE tonic activity, while elevation is associated with higher levels of LC-NE phasic activity and sadness co-occurs with lower than optimal levels of LC-NE tonic activity.

Limitations

One of our study's biggest limitations was that there were not any questions in the post mood induction questionnaire that directly measured people's levels of sadness. We could only measure our participants' levels of induced sadness from their responses on one question asking whether they had positive or negative feelings towards the clip. Adding a few questions specific to measuring levels of sadness will give our participants the opportunity to report their true induced emotions and will allow us to get a better sense of how the sad the audio clips made the participants feel.

In our study we failed to replicate the findings of Navon (1977) regarding participants' general tendency towards global processing of information. As mentioned earlier in the discussion, directing our participants' attention to the drift correction dot in the middle of the screen may have led us to unintentionally focus our participant's attention to the local stimuli at the beginning of each trial, making decision-making regarding the smaller letters (local blocks) much easier. In future studies, there should be at least a 1 second gap between disappearance of the drift correction dot and the start of each trial. In this way, participants' attention would not be directed towards the smaller letter at the beginning of each trial.

In this study we failed to replicate the strong correlations observed between changes in pupil size and performance prevalent in many pupilometry studies. Although our participants' magnitude of pupil dilations and pupil baseline were significantly negatively correlated, this correlation was very weak. Such slight but significant correlations were also seen between pupil dilations and response time, pupil dilations and bonus points and finally, pupil baseline and response time. We believe that such weak correlations may have been caused by two reasons. First, there were rather large calibration errors for many of our participants which may have added noise to their pupil data. Consequently the task irrelevant large variance in their pupil size within a trial may have made the identification of pupil dilations difficult. Second, our task consisted of major changes in the illumination of the screen and we measured participant's pupil size despite such changes. In our task, a big white letter that the participants had to look at was replaced by a completely black screen after 500 ms of display. Such a change from staring at a bright white object to a black screen may have led to physiologically induced, rather than cognitively induced, changes in pupil size. In future research, to maintain the same level of illumination throughout the trial, the white letter flashed on the screen should be replaces by an image of another white object such as a white square.

There was a difference between performance and pupil size changes of participants' in the Sadness mood condition and performance and pupil size changes of participants in the other mood conditions even prior to the first mood induction. We believe such initial difference between our Sadness group and the other participants may have been caused by the timing of their participation. Participants in the Mirth, Elevation and Neutral condition were run late in December (before Christmas) and two weeks after the Winter break, while participants in the sad condition were all run during the last week of January and the first week of February. We believe that the stress of midterms, cold and cloudy weather throughout January and February may have caused our participants in the Sadness condition to be sad even prior to starting the task or receiving a sad mood induction. Their initial sad mood prior to receiving a mood induction makes it difficult to compare their mood induced changes in performance and pupil size to a baseline level. Next time, we need to run all of our participants around the same time of year and preferably in the Fall or Spring season, when the weather or the scholastic requirements would not interfere with the mood of our participants.

Finally, this study should be repeated with a larger group of participants in each mood condition. Since we did not have sufficient number of participants in each mood category, we could not analyze the potential differences between groups regarding how well preferences for global or local processing of information are linked to participants' pupil dilation patterns.

Conclusion

In this experiment, we successfully found mood induced changes in our participants' performance and pupil dilation patterns. The observed pupil size changes specific to each type of induced mood supported the observed changes in one's performance. For instance, decreases in levels of LC-NE tonic activity to a less optimal level (as seen in decrease in pupil baseline and pupil dilations) seen in our participants who received a sad mood induction co-occurs with their higher response times and error rates compared to participants belonging to other mood conditions. This study can lead to future research regarding mood induced changes in patterns of LC-NE activity and one's performance.

References

Aston-Jones, G., & Cohen, J. D. (2005). An integrative theory of locus coeruleus-norepinephrine function: adaptive gain and optimal performance. *Annual Review of Neuroscience*, *28*(1), 403–450. doi:10.1146/annurev.neuro.28.061604.135709

Aston-Jones, G., Foote, S.L., Segal, M. (1985). Impulse conduction properties of noradrenergic locus coeruleus axons projecting to monkey cerebrocortex. *Neuroscience 15,*765–77

Aston-Jones, G., Rajkowski, J., & Cohen, J. (1999). Role of locus coeruleus in attention and behavioral flexibility. *Biological Psychiatry*, *46*(9), 1309–20. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10560036

Aston-Jones G., Rajkowski J., Kubiak P., Alexinsky T. (1994). Locus coeruleus neurons in the monkey are selectively activated by attended stimuli in a vigilance task. *J. Neurosci.* 14:4467–80

Aston-Jones, G., Rajkowski, J., Kubiak, P., Valentino, R. J., & Shipley, M. T. (1996). Role of the locus coeruleus in emotional activation. *Progress in Brain Research*, *107*, 379–402. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8782532

Aston-Jones, G., Rajkowski J., Lu, W., Zhu, Y., Cohen, J.D., Morecraft, R.J. (2002). Prominent projections from the orbital prefrontal cortex to the locus coeruleus in monkey. *Soc. Neurosci. Abstr. 28*, 86–9

Auer, D. P., Pütz, B., Kraft, E., Lipinski, B., Schill, J., & Holsboer, F. (2000). Reduced glutamate in the anterior cingulate cortex in depression: an in vivo proton magnetic resonance spectroscopy study. *Biological Psychiatry, 47*(4), 305–13. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10686265

Baker, S. C., Frith, C. D., & Dolan, R. (1997). The interaction between mood and cognitive function studied with PET. *Psychological Medicine*, *27*, 565–578.

Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. *Psychological bulletin*, *91*(2), 276.

Beatty, J., & Wagoner, B. L. (1978). Pupillometric signs of brain activation vary with level of cognitive processing. *Science*, *199*(4334), 1216-1218.

Bechara, a, Damasio, H., & Damasio, a R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex (New York, N.Y. : 1991)*, *10*(3), 295–307. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10731224

Beer, J. S., Heerey, E. a, Keltner, D., Scabini, D., & Knight, R. T. (2003). The regulatory function of self-conscious emotion: insights from patients with orbitofrontal damage. *Journal of Personality and Social Psychology*, *85*(4), 594–604. doi:10.1037/0022-3514.85.4.594

Bless, H. (2001). Mood and the use of general knowledge structures. *Theories of mood and cognition: A user's guidebook*, 9-26. Bless, H. (2001). Mood and the use of general knowledge structures. *Theories of mood and cognition: A user's guidebook*, 9-26.

Bodenhausen, G. V., Kramer, G. P., & Süsser, K. (1994). Happiness and stereotypic thinking in social judgment. *Journal of personality and social psychology*, *66*(4), 621.Last Name, F.

Bremner, J. D., Vythilingam, M., Vermetten, E., Nazeer, A., Adil, J., Khan, S., … Charney, D. S. (2002). Reduced volume of orbitofrontal cortex in major depression. *Biological Psychiatry*, *51*(4), 273–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11958777

Brown, J. W., & Braver, T. S. (2005). Learned predictions of error likelihood in the anterior cingulate cortex. *Science (New York, N.Y.)*, *307*(5712), 1118–21. doi:10.1126/science.1105783

Brown, J. W., & Braver, T. S. (2007). Risk prediction and aversion by anterior cingulate cortex. *Cognitive, Affective & Behavioral Neuroscience*, *7*(4), 266–77. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18189000

Bush, G., Luu, P., & Posner, M. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, *4*(6), 215–222. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10827444

Cedarbaum, J. M., & Aghajanian, G. K. (1978). Afferent projections to the rat locus coeruleus as determined by a retrograde tracing technique. *The Journal of Comparative Neurology*, *178*(1), 1–16. doi:10.1002/cne.901780102

Clore, G. L., Gasper, K., & Garvin, E. (2001). Affect as information. In JP Forgas (Ed.), Handbook of affect and social cognition. (pp. 121–144). Mahwah, NJ: Erlbaum.

Critchley HD, Rolls ET. 1996. Hunger and satiety modify the responses of olfactory and visual neurons in the primate orbitofrontal cortex. *J. Neurophysiol.* 75:1673–86

Dougherty, D. D., Shin, L. M., Alpert, N. M., Pitman, R. K., Orr, S. P., Lasko, M., … Rauch, S. L. (1999). Anger in healthy men: a PET study using script-driven imagery. *Biological Psychiatry*, *46*(4), 466–72. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10459395

Eldar, E., Cohen, J. D., & Niv, Y. (2013). The effects of neural gain on attention and learning. *Nature Neuroscience*, *16*(8), 1146–53. doi:10.1038/nn.3428

Frank, M. J., Woroch, B. S., & Curran, T. (2005). Error-related negativity predicts reinforcement learning and conflict biases. *Neuron*, *47*(4), 495-501.

Fredrickson, B. L. (1998). What good are positive emotions?. *Review of general psychology*, *2*(3), 300.

Gasper, K., & Clore, G. L. (2002). Attending to the big picture: Mood and global versus local processing of visual information. *Psychological Science*, *13*(1), 34-40.

Gilzenrat M.S., Cohen J.D., Rajkowski J., & Aston-Jones G. (2003). Pupil dynamics predict changes in task engagement mediated by locus coeruleus. *Soc. Neurosci. Abstr.* No. 515.19

Gilzenrat, M. S., Nieuwenhuis, S., Jepma, M., & Cohen, J. D. (2010). Pupil diameter tracks changes in control state predicted by the adaptive gain theory of locus coeruleus function. *Cognitive, Affective & Behavioral Neuroscience*, *10*(2), 252–69. doi:10.3758/CABN.10.2.252

Hewig, J., Trippe, R., Hecht, H., Coles, M. G., Holroyd, C. B., & Miltner, W. H. (2007). Decision-making in Blackjack: an electrophysiological analysis.*Cerebral Cortex*, *17*(4), 865-877.

Isbell, L. M., Lair, E. C., & Rovenpor, D. R. (2013). Affect-as-Information about Processing Styles: A Cognitive Malleability Approach. *Social and Personality Psychology Compass*, *7*(2), 93–114.

Jepma, M., & Nieuwenhuis, S. (2011). Pupil diameter predicts changes in the exploration-exploitation trade-off: evidence for the adaptive gain theory. *Journal of Cognitive Neuroscience*, *23*(7), 1587–1596. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20666595

Jones, B. E., & Moore, R. Y. (1977). Ascending projections of the locus coeruleus in the rat. II. Autoradiographic study. *Brain Research*, *127*(1), 25–53. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/301051

Jones, B. E., & Yang, T. Z. (1985). The efferent projections from the reticular formation and the locus coeruleus studied by anterograde and retrograde axonal transport in the rat. *The Journal of Comparative Neurology*, *242*(1), 56–92. doi:10.1002/cne.902420105

Kahneman, D., & Beatty, J. (1966). Pupil diameter and load on memory.*Science*, *154*(3756), 1583-1585. doi: 10.1126/science.154.3756.1583

Kim, H., Shimojo, S., & O'Doherty, J. P. (2006). Is avoiding an aversive outcome rewarding? Neural substrates of avoidance learning in the human brain.*PLoS biology*, *4*(8), e233.

Kimchi, R. (1992). Primacy of wholistic processing and global/local paradigm: a critical review. *Psychological bulletin*, *112*(1), 24–38. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1529037

Kimchi, R. (1988). Selective attention to global and local levels in the comparison of hierarchical patterns. *Perception and Psychophysics,43,* 189-198.

Kimchi, R., & Palmer, S. E. (1985). Separability and integrality of global and local levels of hierarchical patterns. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 673-688.

Kinchla, R. A, & Wolfe, J. M. (1979). The order of visual processing: "Top down," "bottom up" or "middle-out." *Perception and Psychophysics, 25,* 225-231.

Kuchinke, L., Võ, M. L.-H., Hofmann, M., & Jacobs, A. M. (2007). Pupillary responses during lexical decisions vary with word frequency but not emotional valence. *International Journal of Psychophysiology*, *65*(2), 132–140. doi:10.1016/j.ijpsycho.2007.04.004

Lane, R. D., Weidenbacher, H., Smith, R., Fort, C., Thayer, J. F., & Allen, J. J. B. (2013). Subgenual anterior cingulate cortex activity covariation with cardiac vagal control is altered in depression. *Journal of Affective Disorders*, *150*(2), 565–70. doi:10.1016/j.jad.2013.02.005

Lei, L. G., Sun, S., Gao, Y. J., Zhao, Z. Q., & Zhang, Y. Q. (2004). NMDA receptors in the anterior cingulate cortex mediate pain-related aversion. *Experimental neurology*, *189*(2), 413-421.

Luu, P., Collins, P., & Tucker, D. M. (2000). Mood, personality, and self-monitoring: negative affect and emotionality in relation to frontal lobe mechanisms of error monitoring. *Journal of Experimental Psychology. General*, *129*(1), 43–60. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10756486

Miguel-Hidalgo, J. J., Whittom, A., Villarreal, A., Soni, M., Meshram, A., Pickett, J. C., ... & Stockmeier, C. A. (2014). Apoptosis-related proteins and proliferation markers in the orbitofrontal cortex in major depressive disorder. *Journal of Affective Disorders*.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology*, *9*, 353–383. Retrieved from http://www.sciencedirect.com/science/article/pii/0010028577900123

Navon, D., & Norman, J. (1983). Does global precedence really depend on visual angle? *Journal of Experimental Psychology: Human Perception and Performance, 9,* 955-965.

Nygren, L. G., & Olson, L. (1977). A new major projection from locus coeruleus: the main source of noradrenergic nerve terminals in the ventral and dorsal columns of the spinal cord. *Brain Research*, *132*(1), 85-93.

O'Doherty, J. P. (2004). Reward representations and reward-related learning in the human brain: insights from neuroimaging. *Current Opinion in Neurobiology*, *14*(6), 769–76. doi:10.1016/j.conb.2004.10.016

O'Doherty, J. P., Deichmann, R., Critchley, H. D., & Dolan, R. J. (2002). Neural responses during anticipation of a primary taste reward. *Neuron*, *33*(5), 815–26. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11879657

O'Doherty, J., Kringelbach, M. L., Rolls, E. T., Hornak, J., & Andrews, C. (2001). Abstract reward and punishment representations in the human orbitofrontal cortex. *Nature Neuroscience*, *4*(1), 95–102. doi:10.1038/82959

O'Neill, W. D., & Zimmermann, S. (2000). Neurological interpretations and the information in the cognitive pupillary response. *Methods of information in medicine*, *39*(2), 122-124.

Papesh, M. H., & Goldinger, S. D. (2012). Pupil-BLAH-metry: Cognitive effort in speech planning reflected by pupil dilation. *Attention Perception Psychophysics*, *74*(4), 1–12. doi:10.3758/s13414-011-0263-y

Paquet, L., & Merikle, P. M. (1984). Global precedence: The effect of exposure duration. *Canadian Journal of Psychology, 38,* 45-53.

Pomerantz, J. R. (1983). Global and local precedence: selective attention in form and motion perception. *Journal of Experimental Psychology. General*, *112*(4), 516–40. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6229597

Privitera, C. M., Renninger, L. W., Carney, T., Klein, S., & Aguilar, M. (2010). Pupil dilation during visual target detection. *Journal of Vision*, *10*(10), 3. doi:10.1167/10.10.3.Introduction

Rajkowski, J., Kubiak, P., & Aston-Jones, G. (1993). Correlations between locus coeruleus (LC) neural activity, pupil diameter and behavior in monkey support a role of LC in attention. In *Society for Neuroscience Abstracts 19*, (p. 974).

Rajkowski, J., Lu, W., Zhu, Y., Cohen, J., Aston-Jones, G. (2000). Prominent projections from the anterior cingulate cortex to the locus coeruleus in Rhesus monkey. *Soc. Neurosci. Abstr. 26*, 838–15

Riceberg, J. S., & Shapiro, M. L. (2012). Reward stability determines the contribution of orbitofrontal cortex to adaptive behavior. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *32*(46), 16402–9. doi:10.1523/JNEUROSCI.0776 12.2012

Rogawski, M. A., & Aghajanian, G. K. (1982). Activation of lateral geniculate neurons by locus coeruleus or dorsal noradrenergic bundle stimulation: Selective blockade by the alpha 1-adrenoceptor antagonist prazosin. *Brain research*, *250*(1), 31-39.

Rolls, E.T., Critchley, H.D., Mason, R.,Wakeman, E.A. (1996). Orbitofrontal cortex neurons: role in olfactory and visual association learning. *J. Neurophysiol.* 75(1), 1970–81

Servan-Schreiber, D., Printz, H., & Cohen, J. D. (1990). A network model of catecholamine effects: gain, signal-to-noise ratio, and behavior. *Science*,*249*(4971), 892-895.

Schoenbaum, G., Roesch, M. R., Stalnaker, T. A., & Takahashi, Y. K. (2009). A new perspective on the role of the orbitofrontal cortex in adaptive behaviour.*Nature Reviews Neuroscience*, *10*(12), 885-892.

Siegle, G. J., Steinhauer, S. R., & Thase, M. E. (2004). Pupillary assessment and computational modeling of the Stroop task in depression. *International Journal of Psychophysiology*, *52*(1), 63–76. doi:10.1016/j.ijpsycho.2003.12.010

Steinhauer, S. R., Siegle, G. J., Condray, R., & Pless, M. (2004). Sympathetic and parasympathetic innervation of pupillary dilation during sustained processing. *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology*, *52*(1), 77–86. doi:10.1016/j.ijpsycho.2003.12.005

Strohminger, N., Lewis, R. L., & Meyer, D. E. (2011). Divergent effects of different positive emotions on moral judgment. *Cognition*, *119*(2), 295–300. doi:10.1016/j.cognition.2010.12.012

Verney, S. P., Granholm, E., & Marshall, S. P. (2004). Pupillary responses on the visual backward masking task reflect general cognitive ability. *International Journal of Psychophysiology*, *52*(1), 23–36. doi:10.1016/j.ijpsycho.2003.12.003

Waterhouse, B. D., & Woodward, D. J. (1980). Interaction of norepinephrine with cerebrocortical activity evoked by stimulation of somatosensory afferent pathways in the rat. *Experimental neurology*, *67*(1), 11-34.

Williams J.T., Henderson G., North R.A. (1985). Characterization of alpha 2-adrenoceptors which increase potassium conductance in rat locus coeruleus neurons. *Neuroscience* 14:95–101

Zhu Y., Iba M., Rajkowski J., Aston-Jones G. (2004). Projection from the orbitofrontal cortex to the locus coeruleus in monkeys revealed by anterograde tracing. *Soc. Neurosci. Abstr.* 30:211.3

Tables

Table 1

Self-Report Mean Ratings of the Effects of the Mood Inducing Clips

Response #	Question Type	Mirth (SD)	Elevation (SD)	Neutral (SD)	Sadness (SD)
Response 1	Valence	3.87 (0.82)	3.55 (1.0)	3.18 (0.71)	1.82 (0.97)
Response 2	Engaging	3.78 (0.98)	3.57 (1.01)	3.20 (1.17)	3.69 (0.88)
Response 3	Uplifting	3.46 (1.03)	3.47 (0.79)	2.05 (0.98)	1.39 (0.8)
Response 4	Warmth	2.57 (1.18)	3.37 (1.0)	1.87 (0.9)	1.97 (1.13)
Response 5	Message	3.48 (0.93)	4.20 (0.84)	3.11 (0.7)	2.16 (0.92)
Response 6	Funny	3.56 (0.98)	1.00 (0.0)	1.70 (1.06)	1.05 (0.21)
Response 7	Laughing	2.82 (1.19)	1.06 (0.24)	1.39 (0.81)	1.00 (0.0)
Response 8	Smiling	3.52 (1.20)	1.96 (1.03)	1.77 (1.07)	1.22 (0.64)
Response 9	Interesting	3.49 (1.12)	3.44 (1.10)	3.13 (1.09)	3.44 (1.04)

Note: The responses were based on a 1-5 likert scale with higher numbers meaning higher degrees of the variable.

Table 2

Regression Analysis of Each Post-mood Induction Questionnaire and Pupil Baseline

Response	Question Type	*B*	*SE B*	β
Response1	Valence	-.080***	.019	-.102
Response2	Engaging	.013	.020	.01
Response3	Uplifting	.11***	.021	.16
Response4	Warmth	.004	.017	.006
Response5	Message	-.040*	.020	-.05
Response6	Funny	-.056*	.025	-.08
Response7	Laughing	.097**	.030	.11
Response8	Smiling	.003	.020	.004
Response9	Interesting	-.03	.019	-.038

Note: * $p < .05$, ** $p < .01$, *** $p < .001$

Table 3

Regression Analysis of Each Post-mood Induction Questionnaire and Pupil Dilation

Response	Question Type	*B*	*SE B*	β
Response1	Valence	-.038*	.019	-.047
Response2	Engaging	-.014	.021	-.015
Response3	Uplifting	.041	.021	.056
Response4	Warmth	-.029	.017	-.038
Response5	Message	.001	.020	.001
Response6	Funny	-.058*	.026	-.078
Response7	Laughing	-.005	.031	-.005
Response8	Smiling	.051*	.021	.072
Response9	Interesting	.032	.019	.038

Note: * $p < .05$, ** $p < .01$, *** $p < .001$

Table 4

Regression Analysis of Each Post-mood Induction Questionnaire and Response Time

Response	Question Type	*B*	*SE B*	β
Response1	Valence	-6.87	6.82	-.024
Response2	Engaging	19.6**	7.38	.062
Response3	Uplifting	15.09*	7.54	.058
Response4	Warmth	-17.26**	6.10	-.063
Response5	Message	-3.66	7.16	-.012
Response6	Funny	-19.01*	9.19	-.071
Response7	Laughing	-22.36*	10.90	-.069
Response8	Smiling	30.86***	7.34	.122
Response9	Interesting	-26.09***	6.89	-.087

Note: * $p < .05$, ** $p < .01$, *** $p < .001$

Figures

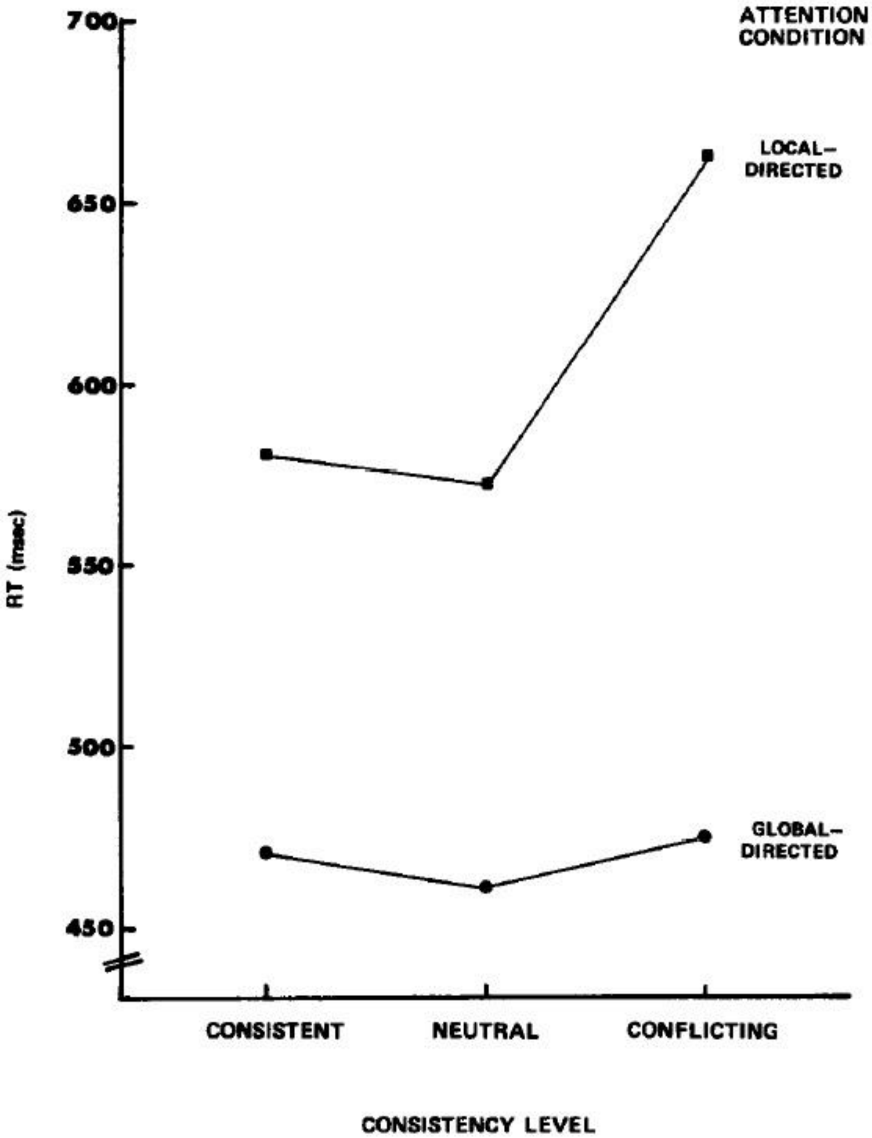


Figure 1. Increased response time for conflicting images when participants are directed to focus on and identify the local stimuli (Navon, 1977).

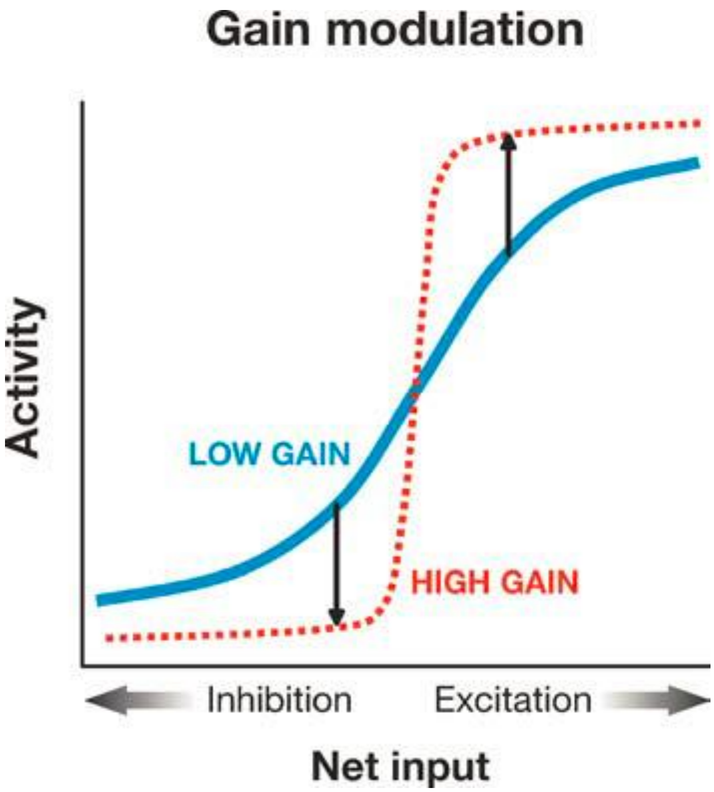


Figure 2. Effect of gain on the output and input of a neuron. High gain results in further excitation of moderately excited neurons and further inhibition of moderately inhibited neurons. Adapted from Servan-Schreiber, Printz and Cohen (1990).

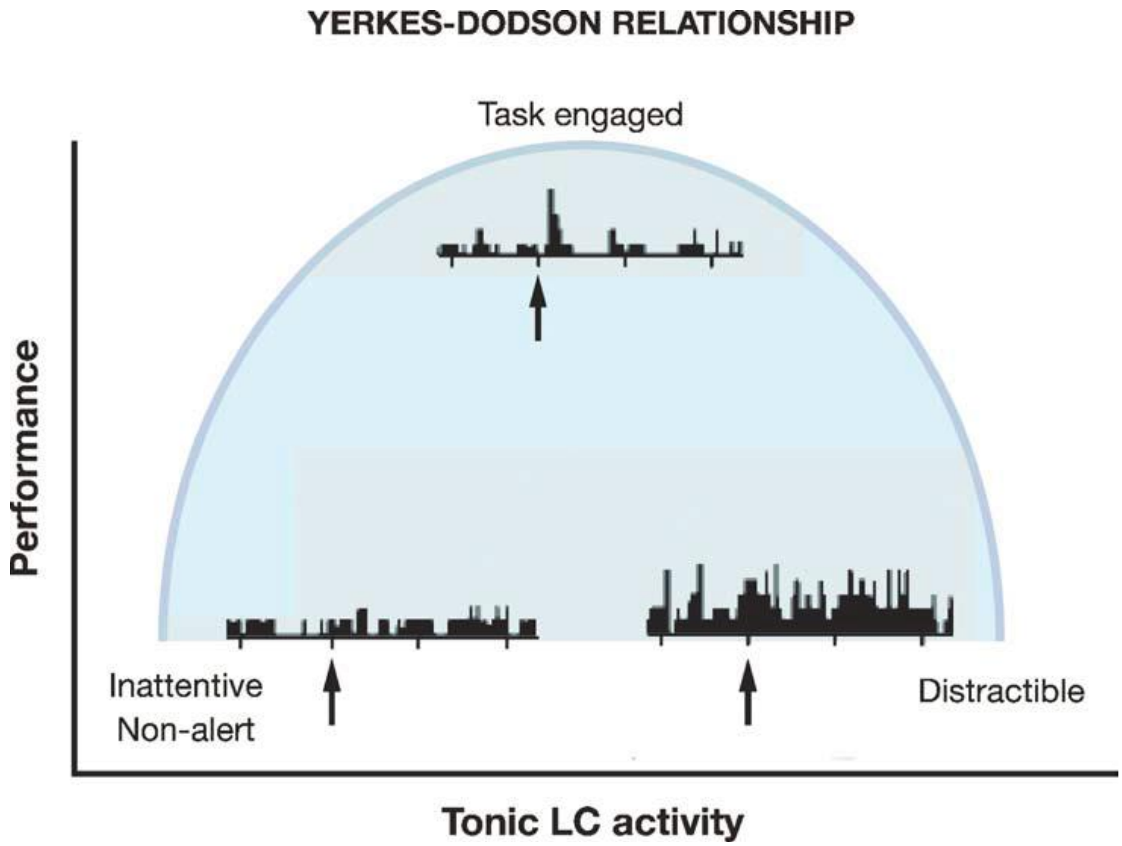


Figure 3. The inverted U shape relationship between LC tonic activity and performance. Lower levels of LC tonic activity leads to drowsiness, while higher levels of LC tonic activity leads to distractibility, and both conditions result in poor task performance. Therefore, LC tonic activity needs to be maintained at moderate levels (higher LC phasic activity) to increase task engagement and gain optimal performance on the task. (Aston-Jones, Rajkowski, & Cohen, 1999).

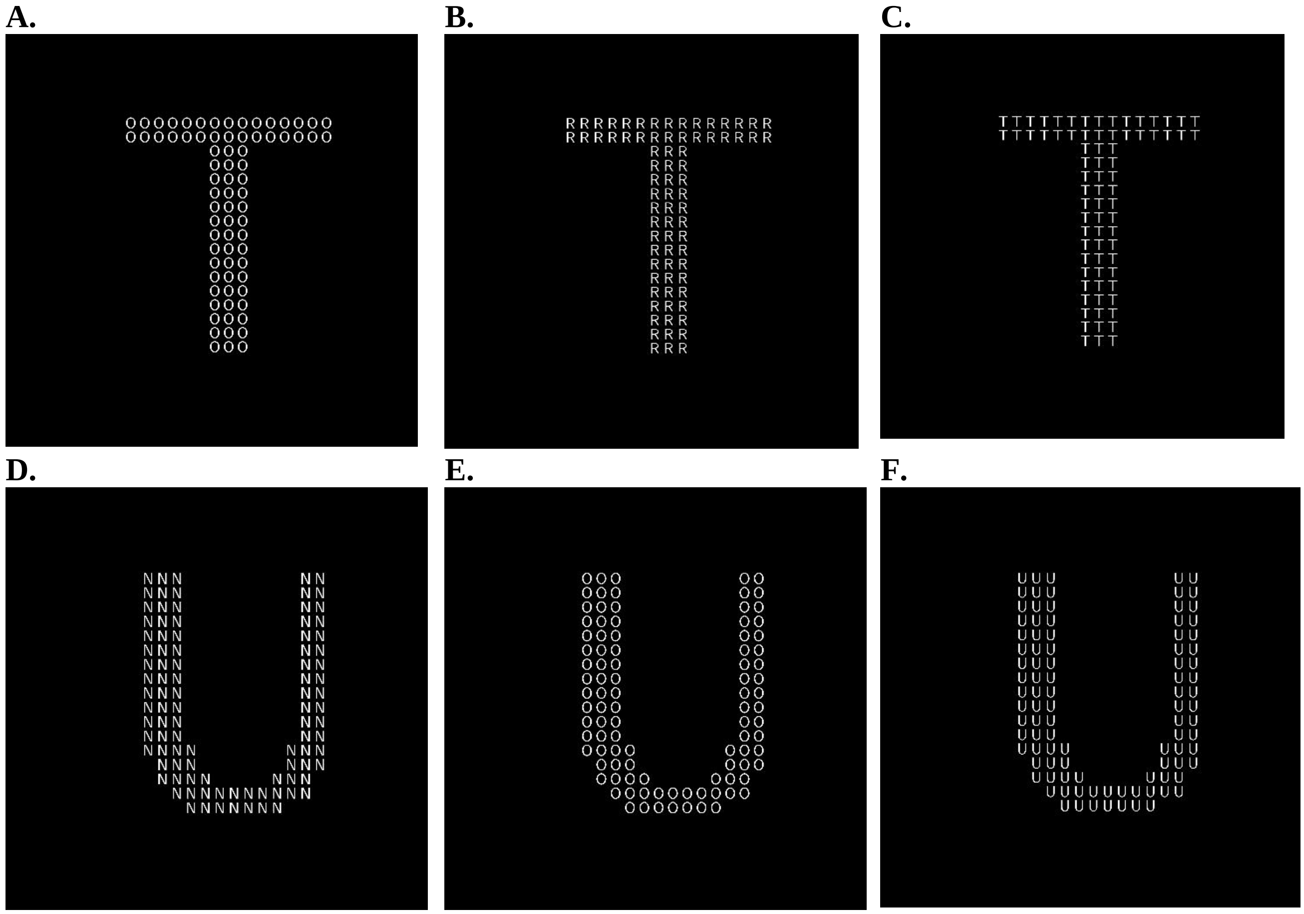
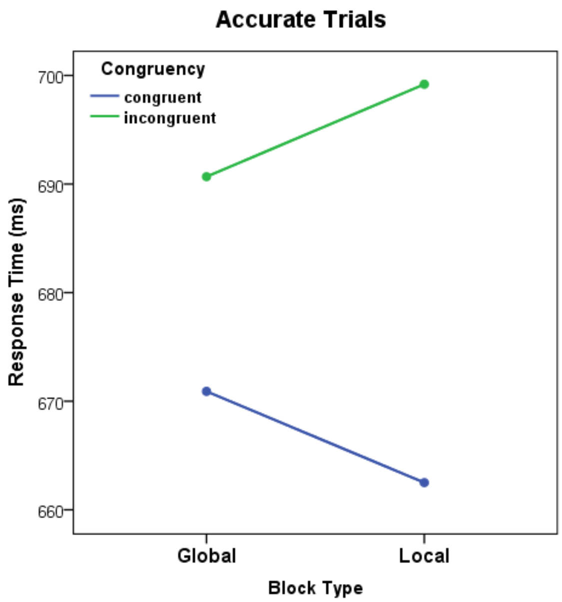


Figure 4. The Navon images used in the experiment. A) An incongruent trial consisting of a consonant as the bigger image and a vowel as the smaller ones. B) A congruent trial with different consonants forming the bigger image and the smaller ones. C) An image made up of identical consonants. D) An incongruent trial consisting of a vowel as the bigger image and a consonant as the smaller ones. B) A congruent trial with different vowels forming the bigger image and the smaller ones. C) An image made up of identical vowels.

A.



B.

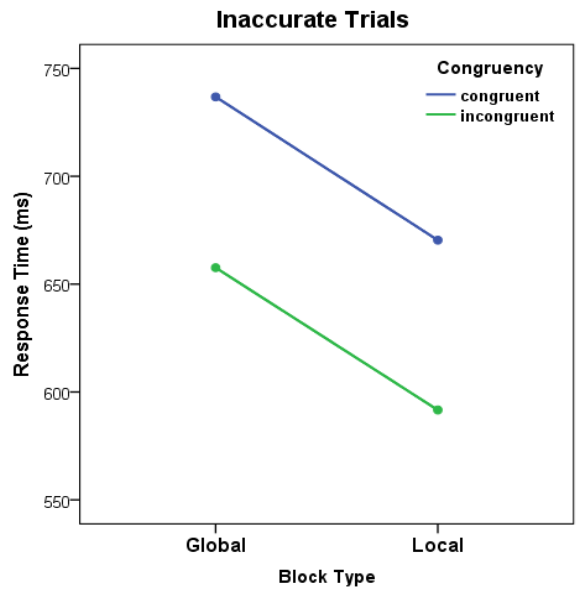


Figure 5. Participants' response time in congruent and incongruent trials belonging to either global to local blocks. As seen in Figure 5A, participants are much faster in correctly responding to congruent trials than incongruent trials. However, as seen in Figure 5B, inaccurate responses are associated with a much faster responses for incongruent trials. Moreover, although the effect is not significant, regardless of the accuracy of the responses, participants seem to be faster in making a decision regarding the smaller letters (local blocks) than the bigger letter (global blocks).

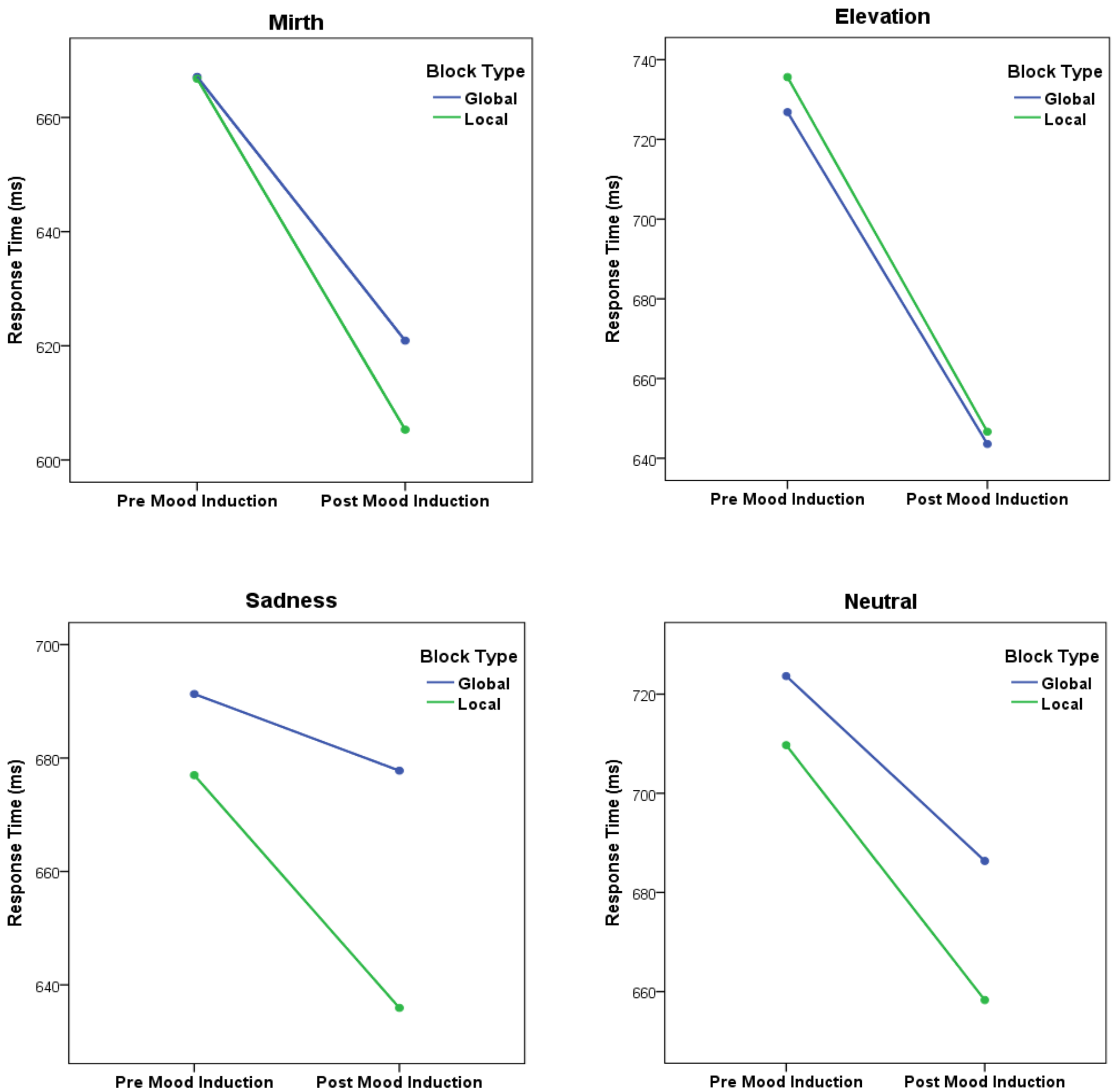


Figure 6. The response time for each trial based on the block type the trial belongs to and whether or not the participant has received mood induction, categorized based on the type of mood induction received. As seen in the figure, participants get faster in responding to trials in both global and local blocks after the mood induction.

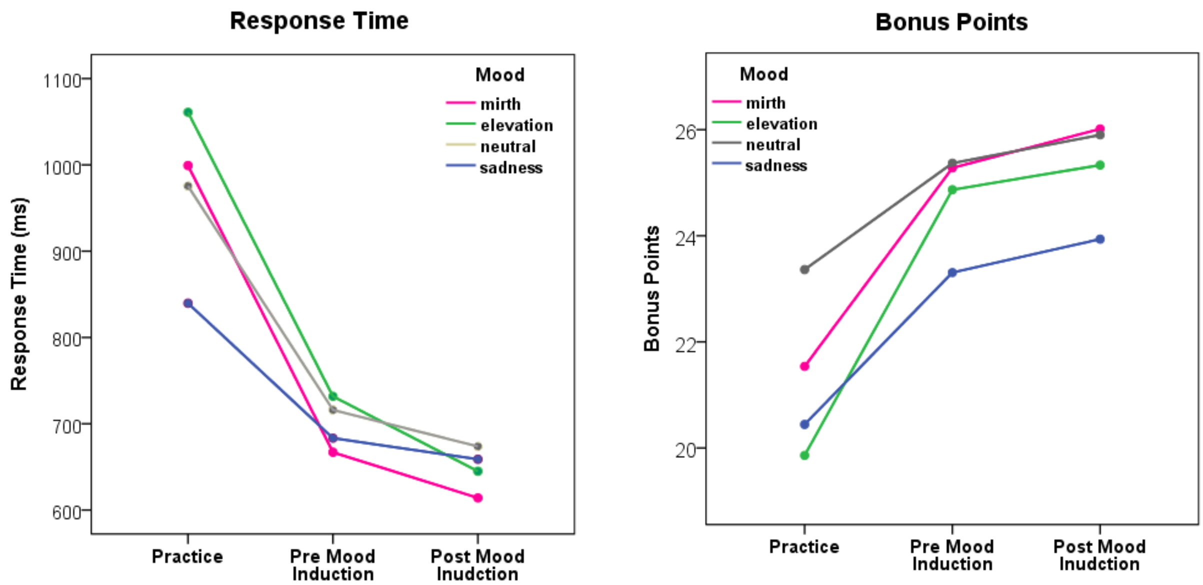


Figure 7. The changes in participants' response time and the bonus points earned for each trial during the practice block, before and after mood induction. As seen in the graph, relative to people who received other types of mood induction, participants who were induced sad moods had a lower response time during the practice block and even before the mood induction. They also tended to gain the least scores throughout the experiment. Moreover, participants who received the mirth mood induction, had the highest increase in their bonus points and the greatest reduction in their response time on the task.

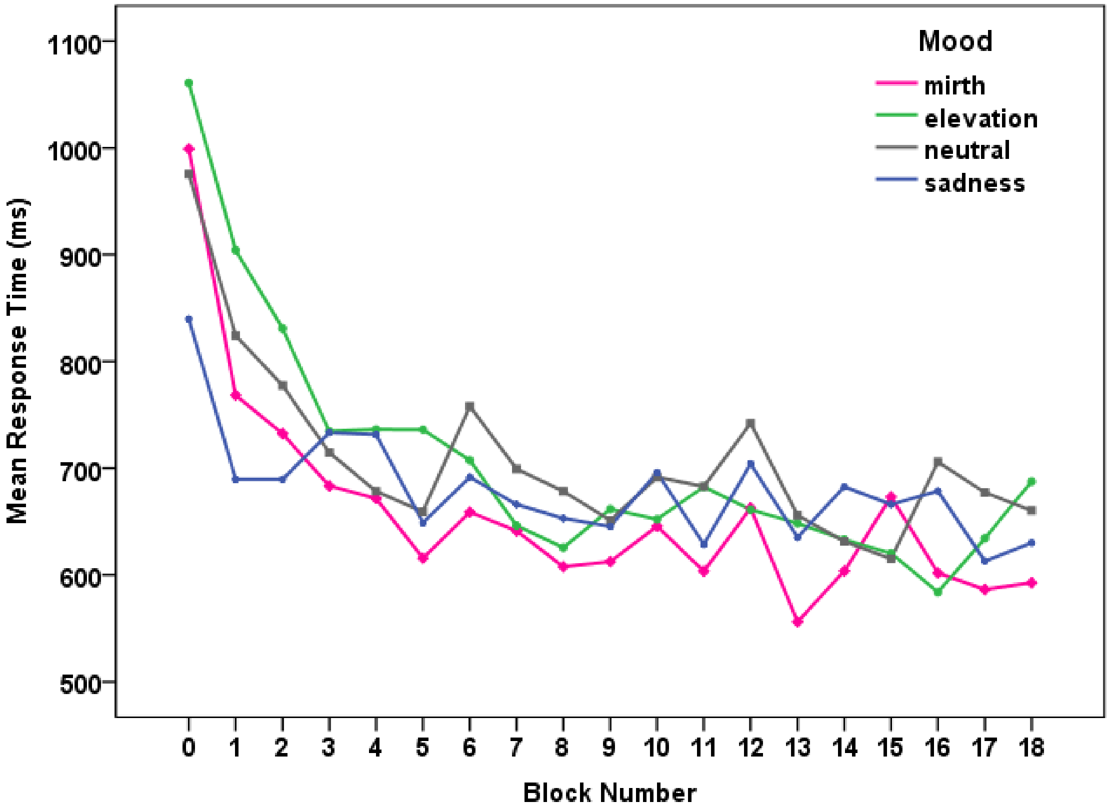


Figure 8. Mean block response time of participants belonging to each mood category. As seen in the figure, with more practice participants got much faster on the task prior to mood induction. However, the mood inductions led to subtle changes in participants' response times in blocks following each induction (mood inductions occurred after the 9th, 12tha and the 15th block).

.

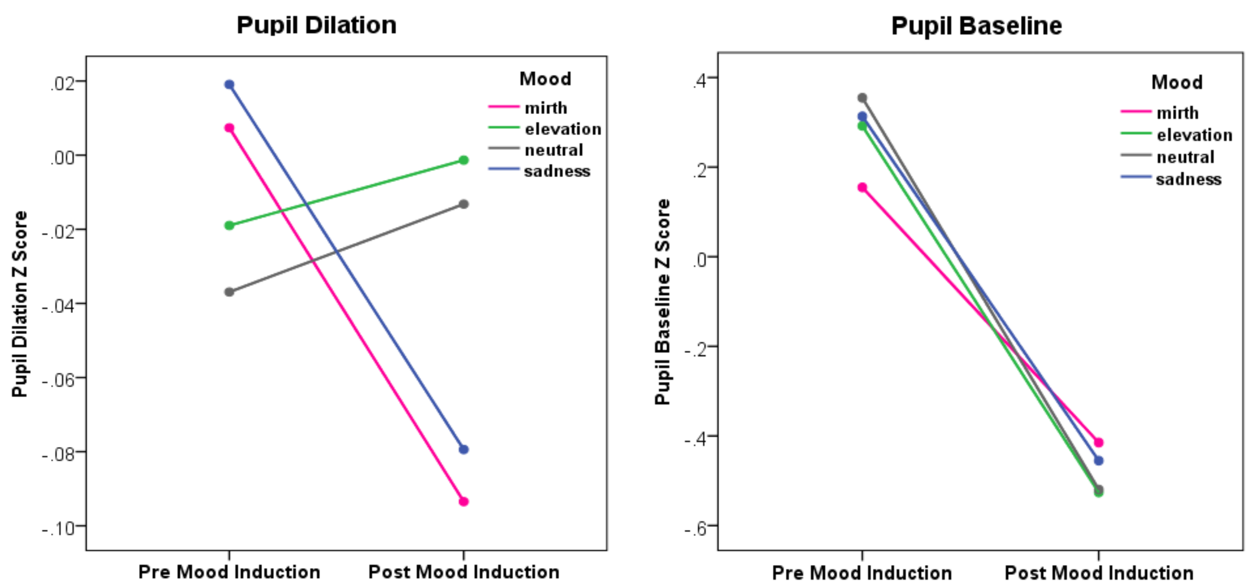


Figure 9. Mood induced changes in pupil dilation (on the left) and pupil baseline (on the right) for participants in each mood induction category.

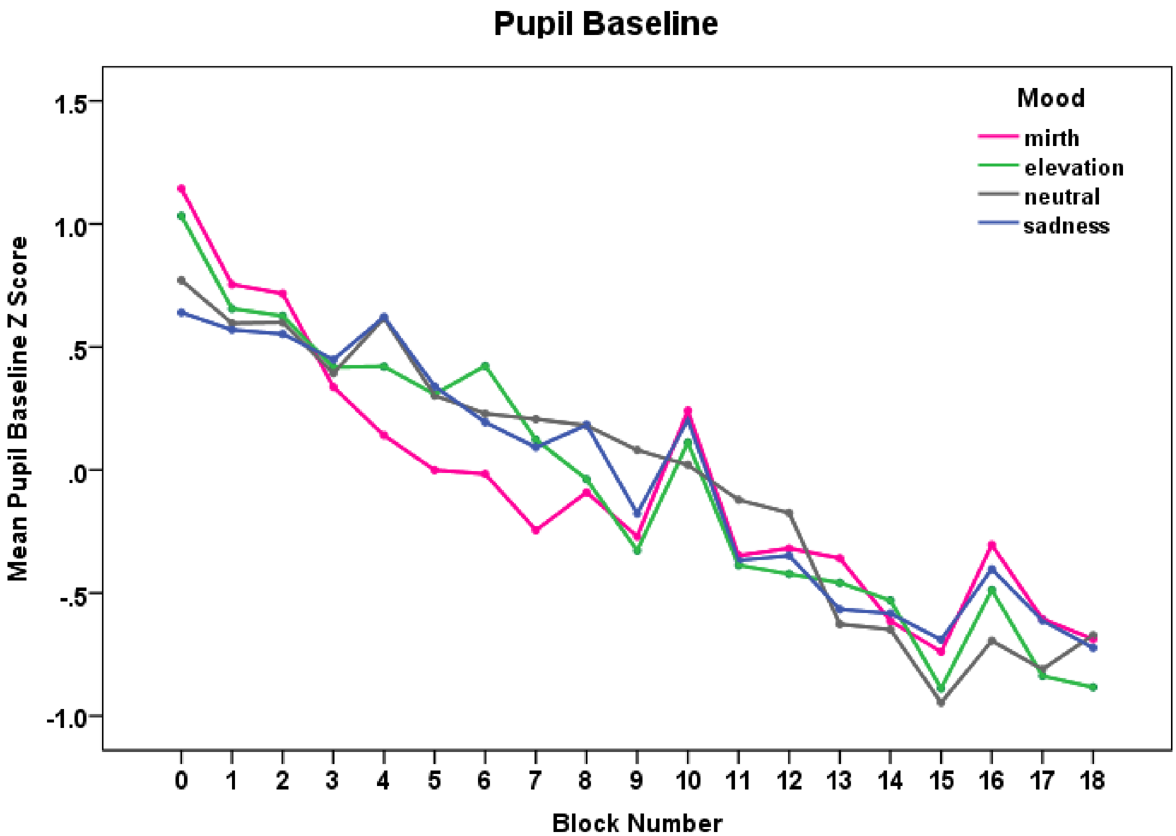


Figure 10. The mean pupil baseline Z score of each block for participants belonging to each of the four mood induction categories. As seen in the figure, only emotionally salient audio clips led to a large increase in pupil baseline in the blocks immediately following mood induction.

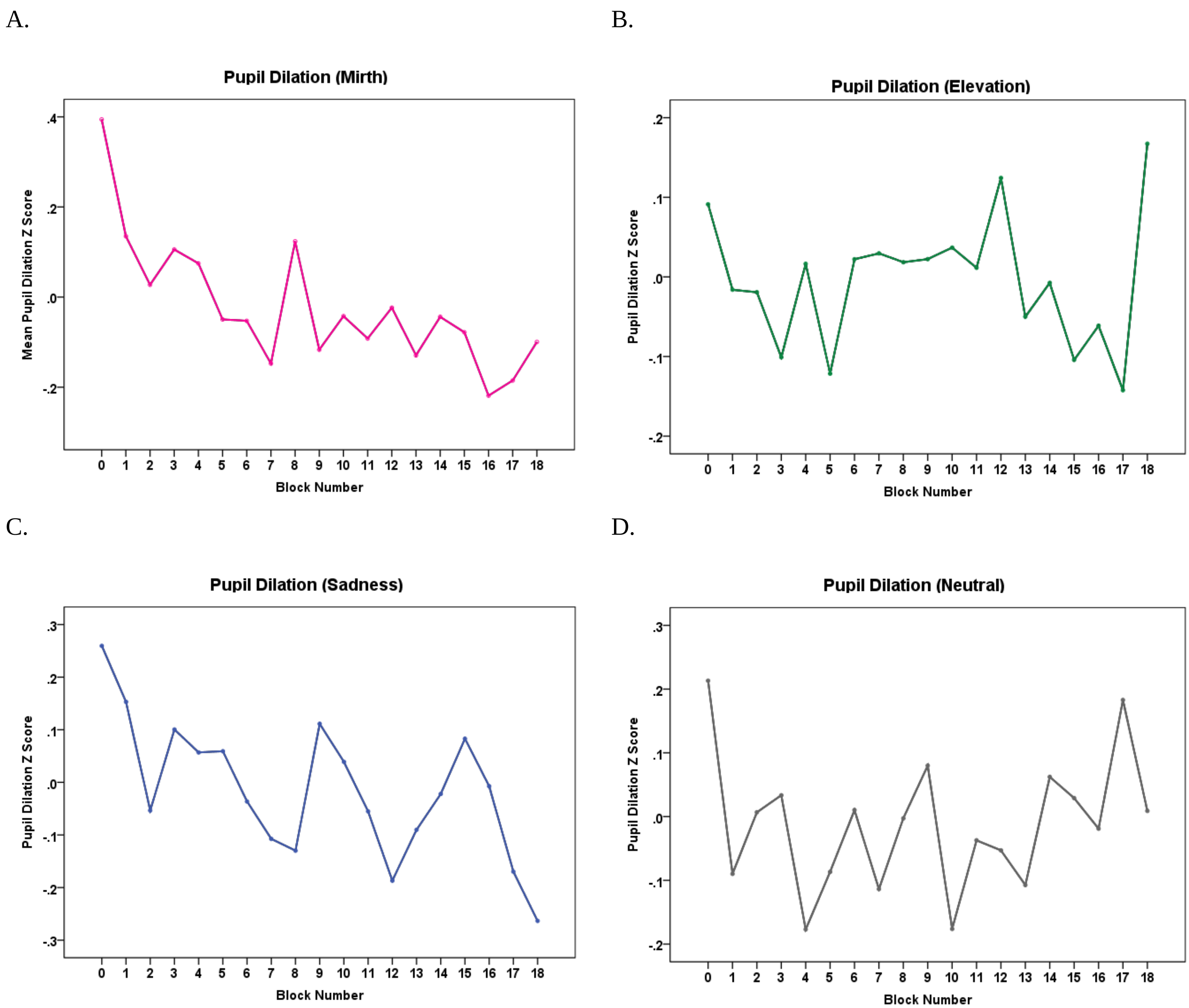


Figure 11. Changes in mean pupil dilation in each block for participants belonging to each of the four mood categories.

Appendix A

Post Mood Induction Questionnaire

This questionnaire was first administered by Strohminger and colleagues (2011) to measure the valence, and the induced affect of different audio clips played in their study.

1. On a scale of 1 to 5, did you have positive or negative feelings when listening to this clip? (1 being extremely negative, 5 being extremely positive)
2. On a scale of 1 to 5, how engaging did you find the clip? (1 being engaging not at all, 5 being extremely engaging)
3. On a scale of 1 to 5, how uplifting did you find the clip? (1 being not uplifting at all, 5 being extremely uplifting)
4. On a scale of 1 to 5, did you feel the warmth in your chest when listening to this clip? (1 being no warmth at all, 5 being extreme feeling of warmth)
5. On a scale of 1 to 5, did you think that this clip had a negative or positive meaning? (1 being extremely negative, 5 being extremely positive)
6. On a scale of 1 to 5, how funny did you find the clip? (1 being not funny at all, 5 being extremely)
7. On a scale of 1 to 5, how much did you find yourself laughing during this clip? (1 being not laughing at all, 5 being laughing a lot)
8. On a scale of 1 to 5, how much did you find yourself smiling during when listening to this clip? (1 being not smiling at all, 5 being smiling a lot)

9. On a scale of 1 to 5, how interesting did you find this clip? (1 being not interesting at all, 5 being extremely interesting)