Attentional Effects of Processing Emotional Faces Using Continuous Flash Suppression

Nicole J. Krellenstein

Vanderbilt University

Abstract

Controversy exists concerning whether emotionally valenced information facilitates or inhibits orientation of spatial attention when presented without observers' awareness. Following prior work by Jiang et al., (2006) suggesting that unconsciously presented erotic cues directed spatial attention, we investigated the attentional effects of unconsciously presented emotionally valenced cues. Using a continuous flash suppression (CFS) paradigm, invisible emotional faces were presented as valid or invalid cues to the location of a grating stimulus. In contrast to prediction, reaction time and accuracy to the target stimuli were unaffected by the validity and valence of emotional faces, though some evidence was found for unique processing of fearful faces. These results may suggest that valenced stimuli presented under CFS are unable to influence spatial attention.

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In recent years, the body of knowledge that surrounds the processing of stimuli presented outside of awareness has grown considerably. Such research aims to understand the way human sensory processing systems work as well as provide insight into the evolutionary purposes for which they were adapted. Research involving the presentation of perceptually invisible or suppressed stimuli is useful in studying the way the human brain may preferentially or selectively respond to certain aspects of their environment (e.g. potentially dangerous situations) without relying on consciousness or attention. Subliminal processing also has implications for political campaigns and the advertising industry; the effects of subliminal messages in music, television, and film have been a point of controversy for many years now (for review see Shrum, 2005)

In the following section, I will first discuss the methods used and the evidence obtained that indicate that stimuli are in fact processed when presented outside of awareness. I will then briefly identify the factors that influence unconscious processing, as well as the problems and limitations present in examining emotional processing under awareness. Next, I plan to examine the types of stimuli processed unconsciously. Here, I will spend a significant amount of time discussing emotional content, specifically, the evolutionary importance of and attentional preference for emotional faces. Finally, I will concentrate on the attentional effects of unconsciously processed emotional stimuli by reviewing and integrating past research into my current objectives.

Behavioral and Psychophysical Studies

The numerous methods used to study the processing of unconscious stimuli fall into one of two varieties. The first variety includes behavioral and psychophysical studies. The second involves brain imaging and physiological techniques. Some of the most prominent psychophysical methods employ backward masking, binocular rivalry, and continuous flash suppression. In backward masking, a target stimulus is quickly replaced by a second stimulus, which results in perceptual masking of the target. Binocular rivalry refers to the fluctuation in visual awareness due to visual conflict: two dissimilar patterns are presented to each eye, causing competition between the two eyes. Because the two patterns cannot be in awareness simultaneously, perception between the two representations fluctuates. Continuous flash suppression (CFS) is a relatively new method in awareness research. Similar to binocular rivalry, participants are presented with different stimuli in each eye. Contour-rich dynamic patterns presented to one eye suppresses the static image presented to the other eye, which enables the prolonged presentation of stimuli outside of awareness, as compared to the relatively short unpredictable suppression phases during binocular rivalry. Other phenomena used to study unconscious processing include crowding, the attentional blink, change blindness, and motion-induced blindness (For a review see Kim & Blake, 2005).

Much evidence has accumulated over the past twenty years from behavioral and psychophysical studies supporting the idea that the brain processes stimuli presented outside of awareness. The presence of visual aftereffects of invisible adapting stimuli suggests that information reaches areas early in the visual processing hierarchy without awareness (Kim & Blake, 2005). Moreover, there is evidence that suppressed input is processed beyond early visual areas. Kunst-Wilson & Zajonc (1980) found that the exposure effect, a strong preference for objects that have become familiar through repeated exposure, developed even when the exposure to stimuli was not consciously recognized (Kunst-Wilson & Zajonc, 1980). Another study used a masked priming paradigm and found that subliminal visual words produced reliable repetition priming effects (Dehaene & Naccache, 2006). Moreover, Wantanabe et al. (2001) demonstrated that perceptual learning occurred without attention or awareness, independently of task relevance (Wantanabe et al, 2001).

There are several factors that influence participants' ability to process unconscious stimuli. Many studies have focused on the role of attention. The effects of both attentional load and type of attention (i.e. feature vs. spatial) have received particular notice. Attentional load refers to the amount of attention available when responding to a task (for review, see Palermo & Rhodes, 2006). Bahrami et al, (2008) found that perceptual after-effects occurred only when attention was available to process the adapting stimulus under CFS. The type of attention was also found to be a significant factor. One study using CFS found that feature-based attention but not spatial attention modulated adaptation to invisible stimuli (Kanai et al., 2006). On the other hand, Jiang et al., (2006) used erotic pictures as suppressed stimuli and found that these images either attracted or repelled observers' spatial attention, which was dependent on participants' sexual orientation (Jiang et al, 2006). Finally, individual differences may also modulate attention and consequently, the processing of suppressed information. For example, individual differences in sensitivity and anxiety levels affect attentional modulation toward potentially threatening stimuli (for review, see Palermo & Rhodes, 2007).

There are also limitations in particular paradigms. In backward masking, these include the possibility of incomplete masking, limited presentation duration of the suppressed stimulus, and individual differences in conditions of physical stimulation necessary to produce awareness. Likewise, binocular rivalry is difficult to control due to the unpredictability of awareness. Finally, crowding presents certain challenges in that experimenters are often unsure whether participants' recognition of discrepant stimuli is based on low or high level features (Kim & Blake, 2005).

Neuroimaging and Physiological Methods

The second approach to researching unconscious processes involves brain imaging and physiological techniques. Because my current research objectives will not involve these techniques, I will simply touch on the methods used here. Imaging studies using functional Magnetic Resonance Imaging (fMRI) report neural activity in response to emotional stimuli presented without awareness (for review see Williams et al., 2006, Williams et al., 2004, and Pasley et al, 2004). Some of these studies examine amygdala response to unconscious emotional stimuli with the hope of establishing a physiological explanation as to how such stimuli are processed. For example, amygdala activation in the absence of awareness may implicate a fast subcortical route for processing emotionally relevant information (for review see Pessoa, 2005 and Zald, 2003).

In other studies, ERP components are linked to the presentation of masked stimuli (For a review of the physiological research, see Pessoa, 2005; Whalen et al., 1998; & Bahrami et al., 2007). Öhman and Soares (1993) found that fear conditioned stimuli elicited a skin conductance response (SCR) when presented unconsciously using backward masking. Finally, neuronal responses during single- and multiple-unit recordings have also been linked to perceptually invisible images (e.g. Kreiman, Fried & Koch, 2002). Studies using single or multi-cell recordings have additionally been performed in non-human primates, although in such cases, it is difficult to monitor conscious awareness (e.g. Wilke, Logothetis & Leopold, 2006). In summary, neuro-physiological methods provide substantial evidence that stimuli presented without conscious awareness are processed by the brain. However, studying unconscious processing using behavioral and physiological methods has certain limitations that remain problematic. The most significant issue is verifying that participants do not consciously process the "subliminally" presented stimuli. This concern is referred to as the perceptual criterion problem. To addresses the fact that it is difficult to establish whether participants are subjectively or objectively unaware of stimuli, participant performance is measured on a forced choice task. 'Objective' criteria require that a subject's performance be at chance. 'Subjective' criteria require that participants merely self-report that they are unable to perceive the stimuli, though their performance may be significantly above or below at-chance level (for review see Pessoa, 2005).

The Content of Unconscious Processing

The extent to which studies find evidence of unconscious processing depends on the type of stimuli presented, which reflects the specific brain processes that are susceptible to subliminal stimulation. Stimuli found to be unconsciously processed include basic features of visual stimuli such as gratings, and signals with directional motion (see review by Kim & Blake, 2005). Words, objects, and categories of objects have also been processed unconsciously (Jiang et al, 2006). Furthermore, familiarity with visual features of stimuli plays an important part in determining the extent of unconscious processing. Two studies conducted by Jiang et al. (2007) found that upright faces and words in a participant's native language came out of suppression faster than upside-down faces or words in a foreign language, respectively.

Perhaps the most interesting stimuli to study, however, are those that have an affective component. Emotionally charged stimuli inform humans of ecologically relevant items in the environment; such stimuli either facilitate or obstruct an individual's objective, which includes self-preservation (Compton, 2003). Therefore, it is advantageous for humans to have developed a system that prioritizes this kind of helpful information, enabling the species to respond fast and efficiently when protecting or advancing their own welfare. Stimuli that are emotionally charged have precedence; they are processed more rapidly than non-emotional content and often interfere with the ongoing processing of other information (for review see Pessoa, 2005, Palmero & Rhodes, 2007, and Compton, 2003).

Discrepancies concerning what information is unconsciously processed are due partially to the context-sensitive nature of emotional stimuli (Pessoa, 2005). Some researchers maintain that emotional stimuli are processed unconsciously only when they are relevant to the task at hand. Hunt et al., (2007) employed a search task paradigm and found that emotional face distracters captured attention only when emotions were the target of search, leading them to suggest that the voluntary goals of the observer modulate the distracter's influence.

The study of emotional faces is particularly interesting because faces have social and biological significance. Recognition of and attention to faces is a crucial component of identifying other members of our species as well as reading social cues that may provide valuable information. Consistent with the evolutionary view that facial recognition is an important adaptive strategy, past studies have demonstrated that participants are biased to attend to faces. One study based on MEG data found that faces were categorized 100 ms faster than objects and words (for review see Palmero & Rhodes, 2007). Another study employing a detection task found that face stimuli presented to the contralateral field were extinguished less often than shapes in patients with chronic left neglect (Vuilleumier & Schwartz, 2001). A third study found that infants display a preference for right side up faces from as early as one month old (for review see Palmer & Rhodes, 2006). These studies support the idea that the processing of faces is prioritized as compared to other stimuli.

Several behavioral and psychophysical studies have compared the effects of various types of faces. Backward masking and binocular rivalry experiments have shown that emotional faces have preference in awareness over neutral faces. Specifically, fearful and fear conditioned faces more often reached awareness than neutral faces (for review see Palmero & Rhodes, 2007). In search task experiments a 'Face in the Crowd effect' has been found. Both Hansen & Hansen (1998) and Öhman et al., (2001) found faster and more accurate detection of discrepant threatening faces embedded in happy or neutral crowds than of discrepant neutral or friendly faces in threatening crowds. Similarly, in an attentional blink experiment conducted by Milders et al., (2006), fearful and fear conditioned neutral faces were detected more frequently than both neutral and happy faces. One study conducted by Mogg & Bradley (1999) employed a dot-probe task using emotional faces and found that attention was facilitated faster to the dot location where a threatening facial cue appeared, in comparison to a neutral or happy facial cue. The role of threatening faces in orienting attention is controversial, however; rather than facilitate attention, some evidence supports the idea that threatening faces have an inhibiting effect. A spatial cueing study conducted by Fox et al., (2001) found that threatening faces held attention at the invalid location, but did not facilitate attention when they appeared at the valid location. Finally, using the CFS paradigm, Yang et al., (2007) found that fearful faces came out of suppression faster than happy or neutral faces.

The current study examines the attentional effects of unconsciously processed emotional stimuli. Recall the study conducted by Jiang et al., (2006), which found that information that has not entered observers' awareness directed their distribution of spatial attention. This study found that the arousing stimuli presented under suppression could either attract or repel observers' spatial attention toward the location of a subsequent presented target stimulus and interestingly, the effect was related to observers' gender and sexual orientation. The findings of this last study inspired the current research objective to determine if the findings by Jiang et al., (2006) are generalizable; does the effect exists with images of different valence?

Objective

Specifically, the present study is composed of four experiments aimed to determine if presenting emotional faces under suppression affects participants' distribution of spatial attention. Experiment 1 established a basic cueing effect under conscious conditions so that we could proceed confidently with our design; Experiment 2 examined whether emotional faces work successfully as cues, and how the results were influenced by type of task; Experiment 3 was designed to see if a cueing effect was maintained without observers' awareness, and if this effect was modulated by spatial configuration; finally, Experiment 4 aimed to elucidate the influence of temporal parameters on the effect, as well as provide a control to measure observers' perception of the suppressed stimuli. Jiang et al. (2006)'s study was adapted in experiments 3 and 4 by replacing erotic pictures with emotional faces. Like Jiang et al., continuous flash suppression and a modified version of the Posner cuing paradigm were employed; four categories of facial expressions (fear, happy, angry, and neutral) served as unconscious valid or invalid cues preceding a target grating. Participants were instructed to indicate the tilt orientation of the grating by pressing a right or left arrow key. Reaction times and accuracy of responses were examined in an effort to measure the attentional effects of suppressed emotional cues.

If the results of Jiang et al., (2006), are generalizable, faces will successfully act like cues under suppression, providing support for the hypothesis that emotional faces are processed to the extent that they are able to orient attention without awareness. To confirm this, it is expected that there will be significant differences in reaction times between trials with faces as cues and trials with no cues. It is also predicted that emotional expression will affect the data. In accordance with the hypothesis that threatening stimuli will orient attention more quickly than non-threatening stimuli, it is expected that fearful and angry faces will be the most effective at 1. facilitating observers' attention to the target grating, resulting in the shortest reaction times on validly cued, and/or 2. holding spatial attention and leading to longer reaction times on invalidly cued trials, in comparison to other facial expressions.

General Methods:

Participants

Participants recruited for all experiments were drawn from the Nashville community and Vanderbilt undergraduate community through Vanderbilt's Department of Psychology online Research Subject Pool (SONA system). For Experiment 1, 12 participants were recruited, for Experiment 2, 21 participants were recruited, for Experiment 3, 15 participants were recruited, and for Experiment 4, 100 participants were recruited. All were between the ages of 18 and 22. Participants either obtained research credit or monetary payment for their participation. All provided written informed consent and were naïve to the purpose of the study. Furthermore, all participants denied visual deficits or reported having corrected vision in the normal range.

General Apparatus and Measurements

With the exception of Experiment 1, in which stimuli were displayed on a CRT monitor (800x600 resolution, 100Hz frame rate) controlled by a Macintosh iMac G3, all stimuli were displayed on a LCD monitor (1280x1024 resolution, 60Hz frame rate) controlled by a DELL OPTIPLEX 745. Stimulus selection, response timing, and data collection were controlled by MATLAB version 7.5.0 (R2007b) and Psychtoolbox version 3.0. A chin rest was used to stabilize participants' heads and control for distance between participants and the monitor (124.5cm).

General Design and Procedure

Subjects were instructed to focus on a centrally located fixation point throughout the entirety of the session. The initial fixation period was always 1s in duration after which a cue stimulus was presented to either the left or right of fixation. After the cue disappeared, the fixation returned. The target stimulus (tilted grating) was then briefly presented either to the left or right of fixation and participants were given 2s to respond to the direction of its tilt. On valid trials, the target appeared in the same side of fixation as the cue; on invalid trials, the target appeared in the opposite side of fixation as the cue.

For all experiments, the target stimulus was a Gabor patch (sinusoidal gratings modulated by a Gaussian envelope, 4 cycles/deg) and its size and/or contrast varied across experiments. For Experiments 2-4, the cue stimuli were faces taken from the standard Ekman set of facial expressions (Ekman & Friesen, 1976). They consisted of 16 photos in all, with four different identities of two males and two females. There were four facial expressions for each identity presented: happy, angry, fearful and neutral. Images were cropped to remove features outside of the face and changed to grayscale. Face stimuli were 1.52 x 1.52 degrees of visual angle (dva) and presented at 10 or 15% contrast.

All test sessions began with practice trials, whereby participants received feedback when their responses were incorrect or when responses were not made within the 2-second response window (as is the case for experimental trials). Reaction time and accuracy were recorded.

General Data Preparation:

A total of 25 subjects were removed from data analysis: 4 participants from Experiment 1, leaving 8 participants, 1 participant from Experiment 2, leaving 12 in the location discrimination task and 8 in the tilt discrimination task, and 20 participants total from Experiment 4, leaving 80 participants that were evenly divided among the five experimental versions. To limit the influence of variability due to task difficulty, participants were removed if mean response accuracy was below 70%. To ensure that data collected in trials using CFS did not include participants that actively perceived the stimuli, participants were removed if they broke suppression in over 10% of a block of 100 trials. Of the 20 subjects excluded from the final experiment, more than half broke suppression. Important to note is that breaking suppression is a common occurrence that is dependent on individuals' perceptual systems. The fact that such people did not meet analysis criterion was unrelated to task difficulty.

Repeated measures analysis of variance (ANOVA) was run for each data set to examine both accuracy and reaction time; however the main dependent variable was reaction time since we tried to control for task difficulty across subjects and this reduced variability in response accuracy. Incorrect trials were removed from the analysis of reaction time.

Experiment 1: Establishing the Basic Cueing Paradigm Using a Neutral Cue

This experiment was designed as a preliminary version of the modified Posner cueing paradigm. Its purpose was to establish a basic cueing effect, ensuring that the design would be applicable for the succeeding experiments.

Participants

8 participants were recruited for Experiment 1 including 3 females and 5 males, with ages ranging from 18 to 22.

Apparatus and Measurements

Stimuli were displayed on a CRT monitor (800x600 resolution, 100Hz frame rate) controlled by a Macintosh iMac G3. Stimulus selection, response timing, and data collection were controlled by MATLAB version 5.2.1 and Psychtoolbox version 2. A chin rest was used to stabilize participants' heads and control for distance between participants and the monitor (52cm).

Design & Procedure

On two-thirds of trials, a red frame (2.7x 2.7dva) was presented to either the right or left of the fixation point (.9dva). The frame remained on the screen for 150ms. On other trials, no frame was presented, but instead the fixation point turned red for 150ms. The inter-stimulus interval (ISI) was fixed at 50ms. The target grating then appeared to the right or left of the fixation point for 50ms. The grating (1.7 x 1.7dva, 20% contrast) was tilted 2° from vertical in one direction and located in the center of either frame location. Participants were instructed to respond to the direction of its tilt using the left and right arrow keys (see Figure 1). Half of the cued trials were valid and the other half were invalid. On trials where the fixation turned red (no cue condition), the grating was randomly presented on either the left or right side of fixation. This condition was included to obtain a baseline RT measure.

The experiment was divided into six blocks of 60 trials, totaling 360 trials, with 120 repetitions for each of the three conditions (valid cue, invalid cue, no cue). Trials for each of the three conditions (valid, invalid and no cue) and location were counterbalanced and presented in random order. Subjects were given 20 practice trials. The average duration of the experiment was 10 minutes.

Results:

Overall Effects:

In order to determine whether cue validity predicted response accuracy concerning tilt of the target grating, a 3 Condition (valid cue, invalid cue, no cue), one-way repeated measures analysis of variance (ANOVA) was performed. There was a strong effect of cue validity ($F(2,14)=17.4$ $p<.001$). Accuracy was significantly higher on validly cued trials (M=86.7%, SD=7.6%) than on invalidly cued trials (M=79.1%, SD=9.7%, $t(7)=4.9$, $p=.002$) and no cue trials (M=82% SD=8.6%, $t(7)=3.7$, $p=.008$). Furthermore, no cue trials resulted in significantly more correct responses than on invalidly cued trials ($t(7)=2.9$, $p=.022$).

To determine whether cue validity predicted the speed at which participants responded to the target grating, a similar 3 Condition, within-subject, one-way ANOVA for reaction time (RT) was performed. It too indicated a strong cueing effect ($F(2,14)=19.7$, $p<.001$). Responses were significantly faster for validly cued trials (M=503ms, SD=70ms) than for invalidly cued trials (M=543ms, SD=76ms, $t(7)= 5.7$,

$p<.001$) and no cue trials (M=527ms, SD=67ms, $t(7)= -3.7$, $p=.008$). No cue trials were significantly faster than invalidly cued trials ($t(7)= -2.9$, $p=.024$) (see figure 2). These analyses indicate that the general procedure performed under conscious conditions produced appropriate influences on spatial attention.

Experiment 2: Comparing Location vs. Tilt Discrimination when Using Faces as Cues

After establishing an effect of validity with our basic cueing paradigm, the paradigm was adapted to include faces as attentional cues. The red frame was replaced with emotional faces in order to confirm that faces work successfully as spatial cues. Furthermore, the validity percentage was changed from 50% to 75%, in order to replicate Posner's original parameters. This higher percentage of valid trials ensures the predictive validity of the cues. We also wanted to compare the effects of task type on reaction time. Thus, one set of participants were instructed to discriminate the tilt of the grating (right or left of vertical, irrespective of location) while another set was instructed to discriminate the location of the grating (right or left of fixation, irrespective of tilt). In order to make the location task equally difficult, a grating low in contrast was used. Based on preliminary observations, face stimuli produced a type of forward masking, which made the grating difficult to perceive, specifically in the location task. For this reason, face and grating stimuli were spatially adjacent to one another, rather than overlapping, for Experiment 2.

Participants

20 participants were recruited for Experiment 2, in which 12 performed the location discrimination task and 8 performed the tilt discrimination task. They consisted of 9 females and 11 males, with ages ranging from 18 to 22.

Design and Procedure

On all trials, a face was presented either directly to the right or left of the fixation point. The face remained on the screen for 100ms. After an ISI of 50ms, the target grating appeared to the right or left of the fixation point (but more peripheral than the cue) for duration of 50ms. Depending on which version of the experiment was run, participants were instructed to respond to the direction of the grating's tilt or location, using the left and right arrow keys (see Figure 3).

The target grating edge was 1.87dva from fixation. For the tilt discrimination task, grating contrast was at 100% and for the location task the grating contrast was at 10%. The edge of the face stimuli was .35dva from fixation. The experiment was divided into 16 blocks of 48 trials each, totaling 768 trials, with 192 repetitions for each of the 4 emotion conditions. 75% of trials for each condition consisted of valid cues (576 total trials), and the remaining 25% consisted of invalid cues (192 total trials). Trials varying in condition, face identity, cue location, and validity were counterbalanced and presented in random order. Subjects were given practice trials until they correctly responded to 80% of trials, or they reached 50 trials. The average duration of the experiment was 30 minutes.

Results:

Location Discrimination Task: Overall Effects

To determine whether the emotion or validity of the cue influenced response accuracy during the location discrimination task, a within-subject, 4 (Emotion: neutral, happy, fearful, angry) X 2 (Cue validity: valid, invalid) ANOVA was performed. Though no main effect for emotion was found ($F(3,33)=1.8$, $p=.17$), there was a strong effect of Cue validity ($F(1,11)=27.6$, $p<.0001$). Trials with valid cues (M=98.2%, SD=1.8%) had higher response accuracy than trials with invalid cues (M=81.1%, SD=1.3%). There was also a significant interaction effect between Emotion and Validity ($F(3,33)=3.4$, $p=.038$). Paired T-tests were then performed to determine which specific interactions were significant. T-tests revealed that valid trials resulted in significantly more correct responses than invalid trials for every emotion (neutral: *M diff*= 17.8%, SD=10.9%, $t(11)=5.34$, $p<.0001$; happy: *M diff*=16.5%, SD=12.6%, $t(11)=4.56$, $p<.001$; fearful: *M diff*= 21%, SD= 12.8%, $t(11)=5.69$, $p<.0001$; angry: *M diff*=14.7%, SD=12.3%, $t(11)=4.1$, $p<.002$). Furthermore, valid trials with fearful faces as cues (M=98.9%, SD=1.6%) resulted in significantly more correct responses than valid trials with neutral (M=98% SD=2.1%, $t(11)= -2.8$, $p=.016$), happy (M=98.3%, SD=1.8%, $t(11)= -2.6$, $p=.027$), or angry (M=98%, SD=1.9%, $t(11)=3.2$, $p=.008$) faces as cues. In addition, invalid trials with angry faces (M=83.3%, SD=13.2%) resulted in more correct responses than invalid trials with fearful faces (M=78%, SD=13.1%, $t(11)=2.9$, $p=.014$).

A within-subject, 4x2 ANOVA was also performed to see if there were significant differences in reaction times due to Emotion, Validity, or an interaction between the two during the location discrimination task. Though there was no main effect of Emotion ($F(3,33)=.4$, $p=.6$), there was a main effect for Validity ($F(1,11)=44.260$, $p<.0001$). Valid cues resulted in significantly faster reaction times (*M*=333ms, *SD*=69ms) that invalid cues (*M*=414ms, *SD*=97ms) (see Figure 5). The interaction between Emotion and Validity did not reach significance ($F(3,33)=.6$, $p=.552$).

Tilt Discrimination Task: Overall Effects

Identical within-subject ANOVAs were performed on response accuracy and reaction time with the data acquired from the tilt discrimination task. Turning first to the accuracy data, a main effect of Emotion was found ($F(3,21)=3.5$, $p<.05$). Paired T-tests revealed that fearful faces (*M*=83.7%, *SD*=5.6%) resulted in significantly more correct trials than happy faces, (*M*=79.7%, *SD*=7.2%, $t(7)= 4.3$, $p=.004$), or angry faces (*M*=81.0%, *SD*=7.7%, $t(7)=2.6$, $p<.034$). The effect of Validity was not statistically significant ($F(1,7)=.4$, $p=.57$), nor was the interaction effect between Emotion and Validity, ($F(3,21)=.6$, $p=.57$).

A similar 4 X 2 ANOVA was run to determine whether Emotion, Validity, or a combination of the two was predictive of participant response speed. No main effect of Emotion was found ($F(3,21)=.7$, $p=.509$); however there was a strong Validity effect ($F(1,7)=17.8$, $p=.004$). Valid trials (*M*=583ms, *SD*=99ms) resulted in significantly faster reaction times that invalid trials, (*M*=617ms, *SD*=96ms). The interaction between Emotion and Validity did not reach significance ($F(3,21)=.2$, $p=.844$).

In summary, strong effects of Cue validity on observers' reaction time were found for both location and tilt discrimination experiments (see Figure 4). As for observers' accuracy, trials with fearful cues were associated with greater correct responses than trials with other facial expressions. This held true for the tilt discrimination task (in comparison to happy and angry cues) but only for valid trials in the location discrimination task (in comparison to neutral and happy cues) (see Figure 5). Given that both tasks provided significant effects of Cue validity, the tilt discrimination task was chosen for continued use since it was: 1. consistent with the study by Jiang et al., (2006) and 2. easier to equate task difficulty across observers by changing the orientation than contrast of the grating.

Experiment 3: Comparing the Effects of Stimuli Spatial Configuration on Attentional Cueing Under Suppression:

After determining that faces proved to be robust cues in guiding attention and that the tilt discrimination task was sensitive in providing this Cue validity effect in RT, it was next examined whether this attentional effect with faces remained without observers' awareness. The design from Experiment 2 was adapted to include a CFS display and used the cue duration of 800ms, identical to the study by Jiang et al. The main objective of Experiment 3 was to determine the optimal presentation method for displaying faces under CFS. Three different versions of the experiment were created that varied in spatial overlap between the cue, target, and CFS display. The CFS display must spatially overlap with the location of the face presented to the other eye; however, it is unclear whether the spatial overlap between the CFS display and the location of the subsequently presented grating stimulus has an effect on spatial attention. One might suggest that monocularly presenting transient noise over the location of both the cue and the target (thus, no abrupt edges) may make it easier to guide exogenous attention from one location to the other. Thus, two experiments were created where the CFS display spatially overlapped with only the cue or with both the cue and target. The third version involved the spatial overlap of the CFS display, cue, and target since forward masking (a concern in the location discrimination task in Experiment 2) was highly unlikely, given the low contrast face and subsequent high contrast target presented. Finally, to ensure that any attentional cueing effects were due to the presentation of the face (or emotional expression) and not just the presence of a stimulus under suppression, the face cue was simultaneously presented with its phase-scrambled counterpart in the opposite location of fixation to equate for low-level stimulus features.

Participants

Fifteen participants were recruited in this study, with five assigned to each of the experiment's three versions. Participants were 4 females and 11 males, with ages ranging from 18 to 22. Because this was an exploratory study, small sample sizes were used with the assumption that if a particular version showed an effect, we would follow it up with a larger sample. Furthermore, the experiment's within-subjects design provided sufficient power to test for effects in this sort of design, as evidenced by the results of Experiments 1 and 2.

Apparatus and Measurements

Subjects were situated in front of a mirror stereoscope with chin rest, 119cm from the monitor. During the beginning of the session, the stereoscope's mirrors were adjusted on an individual basis to accommodate all participants.

Design & Procedure

Two square frames with a fixation cross in between were displayed in the center of the left and right halves of the monitor and thus, presented to both eyes. They remained on the screen throughout the trial and served to promote stable binocular alignment. On 80% of trials, a face was presented within one of the two frames while its phase-scrambled counterpart was presented within the other frame. The face and scrambled counterpart were presented to one eye while the other eye viewed a CFS display of dynamic Mondrian patterns in both frames. The CFS display and face stimuli remained on the screen for 800ms. On 20% of trials (no cue condition), only the CFS display was presented to one eye. After an ISI of 50ms, the target grating appeared to either the left or right of fixation for 50ms (to both eyes) and participants were instructed to respond to its direction of tilt with the left or right arrow key. Experiment 3 can be separated into three versions that were conducted simultaneously with different groups of participants: In Experiment 3a (Face-CFS overlap; FC), the target grating was presented peripheral to the cue display (see Figure 6a). The CFS display spatially overlapped with only the cue display. In Experiment 3b (Face-CFS overlap and Grating-CFS overlap; FC+GC), the target grating was presented peripheral to the cue display and the CFS display spatially overlapped with the locations of both cue and target stimuli (see Figure 6b). In Experiment 3c (Face-Grating-CFS overlap; FGC) the target grating and CFS display was presented in the same location as the cue display (see Figure 6c). Valid trials occurred when the grating appeared on the same side (Experiment 3a/b), or in the same location (Experiment 3c) as the preceding face and invalid trials occurred when the grating appeared on the opposite side, or in the opposite location of the preceding face (same location as the phase-scrambled counterpart).

In order to better equate task difficulty across participants, an initial test was conducted to determine the degree of grating tilt (100% contrast) at which each participant performed at 70% accuracy using the PEST adaptive staircase method (Taylor & Creelman, 1967). This initial test took approximately 5min to complete. It looked exactly like the main experiment except that no facial cues were shown.

The CFS display consisted of images of overlapping colorful squares (Mondrian patterns). The Mondrian patterns were the same size as the face and grating stimuli (1.52 x 1.52dva) in Experiment 3a (FC) and 3c (FGC) or equal to the length of both (3.04x1.52dva) in Experiment 3b (FC+GC). This was also the case for the size of the frames as well. The Mondrian patterns changed at a rate of 10 Hz. Recognizing that it is possible that on some trials the face might break suppression, participants were instructed to press the down arrow key to indicate that they perceived something other than the CFS display. This response was made instead of their response to the tilt discrimination task during the response window. If participants responded with the down arrow key more than 10% of the time within a 100 trial block, this effectively terminated the program and that participants' data was excluded from group analyses. Reaction time and accuracy were recorded.

The experiment was divided into 4 blocks of 200 trials (800 trials in all). Participants took a mandatory 15s break at intervals of 50 trials. There was no break between trials within intervals. Each condition (4 facial expression cue conditions and a no cue condition) consisted of 160 trials where 75% of cued trials were valid (480 total trials), and the remaining 25% were invalid (160 total trials). Trials varying in condition, face identity, validity, eye to which the cue was presented, and visual field to which the grating was presented were counterbalanced and presented in random order. Subjects were given practice trials until the computer confirmed they correctly responded to 70% of completed trials, or they exceeded 50 trials. The average duration of the experiment was 40 minutes.

Results: Overall Effects

The same within-subject ANOVAs were performed on the accuracy and RT data collected from each experiment. To determine whether different emotional cues, as compared to no cue, influenced participants' response accuracy or reaction time, a within-subject 5 Condition (Cue type: neutral cue, happy cue, fearful cue, angry cue, no cue) one-way ANOVA was performed. To see whether response accuracy or reaction time could be affected by emotional condition or cue validity, a 4 (Emotion: neutral, happy, fearful, angry) X 2 (Validity: valid, invalid) within-subject ANOVA was performed.

Experiment 3a (Face-CFS Overlap)

Concerning accuracy, the within-subject 5 Condition ANOVA revealed no main effect for Cue type, ($F(4,20)=1.3$, $p=.299$). The 4 X 2 ANOVA did not reveal a statistically significant effect for Emotion ($F(3,15)=2.3$, $p=.146$), Validity ($F(1,5)=.05$, $p=.84$), or an interaction between the two ($F(3,15)=.5$, $p=.605$).

With respect to reaction time, the one-way ANOVA did not reveal a main effect for Cue type ($F(4,20)=.5$, $p=.62$) nor did the 4 X 2 ANOVA reveal a main effect for Emotion ($F(3,15)=.3$, $p=.690$), Validity ($F(1,5)=.7$, $p=.439$), or an Emotion X Validity interaction ($F(3,15)=.7$, $p=.525$). These results indicate that neither the presence of a cue, the validity of the cue, the emotional condition of the cue, or an interaction between the emotion and validity, affected participant accuracy or response speed.

Experiment 3b (Face-CFS Overlap + Grating-CFS Overlap)

Again, with respect to accuracy, no main effect for Cue type ($F(4,16)=.3$, $p=.727$) was found. The 4 X 2 ANOVA did not reveal a main effect for Emotion ($F(3,12)=.1$, $p=.858$), Validity ($F(1,4)=.1$, $p=.719$), or an interaction between the two ($F(3,12)=.3$, $p=.656$).

Concerning reaction time, the one-way ANOVA found no main effect for Cue type ($F(4,16)=.3$, $p=.727$). The 4 X 2 ANOVA revealed no main effects for Emotion ($F(3,12)=.1$, $p=.890$), Validity ($F(1,4)=1.0$, $p=.385$), or an interaction between the two ($F(3,12)=.7$, $p=.514$). These results indicate that the presence of a cue in comparison to no cue, as well as the validity of the cue, emotional condition of the cue, and the validity X emotion interaction, does not influence participant response accuracy or speed.

Experiment 3c (Face-Grating-CFS Overlap)

Once again, no main effect concerning Cue type was revealed from the 5 Condition, one-way ANOVA with respect to accuracy ($F(4,16)=.2$, $p=.873$), indicating that the presence of facial cues did not influence response accuracy in comparison to no cue. The 4 X 2 ANOVA performed revealed neither a main effect for Emotion (F(3,12)=.3 p=.668), Validity (F(1,4)=.1 p=.767), or their interaction (F(3,12)=1.6 p=.257), indicating that these variables had no predictive power on accuracy.

Concerning reaction time, the 5 Condition, one-way ANOVA revealed no main effect concerning Cue type (F(4,16)=1.8, p=.256), indicating that the presence of facial cues did not affect response time in comparison to trials with no cue. A 4 X 2 ANOVA then revealed a significant main effect for Validity (F(1,4)=47.0, p<.002). In contrast to prediction, validly cued trials resulted in significantly slower reaction times (M=523ms, SD=76ms) than invalidly cued trials (M=515ms, SD=76ms). The main effect of Emotion was close to significant (F(3,12)=3.873, p<.074). Paired t-tests showed that trials with neutral faces (M=509ms, SD=75ms) were responded to more quickly than both trials with fearful faces (M=522ms, SD=76ms, t(4)=-3.1, p=.035) and angry faces (M=527ms, SD=79ms, t(4)=-3.2, p=.033) The interaction effect did not reach significance, F(3,12)=.187, p=.841.

In summary (see figure 7), none of the experiments found an effect for Cue validity, Emotional expression, or a Validity X Emotion interaction on accuracy. However, Experiment 3c (Face-Grating-CFS overlap), as compared to experiments 3a (Face-CFS overlap) and 3b (Face-CFS + Grating-CFS overlap) found that Cue validity significantly influenced reaction time, with invalid cues resulting in shorter reaction times than valid cues. In addition, the effect of Emotion was close to significant; paired t-tests revealed that trials with neutral faces resulted in significantly shorter reaction times than trials with both fearful and angry faces. Because experiment 3c was the only spatial configuration to yield a significant result for cue validity concerning reaction time, it was thought to be the most promising version to continue using. Furthermore, its spatial configuration was most similar to that of Jiang et al., (2006). Intrigued by the reverse cueing effect and encouraged by a near significant emotional effect, a decision to collect more data was made to see if the burgeoning emotional effect might be enhanced.

Experiment 4: Tests of Timing: Comparing the effects of Cue Duration and Interstimulus Interval on Attentional Cueing Under Suppression.

Main Experiment

Given the results of Experiment 3, the spatial configuration of Experiment 3c (FGC) was chosen, where the cue, target and CFS display spatially overlapped. In the following experiment, it was investigated whether the reversed attentional cueing effect (under CFS) in Experiment 3 was due to the temporal parameters of the stimulus display. In past studies, temporal parameters have proven to be important design features and are often responsible for the difference in eliciting a facilitative or inhibitory effect (Lupiáñez, 2001, Posner et al., 1980, Posner & Cohen, 1984, & Klein, 2001). One study that employed an attentional blink paradigm found that aversively conditioned images impaired target detection relative to other distracters only at 200ms lags, and not at 800ms lags (Smith et al, 2006). Similarly, Koster et al., (2007) found that threatening images capture attention only at cue durations below 200ms, in comparison to cue durations over 200ms which resulted in reduced attentional capture by threat as compared with neutral images. In Experiment 4, the exact temporal parameters as those used in the study by Jiang et al., (2006) were replicated, in addition to other combinations in cue, ISI, and grating durations. One could argue that the cueing effect observed with an 800ms cue duration in Jiang et al.'s study is unusual since it is well known that the temporal window for exogenous cueing of spatial attention is under 500ms (Klein, 2000). Furthermore, studies have reported either no attentional effects or Inhibition of Return when using cue durations beyond this temporal window (Posner & Cohen, 1984). IOR refers to the tendency of individuals to avoid previously attended stimuli, and is potentially part of a mechanism that functions to promote attention toward novel items in the environment (Klein, 2001, and Posner, 1984, Lupiáñez et al, 2001). It is for these reasons that shorter durations were tested in order to enhance the cueing effect, if one existed under CFS.

Participants

80 participants were recruited in this study, with 16 assigned to one of 5 versions of Experiment 4. Participants were 46 females and 34 males, with ages ranging from 18 to 22. 36 of the 80 observers that completed the main test of Experiment 4 participated in the control experiment in the same session.

Apparatus and Measurements

The apparatus and measurements used for this experiment are identical to those used in Experiment 3.

Design & Procedure

With the exception of temporal parameters, the design and procedure of this experiment are identical to those used in Experiment 3c. On trials when faces were presented as cues, the cue remained on the screen for 200ms, 500ms, or 800ms. ISI was either 50ms or 100ms, making the 5 conditions that varied in cue and ISI duration: 200ms-50ms, 500ms-50ms, 500ms-100ms, 800ms-50ms, and 800ms-100ms. Gabor target duration mirrored the ISI duration on each of the five versions, and thus also appeared for a duration of 50ms or 100ms (see Figure 6c). Subjects performed 8 practice trials. The average duration of the experiment was 40 minutes.

Results: Overall Effects

As in experiment 3, the same within-subject ANOVAs were performed on the accuracy and RT data collected from each version of Experiment 4. Again, to determine whether different emotional cues, as compared to no cue, influenced participants' response accuracy or reaction time, a within-subject 5 Condition (Cue type: neutral cue, happy cue, fearful cue, angry cue, no cue) one-way ANOVA was performed. To see whether response accuracy or reaction time was affected by emotional condition or cue validity, a 4 (emotion: neutral, happy, fearful, angry) X 2 (validity: valid, invalid) within-subject ANOVA was performed. The results of Experiment 4 are presented in Table 1. None of the results from the 5 versions reached significance.

<u>Control Experiment</u>

While participants had the option in the main experiment to indicate on any trial whether they perceived something other than the CFS display while it was presented, it is unclear whether participants perceived (parts of) the face stimuli but failed to report it. The purpose of this control experiment is to determine whether participants were able to perceive the face or discriminate its location from that of its phase-scrambled counterpart greater than chance, using a forced choice technique.

Design and Procedure

Participants completed this experiment after they finished the main test of Experiment 4. The design is identical to the main test (including the same cue duration) with the exception that no target grating was presented after the CFS display was removed. Participants were told prior to beginning the experiment that a face was presented simultaneously in one of the two locations as the Mondrian patterns. Rather than use the right and left arrow keys to indicate tilt discrimination, participants were instructed to indicate the location in which they believed the face appeared within the 2s response period (see Figure 8).

The experiment was presented as one block of 64 trials. Each of the 4 emotional conditions was repeated 16 times. 4 practice trials were given, but unlike the other experiments, there was no feedback. Accuracy was recorded. The experiment took approximately 5 minutes to complete.

Control Results: Overall Effects

To determine if one emotional condition was significantly stronger than another at influencing response accuracy when presented under CFS, a within-subject, 4 Condition (Emotion: neutral, happy, fearful, angry) one-way ANOVA was performed with cue duration (200ms, 500ms, 800ms) as a between-subjects factor. Differences between emotions were not significant ($F(3,99)=2.1$, $p=.107$), nor was the interaction between

Emotion and Cue duration ($F(6,99)=.3$, $p=.956$). Single sample T-tests were then run to measure accuracy of detecting the location of each emotional face against chance (.5). Though neutral trials (M=50.8%, SD=14.4%,; $t(35)=.5$; $p=.646$), happy trials (M=52.4%, SD=12%; $t(35)=1.2$; $p=.251$), and angry trials (M=50.2%, SD=13.8%; $t(35)=.2$; $p=.844$) were not significantly different from chance, fearful trials resulted in significantly more correct responses than at chance (M=56.3%, SD=11.4%; $t(35)=3.3$; $p<.002$) (see Figure 9).

Discussion

The aim of this study was to determine if differently valenced stimuli were capable of directing spatial attention when they were presented without awareness using CFS. While a cueing effect was found when observers were aware of the emotional faces, minimal evidence was found that invisible emotional faces were capable of attracting or repelling attention when presented as either valid or invalid cues. Ultimately, in the final version of our experiment, there was no main effect of emotion, validity, or an interaction between the two, indicating that none of the above mentioned factors successfully modulated the distribution of attention. The results suggest that emotional faces are unable to orient attention under CFS. Though the final results were not statistically significant, the progression of experiments did reveal a collection of data indicative of possible trends concerning the influence of cue validity and emotional condition on reaction time and accuracy. The progression was designed to begin with a basic cueing effect and methodically explore several dynamics of the CFS paradigm, including the effectiveness of stimuli content, placement, and timing of onset. These parameters were systematically manipulated, providing a review concerning the ways in which different parameters function within the attention cueing paradigm that is sure to aid future researchers in their attempts to design experiments using CFS.

To briefly summarize the results, Experiment 1 demonstrated a basic cueing effect using an adapted version of the Posner cueing paradigm (Posner et al., 1980). When presented within observers' awareness, valid cues resulted in significantly faster and more accurate responses than both trials with invalid cues or no cue, indicating that a cue presented in the same location as a subsequent target grating successfully facilitated attention to the target location. Furthermore, trials with no cue resulted in significantly faster and more correct responses than trials with invalid cues, indicating that invalid cues actively hindered performance when presented in the opposite location of the target grating.

Experiment 2 found strong validity effects in both location and tilt discrimination tasks, establishing that faces act as robust cues in directing attention. Furthermore, it determined that the tilt discrimination task was sufficiently sensitive at providing a cue validity effect in RT, comparable to Posner's original location detection task. Results from both tasks together indicated that trials with fearful facials cues resulted in higher response accuracy levels than trials with neutral, angry, and happy facial cues. These results provide support that fearful faces successfully orient attention to the target location better than other emotional conditions. This finding is consistent with the findings of Van Damme et al., (2008), who found that threatening, or fear-conditioned cues, resulted in significantly more correct responses than non-threatening cues in a spatial cueing paradigm. One explanation for why fearful faces should be better at allocating attention than angry faces has to do with the different types of information they convey. With fearful faces, the source of threat is ambiguous, while with angry faces, the source of threat is clearly the person expressing anger (Whalen et al., 1998). It is therefore possible that fearful faces increase overall alertness without causing an observer to fasten their gaze onto the specific fearful image, while an angry face holds attention longer, and thus makes it more difficult to disengage attention in order to reorient it to the target stimulus. The finding that fearful faces orient spatial attention better than other emotional faces was also demonstrated in several studies measuring response time, including experiments that employed a visual search paradigm (Hansen & Hansen, 1998 and Öhman et al., 2001), a spatial cueing paradigm (Mogg, & Bradley, 1999), and an attentional blink paradigm (Milders et al., 2006).

Experiment 3 found that spatial configuration had an effect when trying to determine whether a cueing effect was sustainable when the cues were presented without observers' awareness. In addition to using CFS for this experiment, different stimuli spatial configurations of stimuli placement were examined. Experiment 3a (Face-CFS Overlap), in which a Mondrian display overlapped only with the underlying facial cue, and experiment 3b (Face-CFS Overlap + Grating-CFS Overlap), in which the Mondrian display overlapped with both the underlying facial cue and location of subsequent target grating, revealed no significant results. Experiment 3c (Face-Grating-CFS Overlap), in which the Mondrian display, facial cue, and target grating all overlapped, revealed an effect for cue validity in RT. In contrast to prediction, however, invalid cues were responded to more quickly than valid cues, possibly indicating an inhibition of return (IOR). As mentioned above, IOR often occurs at a longer temporal window for which detection time and accuracy of a target is enhanced (longer than 300-500ms). Because the cue duration in this experiment was 800ms, the cue presented might have inhibited rather than facilitated attention.

Being close to significant, the effect of emotional condition in Experiment 3c revealed an inhibitory trend on reaction time in response to fearful and angry facial cues in comparison to neutral facial cues. Length of cue duration partly explains the discrepancy between the results of Experiment 2 and Experiment 3c; rather than facilitate attention to the target location, as the results of Experiment 2 suggest, IOR caused the threatening stimuli to have the opposite effect in 3c, providing evidence for hindered spatial attention. However, it does not explain why only threatening cues in comparison to other emotional cues had this effect, or why an inhibitory effect was found for both valid and invalid cues, rather than just valid cues. There is also research indicating that in discrimination tasks, inhibition of return occurs at SOAs up to 300ms longer than in detection tasks (Lupiáñez et al., 1997, 2001). Thus, it is likely that inhibition of return is not the only explanation for the current results.

As mentioned earlier one, in addition to the literature that has found attention facilitating effects in response to threatening cues, there have also been findings that threatening stimuli make it more difficult or time-consuming to disengage spatial attention than neutral or positive stimuli (Fox et al, 2001, 2002). By comparing response times on invalid trials, these studies determined that threatening stimuli might hold attention at the invalidly cued location longer than neutral or positive stimuli. Though an inhibitory effect was found in these studies concerning invalid trials, the inhibitory effect in the present study occurred for both valid and invalid trials. This may indicate difficulty in disengagement of stimulus processing rather that simply spatial attention disengagement. In other words, rather than disengagement difficulty being a result of threatening faces holding attention at the invalidly cued spatial location, perhaps threatening faces, whether presented at the validly or invalidly cued location, are taking longer to be processed, and thus result in a delayed response to the target discrimination task.

Length of cue duration might also be responsible for the lack of a cue validity effect in experiments 3a and 3b. Or, the lack of cueing effect might be a result of the spatial configuration; it is possible that in experiments 3a and 3b, the area used to present the stimuli was too big, resulting in too large a distribution of attention. Importantly, sample size is a major limitation. Only 5 participants were examined in each of the three experimental versions, making the results, as well as the interpretations that may be drawn from them, extremely vulnerable to individual differences. Ultimately, it was decided to use the spatial configuration of Experiment 3c; not only was it the only design that resulted in a statistically significant cue validity effect for RT, but it was consistent with the design of Jiang et al, (2006), the study we aimed to replicate.

In Experiment 4, different temporal parameters were tested and sample size was increased. In attentional paradigms such as this one, the timing of SOA is a sensitive element, key to obtaining facilitative or inhibitory effects (Lupiáñez, 2001, Posner et al., 1980, Posner & Cohen, 1984, & Klein, 2001). In this experiment, five combinations of cue, ISI, and Gabor grating durations were examined in groups of over 15 participants; included were the temporal parameters used by Jiang et al. None of the results, however, reached significance. Consistent with the findings of this experiment are the findings of

Schall et al., (1993) and Kanai et al., (2006). Using stimuli suppression paradigms similar to ours (binocular rivalry and CFS respectively,) these studies found no evidence of change in spatial attention when stimuli were presented without awareness.

Jiang et al., (2006) found that when emotional cues were visible, no cueing effect was apparent. He did not, however, venture to explain why effects were found only in the invisible condition. To examine the possibility that perhaps the emotional cues weren't effective because parts were being consciously processed, a forced choice control study was performed to determine whether participants were truly unaware of the invisible stimuli. Interestingly, only fearful facial cues resulted in a response accuracy rate significantly above chance. However, the effect was relatively modest, as performance was only 6% higher than chance (56% vs. 50%). Nevertheless, this effect was not modulated by cue duration, as there was no significant difference between responses at the 200, 500, and 800ms durations. There is a strong precedence of fearful faces reaching awareness more frequently and more quickly than other emotions (for review see Milders et al., 2006, Öhman et al., 2001, Yang et al., 2007). Important to note, however, is that these studies report the rate and frequency of fearful stimuli being consciously recognized. In our study, these images did not break suppression; participants remained unaware that they were accurately guessing the location of fearful images. This was confirmed by asking participants individually whether or not they were aware of the face stimuli.

The current study's results seem to implicate that fearful information is processed differently than neutral or positive stimuli. Though consistent effects of facial emotions on cueing of attention were not seen, to the extent that effects were observed, they appeared uniquely related to fearful expressions. To reiterate, fearful faces elicited significant effects or trends across experiments 2, 3, and 4 (control). In Experiment 2, the location and tilt discrimination tasks revealed that fearful facial cues resulted in significantly higher response accuracy levels than neutral, happy, and angry faces. The results of Experiment 3c indicated an inhibitory trend for threatening faces in comparison to neutral cues. Finally, though modest, fearful faces were the only cues to result in a response accuracy level significantly above chance level in the control version of Experiment 4. Results reported by Williams et al., (2004) and Pasley et al., (2004) supplement these findings. These imaging studies detected activity in the amygdala in response to unperceived fearful faces in contrast to unperceived neutral and non-face objects, respectively. This evidence supports the idea that fearful stimuli may be processed differently than non-threatening or neutral stimuli.

One reason why the results of Experiment 3 and 4 did not replicate those of Jiang et al., (2006) might be because of the content that we presented under suppression. Emotional faces may not be sufficient to orient spatial attention under continuous flash suppression. Jiang et al.'s use of erotic stimuli indicated that highly arousing items were capable of directing attention; it is possible that arousal, rather than valence, modulates the distribution of attention. Past behavioral and imaging studies have found evidence that valenced stimuli and arousing stimuli are processed differently (Anders et al., 2004, & Dolcos, LaBar, & Cabeza, 2004). For instance, study conducted by Vogt et al., (2008) found that arousing emotional pictures presented as cues resulted in attention disengagement, and that the effect was independent of cue valence. Another explanation might be that the Ekman photos chosen to be the stimuli for this study were not adequate vehicles for presenting valenced information. It is possible that other types of emotional stimuli including images of food, drugs, or threatening scenes, might have had better success under suppression. This is an opportunity that future studies might want to explore further.

It is also possible that low-level features drive the validity effect. Moradi et al., (2005) found that face adaptation aftereffects are erased when binocular rivalry is induced, suggesting that faces aren't processed under suppression. Though we attempted to control for the possibility of a validity effect being driven by low level features by using a phase scrambled counterpart on the opposite side of the central fixation point, the inclusion of this measure might have inhibited the finding of significant results if the processing of low level features are necessary to activate valence-related areas.

A final reason why significant results were not found might be due to individual differences. Though we did not include measures of individual differences, there is reason to believe that such information might have revealed a significant interaction effect. Interestingly, Jiang et al. did not report a significant main cueing effect; the study only reported an interaction effect between cue type and participants' gender and sexual orientation. Several studies have revealed an anxiety-related attentional bias for threat, indicating a more pronounced attentional cueing effect in response to threatening words or images in subject pools with heightened anxiety levels (Fox et al., 2001 & 2002, MacLeod et al., 1986, Bradley et al., 1998). The next step then, would be to conduct individual measures for trait-anxiety, specific phobias, and positive or negative affect in mood in both normal and clinical populations. It would be interesting to see how effects differ in populations with anxiety disorders and mood disorders. In addition, examining the effect among autistic individuals might be worthwhile. Krysko & Rutherford, (2009) found evidence of an anger superiority effect in a visual search task among autistic individuals; response times among autistic individuals were comparable to those found in normal individuals, but response accuracy levels were overall lower. Use of the present cueing paradigm might reveal a more sensitive measure of the attentional mechanisms employed in emotional processing.

In conclusion, the present study provides weak evidence that emotional stimuli rendered invisible with CFS influence the distribution of spatial attention. The initial experiments replicated previous findings that valid emotional cues facilitate attention to the location of a subsequent target grating when presented under awareness; fearful cues resulted in significantly higher accuracy levels than angry, neutral, and happy facial cues. The latter experiments had mixed results; they demonstrated an inhibitory effect or null effect when participants were shown emotional facial cues under CFS. Though our manipulation of temporal parameters did not reveal significant changes in cue validity or emotional effects, the manipulation of spatial configuration did suggest that spatial configuration influences response time. In conjunction with the results of the control experiment, which indicated that fearful faces elicited significantly more correct responses than chance would predict, the findings of this study suggest that fearful expressions are preferentially processed relative to other types of valenced expressions. In addition, the presence of an inhibitory effect as a result of fearful trials might suggest a disparity between how information is processed under awareness and without awareness. As discussed above, inhibition of return does not account for why the effect was found only in fearful trials, nor does IOR or current disengagement theories account for the effect being found in both valid and invalid trials. Finally, because stimuli presentation parameters were thoroughly explored and the results remain inconsistent with those cited by Jiang et al, (2006), the findings of this study suggest that emotional faces are processed differently from arousing nude pictures under suppression. This idea might explain why his temporal parameters did not result in inhibition of return or a null effect, and perhaps why the effect he found was only present in the invisible condition. In conclusion, the results of the current study indicate that CFS is a powerful tool in making a stimulus perceptually disappear to such an effect as to possibly hinder the guidance of spatial attention to ecologically- and socially- relevant information.

Reference Section:

Anders, S., Lotze, M., Erb, M., Grodd, W., & Birbaumer, N. (2004). Brain activity underlying emotional valence and arousal: A response-related fMRI study. *Human Brain Mapping, 23,* 200-209.

Bahrami, B., Lavie, N., & Rees, G. (2007). Attentional load modulates responses of human primary visual cortex to invisible stimuli. *Current Biology, 17,* 509-513.

Bradley, B. P., Mogg, K., Falla, S. J., & Hamilton, L. R. (1998). Attentional bias for threatening facial expressions in anxiety: Manipulation of stimulus duration. *Cognition and Emotion*, *12,* 737–753.

Compton, R. (2003). The interface between emotion and attention: A review of evidence from psychology and neuroscience. *Behavioral and Cognitive Neuroscience Reviews, 2,* 115–129.

Dehaene, S., & Naccache, L. (2006). Can one suppress subliminal words? *Neuron, 52,* 397-399.

Dolcos, F., LaBar, K.S., & Cabeza, R. (2004). Dissociable effect of arousal and valence on prefrontal activity indexing emotional evaluation and subsequent memory: An event-related fMRI study. *Neuroimage, 23,* 64-74.

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

Fox, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition & Emotion, 16,* 355-379.

Hansen, C.H., & Hansen, R. (1988). Finding the face in the crowd: An anger superiority effect. *Journal of Personality and Social Psychology, 54*, 917-924.

Hunt, A.R., Cooper, R.M., Hungr, C., & Kingstone, A. (2007). The effect of emotional faces on eye movements and attention. *Visual Cognition, 15*, 513-531.

Jiang, Y., Costello, P., Fang, F., Huang, M., & He, S. (2006). A gender- and sexual orientation-dependent spatial attentional effect of invisible images. *PNAS, 103,* 17048-17052.

Jiang, Y., Costello, P., & Sheng, H. (2007). Advantages of upright faces and recognizable words in overcoming interocular suppression. *Psychological Science, 18,* 349-355.

Kanai, R., Tsuchiya, N., & Verstraten, F.A. (2006). The scope and limits of top-down attention in unconscious visual processing. *Current Biology, 16,* 2332-2336.

Kim, C.-Y., & Blake, Randolph. (2005). Psychophysical magic: Rendering the visible 'invisible'. *Trends in Cognitive Science, 9,* 381-388.

Klein, R.M. (2000). Inhibition of Return. *Trends in Cognitive Sciences, 4,* 138-147.

Koster, E. H., Crombez, G., Verschuere, B., Vanvolsem, P., & De Houwer, J. (2007). A time-course analysis of attentional cueing by threatening scenes. *Experimental Psychology, 54,* 161-171.

Kreiman, G., Fried, I., & Koch, C. (2002). Single-neuron correlates of subjective vision in the human medial temporal lobe. *Proceedings of the National Academy of Science of the United States of America, 99,* 8378-8383.

Krysko, K. M., & Rutherford, M. D. (2009). A threat-detection advantage in those with autism spectrum disorders. *Brain Cognition, 69,* 472-480.

Kunst-Wilson, W.R., & Zajonc, R.B. (1980). Affective discrimination of stimuli that cannot be recognized. *Science, 207,* 557-558.

Lupiáñez, J., Milán, E. G., Tornay, F. J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks? Yes, it does, but later. *Perceptual Psychophysics, 59,* 1241-54.

Lupiánez, J., Milliken, B., Solano, C., Weaver, B., & Tipper, S. P. (2001). On the strategic modulation of the time course of facilitation and inhibition of return. *The Quarterly Journal of Experimental Psychology, 54A,* 753-773.

MacLeod, C., Mathews, A., & Tata, P. (1986). Attentional bias in emotional disorders. *Journal of Abnormal Psychology*, *95,* 15–20.

Milders, M., Sahraie, A., Logan, S., & Donnellon, N. (2006). Awareness of faces is modulated by their emotional meaning. *Emotion, 6,* 10-17.

Mogg, K., & Bradley, B. (1999). Orienting of attention to threatening facial expressions presented under conditions of restricted awareness. *Cognition and Emotion, 13,* 713-740.

Mogg, K., Holmes, A., Garner, M., & Bradley, B.P. (2008). Effects of threat cues on attentional shifting, disengagement and response slowing in anxious individuals. *Behavior Research and Therapy, 46,* 656-667.

Moradi, F., Koch, C., & Shimojo, S. (2005). Face adaptation depends on seeing the face. *Neuron, 45,* 169-175.

Öhman, A., Lundqvist, D., & Esteves, F. (2001). The face in the crowd revisited: A threat advantage with schematic stimuli. *Journal of Personality and Social Psychology, 80,* 381-396.

Öhman, A., & Soares, J. (1993). On the automaticity of phobic fear: Conditioned skin conductance responses to masked phobic stimuli. *Journal of Abnormal Psychology, 102,* 121-132.

Palermo, R., & Rhodes, G. (2007). Are you always on my mind? A review of how face perception and attention interact. *Neuropsychologia, 45,* 75-92.

Pasley, B. N., Mayes, L. C. & Schultz, R. T. (2004). Subcortical discrimination of unperceived objects during binocular rivalry. *Neuron, 42*, 163–172.

Pessoa, L. (2005). To what extent are emotional visual stimuli processed without attention and awareness? *Current Opinion in Neurobiology, 15,* 188-196.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), Attention and performance X: Control of language processes (pp. 531–556). London: Erlbaum.

Posner, M.I., Snyder, C.R., & Davidson, B.J. (1980). Attention and the detection of signals. *Journal of Experimental Pschology: General, 109,* 160-174.

Schall, J.D., Nawrot, M., Blake, R., & Yu, K. (1993). Visually guided attention is neutralized when informative cues are visible but unperceived. *Vision Research, 33*, 2057-2064.

Shrum, L.J. (2005). *The psychology of entertainment media: Blurring the lines between entertainment and persuasion.* Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers. xvi, 360 pp.

Smith, S. D., Most, S. B., Newsome, L. A., & Zald, D. H. (2006). An emotion-induced attentional blink elicited by aversively conditioned stimuli. *Emotion, 6,* 523-527.

Taylor, M.M., & Creelman, C.D. (1967). PEST: Efficient estimates on probability functions. *Journal of the Acoustical Society of America, 41,* 782-787.

Vogt, J., De Houwer, J., Koster, E.H.W., Van Damme, S., & Crombez, G. (2008). Allocation of spatial attention to emotional stimuli depends upon arousal and not valence. *Emotion, 8,* 880-885.

Vuilleumier, P., & Schwartz, S. (2001). Emotional facial expressions capture attention. *Neurology, 56,* 153-158.

Wantanabe, T., Náñez, J.E., & Sasaki, Y. (2001). Perceptual learning without perception. *Nature, 413*, 844-848.

Whalen, P.J., Rauch, S.L., Etcoff, N.L., McInerney, S.C., Lee, M.B., & Jenike, M.A. (1998). Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. *The Journal of Neuroscience, 18,* 411-418.

Wilke, M., Logothetis, N.K., & Leopold, D.A. (2006). Local field potential reflects perceptual suppression in monkey visual cortex. *Proceedings of the National Academy of Science of the United States of America, 103,* 17507-17512.

Williams, L. M., Liddell, B. J., Kemp, A. H., Bryant, R. A., Meares, R. A. & Peduto, A. S. (2006). Amygdala-prefrontal dissociation of subliminal and supraliminal fear. *Human Brain Mapping, 27,* 652–661.

Williams, M. A., Morris, A. P., McGlone, F., Abbott, D. F. & Mattingley, J. B. (2004). Amygdala responses to fearful and happy facial expressions under conditions of binocular suppression. *Journal of Neuroscience, 24,* 2898–2904.

Yang, E., Zald, D.H., & Blake, R. (2007). Fearful expressions gain preferential access to awareness during continuous flash suppression. *Emotion, 7,* 882-886.

Zald, D.H. (2003). The human amygdala and the emotional evaluation of sensory stimuli, *Brain Research Review, 41,* 88–123.

Tables

Table 1. 1 and 2-way ANOVA results for accuracy (percent correct) and response time (RT) from 5 versions of Experiment 4. None of the results reached significance.

Percent Correct	5 cond, 1-way ANOVA		4x2 ANOVA	
	cue type	emotion	validity	emot*validity
200/50	f(4,60)=1.2 p=.325	f(3,45)=.3 p=.769	f(1,15)=.1 p=.263	f(3,45)=.9 p=.434
500/50	f(4,56)=.1 p=.953	f(3,42)=.647 p=.573	f(1,14)=2.5 p=.133	f(3,42)=1.9 p=.120
500/100	f(4,60)=.3 p=.867	f(3,45)=.4 p=.716	f(1,15)=4.2 p=.058	f(3,45)=1.5 p=.244
800/50	f(4,52)=.9 p=.436	f(3,39)=.3 p=.782	f(1,13)=.1 p=.8	f(3,29)=.2 p=.865
800/100	f(4,60)=1.0 p=.391	f(3,45)=.5 p=.662	f(1,15)=1.5 p=.234	f(3,45)=.6 p=.557

RT	5 cond, 1-way ANOVA		4x2 ANOVA	
	cue type	emotion	validity	emot*validity
200/50	f(4,60)=1.2 p=.322	f(3,45)=1.2 p=.310	f(1,15)=.2 p=.696	f(3,45)=.2 p=.817
500/50	f(4,56)=.9 p=.382	f(3,42)=1.6 p=.229	f(1,14)=.9 p=.363	f(3,42)=.5 p=.6
500/100	f(4,60)=1.4 p=.264	f(3,45)=1.6 p=.199	f(1,15)=.2 p=.642	f(3,45)=.3 p=.818
800/50	f(4,52)=.3 p=.765	f(3,39)=1.1 p=.354	f(1,13)=.007 p=.936	f(3,39)=2.2 p=.145
800/100	f(4,60)=2.1 p=.103	f(3,45)=1.9 p=.148	f(1,15)=1.3 p=.265	f(3,45)=.5 p=.669

Figure Captions:

Figure 1. Schematic representation of basic cueing paradigm with neutral cue (Experiment 1): On most trials, a red frame is presented to the right or left of a centrally located fixation point, either correctly (valid trial) or incorrectly (invalid trial) predicting the location of a subsequent target grating. On other trials (no cue), the fixation point turns red instead. When the target grating disappears, participants are asked to indicate, using the right and left arrow keys, the orientation of the grating's tilt.

Figure 2. Results of Experiment 1: Mean reaction time (RT) of tilt discrimination as a function of cue condition. Validly cued trials resulted in significantly faster response times than both invalidly cued trials and no cue trials. In addition, no cue trials resulted in significantly faster response times than invalidly cued trials. Error bars represent standard errors of the mean.

Figure 3. Schematic representation of Location Discrimination/Tilt Discrimination Task (Experiment 2): A face is presented to the right or left of a centrally located fixation point, either correctly (valid trial) or incorrectly (invalid trial) predicting the side of a subsequent target grating. Participants are asked to indicate, using the right and left arrow keys, the location or the orientation of the target grating. Unlike the design for Experiment 1, the target grating is positioned lateral to the location of the facial cue, rather than at an overlapping location.

Figure 4. Results of Experiment 2: Mean RTs as a function of task and cue validity. In both tasks, validly cued trials resulted in significantly faster response times than invalidly cued trials. Error bars represent standard errors of the mean.

Figure 5. Mean accuracy results of Experiment 2: The left figure illustrates the emotion X validity interaction observed in the location discrimination task. Valid trials with fearful faces as cues resulted in significantly more correct responses than valid trials with neutral, happy, or angry faces. The right figure illustrates the main effect for emotional condition in the tilt discrimination task. Fearful faces resulted in significantly more correct trials than happy faces or angry faces. Error bars represent standard errors of the mean.

Figure 6a. Schematic representation of Experiment 3a: One eye is presented with a face and its phase-scrambled counterpart to opposite sides of the fixation point. The face either correctly (valid trial) or incorrectly (invalid trial) predicts the side of a subsequent target grating. The other eye is presented with a dynamic Mondrian display that overlaps with the locations of the facial cue. Participants are asked to indicate, using the right and left arrow keys, the orientation of the grating's tilt. As before, the target grating is positioned lateral to the location of the facial cue, rather than at an overlapping location. Dotted lines are used to indicate the spatial configuration, but do not represent frames.

Figure 6b. Schematic representation of Experiment 3b: The spatial and temporal configuration is the same as Experiment 3a except that Mondrian display overlaps with the locations of both the facial cue and subsequent grating.

Figure 6c. Schematic representation of Experiment 3c and Experiment 4: One eye is presented with a face and its phase-scrambled counterpart to opposite sides of the fixation point. The face either correctly (valid trial) or incorrectly (invalid trial) predicts the location of a subsequent target grating. The other eye is presented with a dynamic Mondrian display that overlaps with the locations of the facial cue and subsequent target. Participants are asked to indicate, using the right and left arrow keys, the orientation of grating's tilt. Unlike the other versions of this experiment, the target grating overlaps the location of the facial cue. Dotted lines are used to indicate the spatial configuration, but do not represent frames. In Experiment 4 the cue duration (200ms, 500ms, 800ms), inter-stimulus interval (50ms, 100ms) and grating duration (50ms, 100ms) varied.

Figure 7. Results of Experiment 3: Figure on left shows mean RT as a function of spatial configuration and cue validity. Only version FCG (3c) exhibited a statistically significant cueing effect. Validly cued trials resulted in significantly longer RTs than invalidly cued trials. Figure on right shows the breakdown of mean RTs as a result of emotional condition. In version FCG (3c), trials with neutral facial cues were responded to more quickly than trials with fearful or angry facial cues. Error bars represent standard errors of the mean.

Figure 8. Schematic representation of the control test in Experiment 4: One eye is presented with a face either to the right or left of a central fixation point. On the opposite side of the fixation point, a phase scrambled counterpart is presented. The other eye is presented with a dynamic Mondrian display that overlaps with the location of the facial cue. Participants are asked to indicate with the left or right arrow keys, the side at which the face was presented.

Figure 9. Results of the control test in Experiment 4: Mean accuracy as a function of emotional condition. Differences between conditions were not significant nor was the interaction between emotion and cue duration. However, fearful trials resulted in significantly more correct responses when compared to chance (.5). Error bars represent standard errors of the mean.

Figure 1.

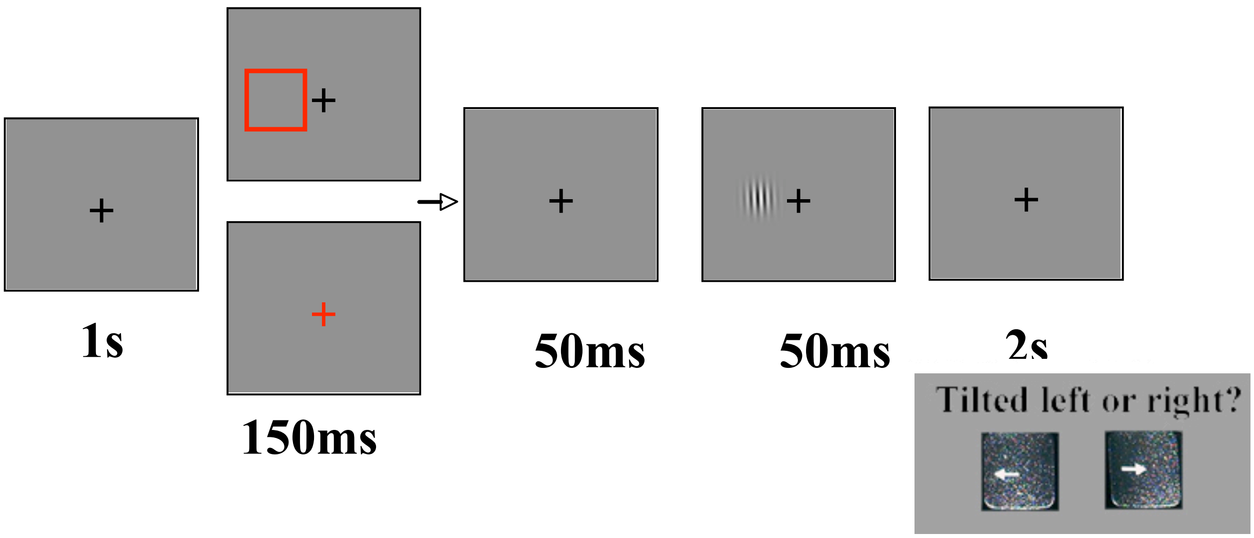


Figure 2.

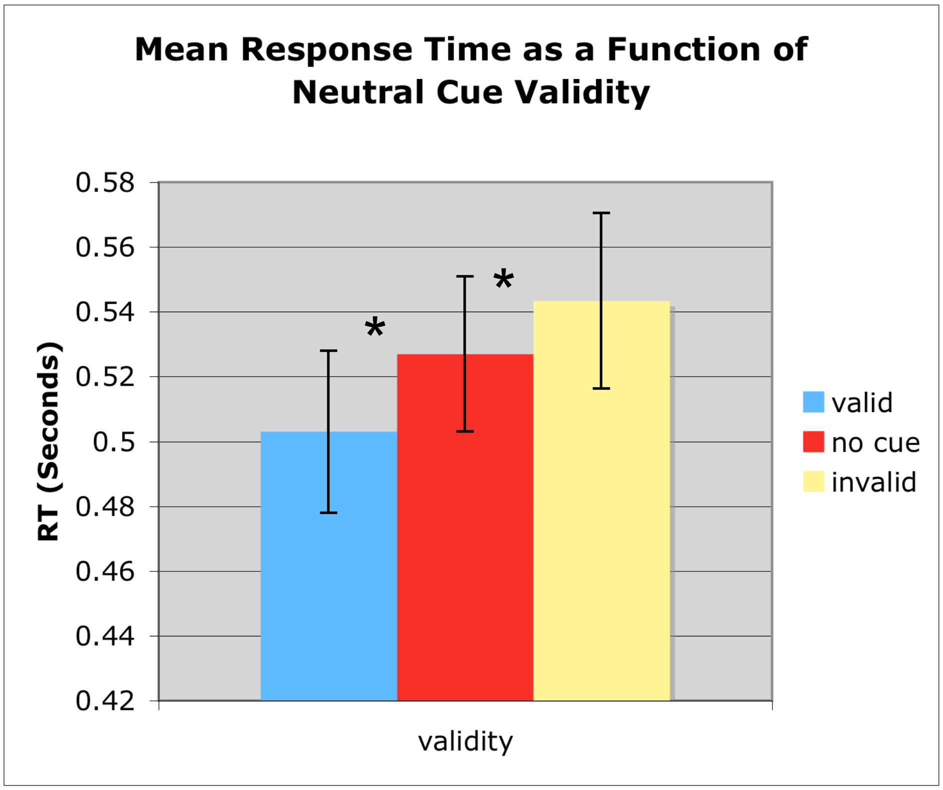

Mean Response Time as a Function of Neutral Cue Validity
RT (Seconds)
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
*
*
validity
valid
no cue
invalid

Figure 3.

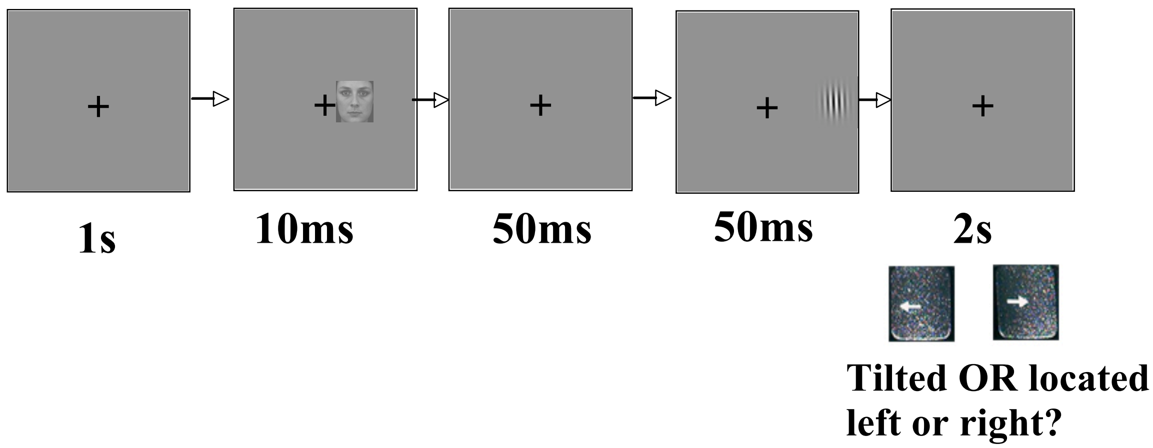


Figure 4.

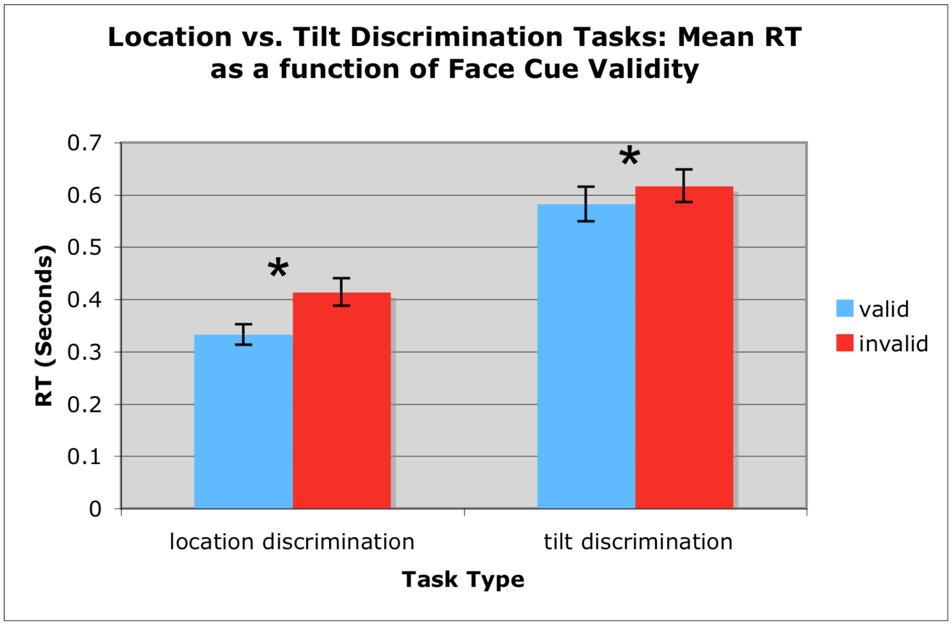
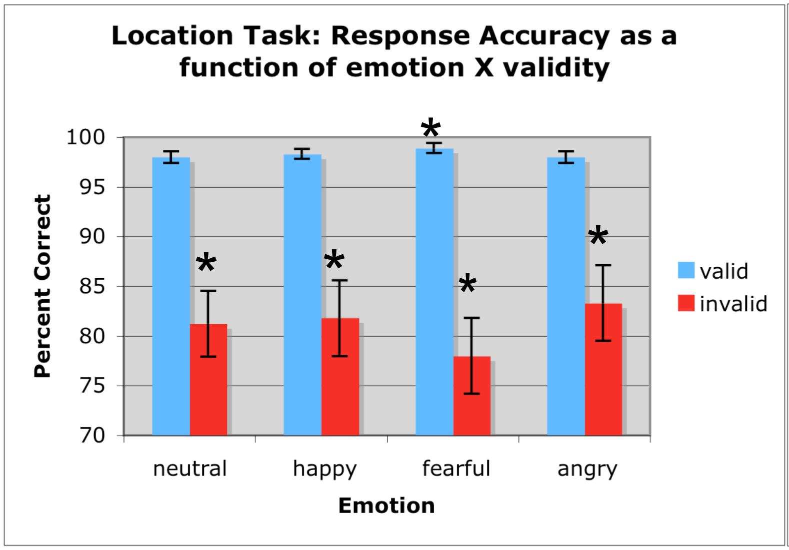

Location vs. Tilt Discrimination Tasks: Mean RT as a function of Face Cue Validity
RT (Seconds)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
*
*
location discrimination
tilt discrimination
Task Type
valid
invalid

Figure 5.


Location Task: Response Accuracy as a function of emotion X validity
Percent Correct
100
95
90
85
80
75
70
neutral
happy
fearful
angry
Emotion
valid
invalid
*
*
*
*
*

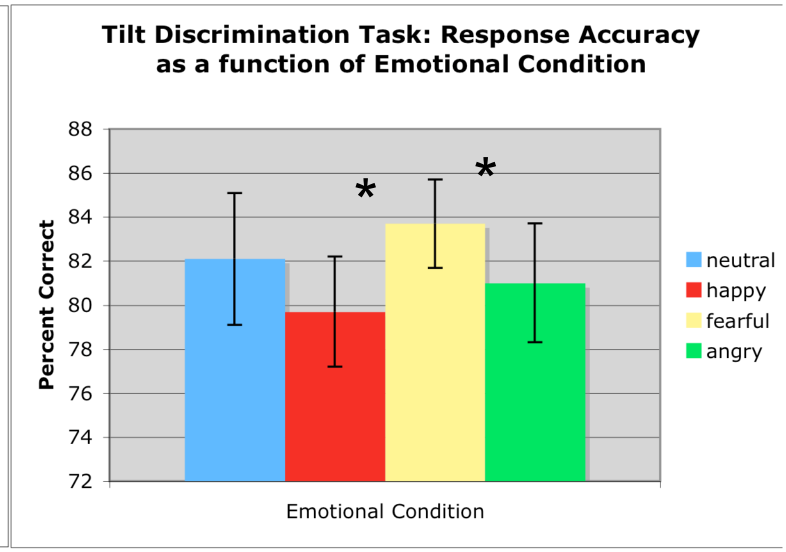

Tilt Discrimination Task: Response Accuracy as a function of Emotional Condition
Percent Correct
88
86
84
82
80
78
76
74
72
Emotional Condition
neutral
happy
fearful
angry
*
*

Figure 6a.

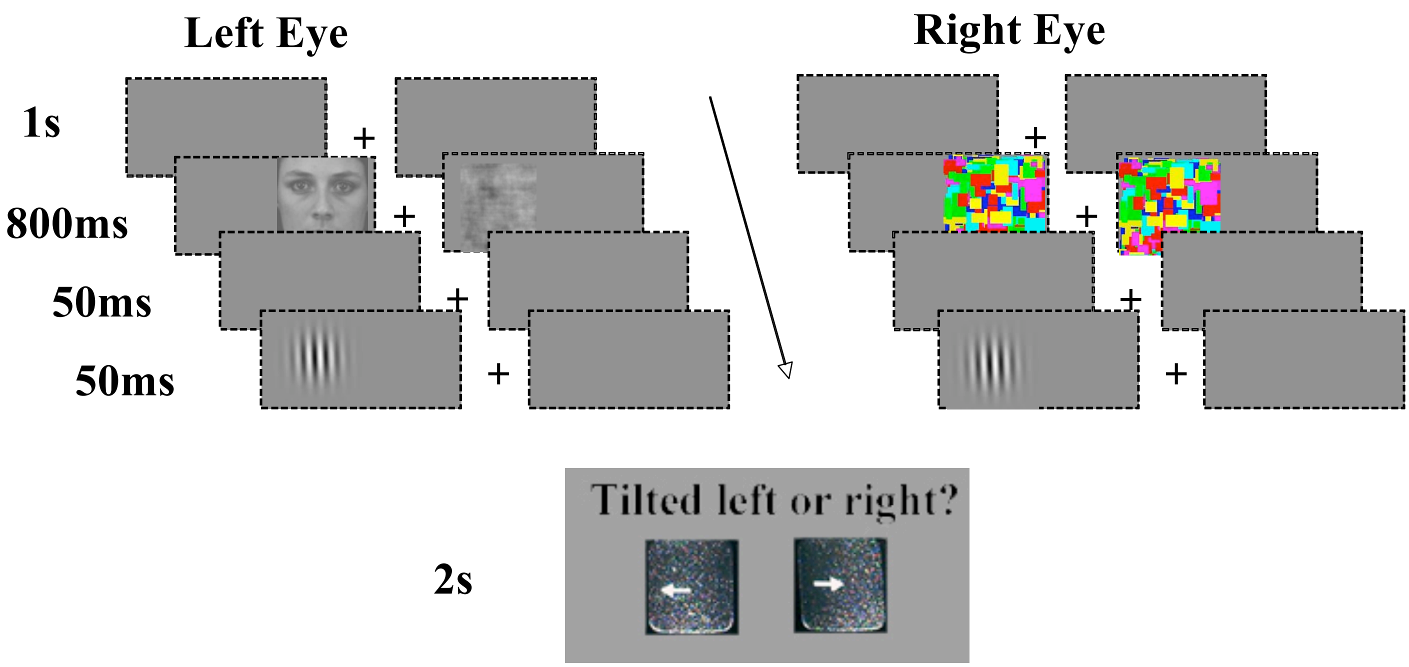


Figure 6b.

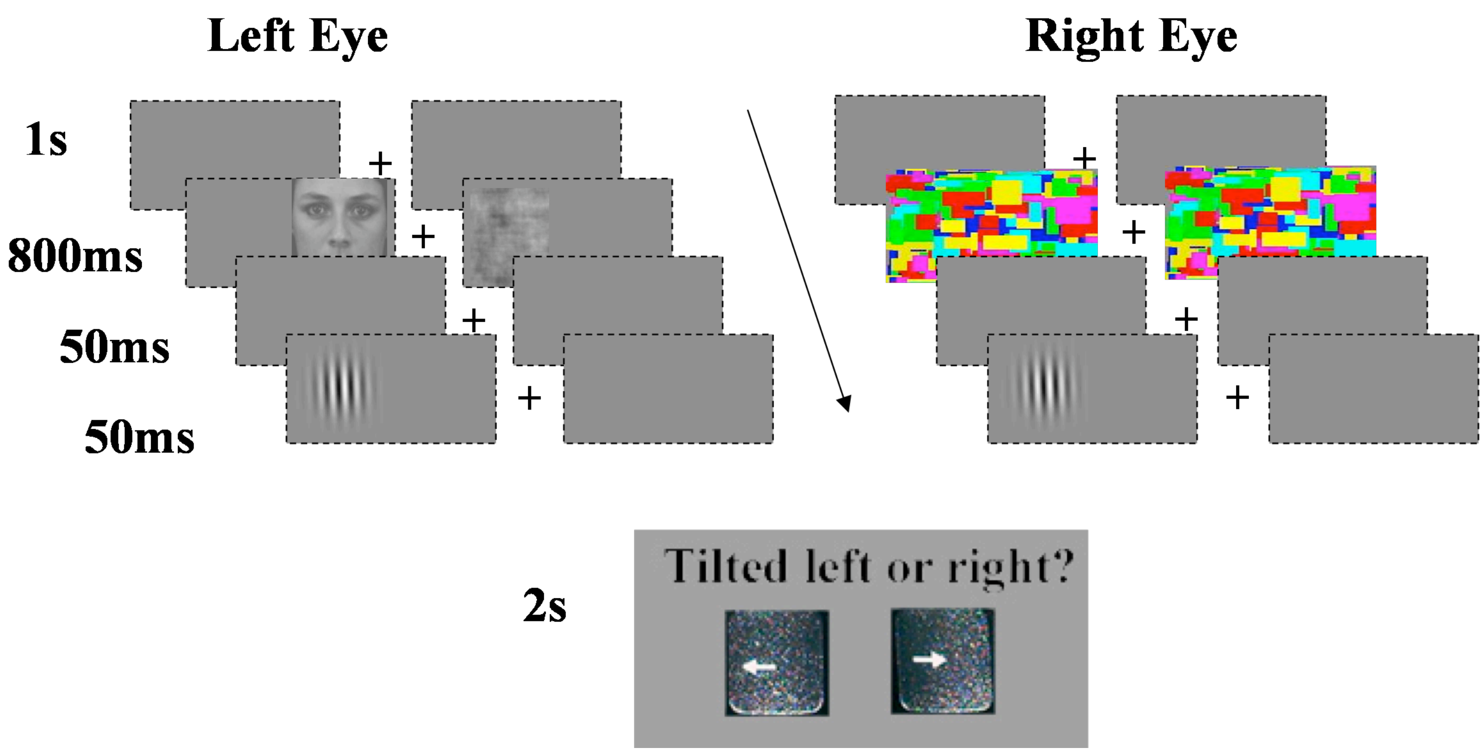


Figure 6c.

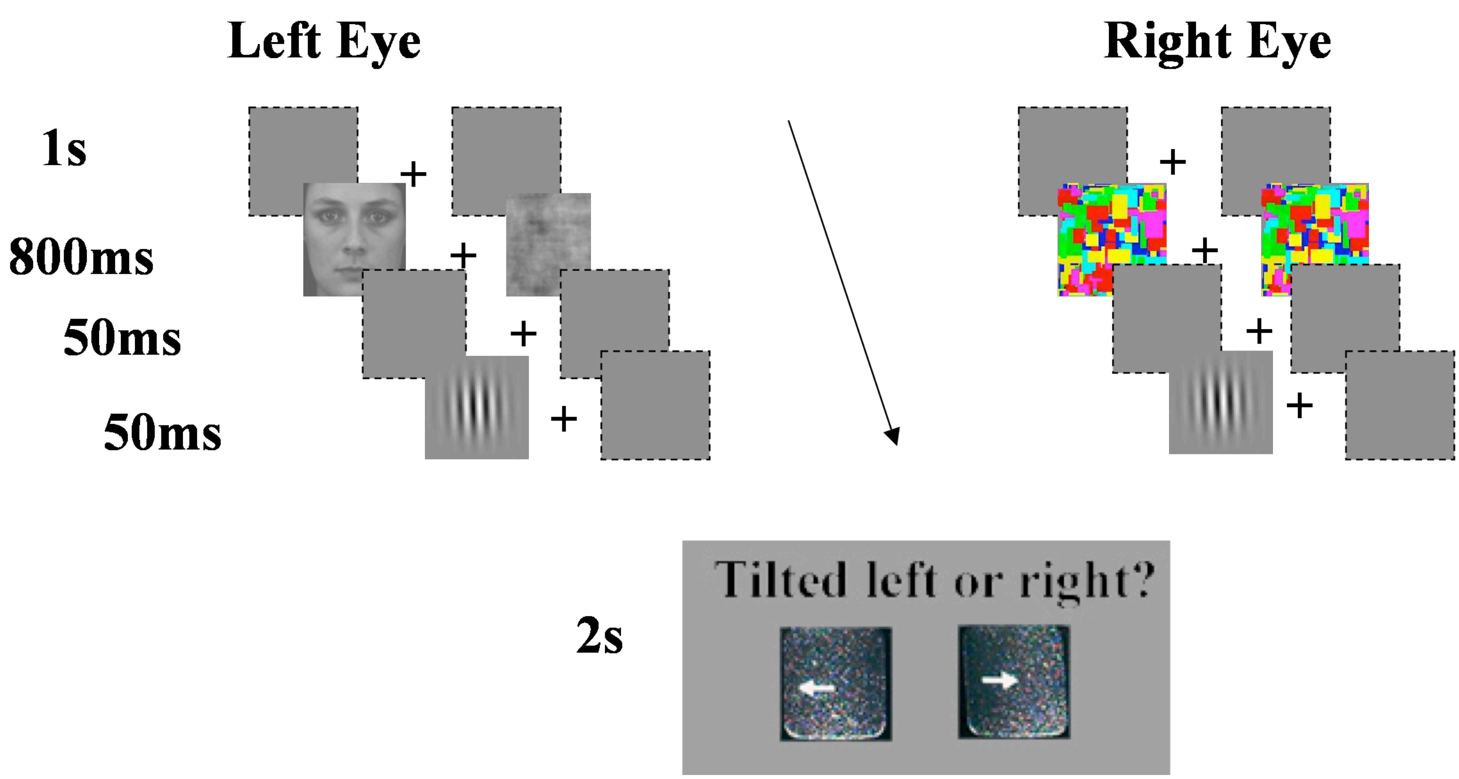


Figure 7.

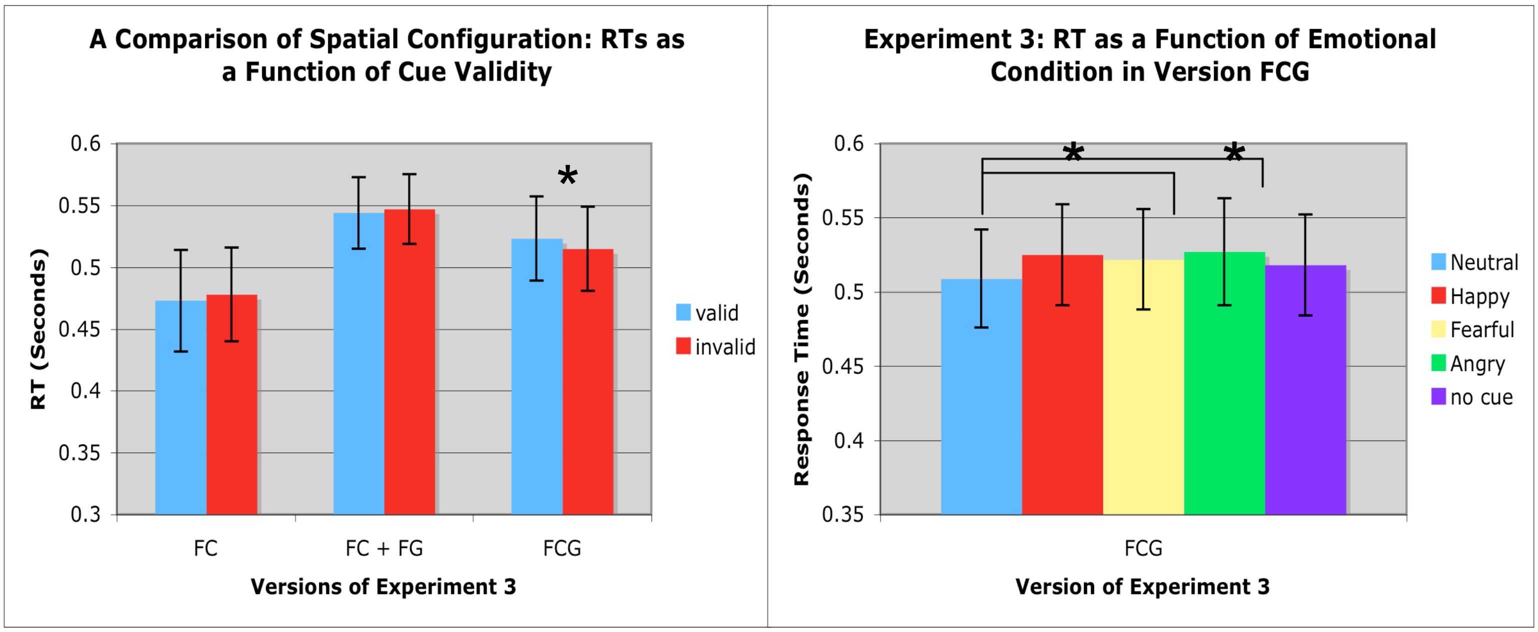

A Comparison of Spatial Configuration: RTs as a Function of Cue Validity
0.6
0.55
0.5
0.45
0.4
0.35
0.3
RT (Seconds)
*
FC
FC + FG
FCG
Versions of Experiment 3
valid
invalid
Experiment 3: RT as a Function of Emotional Condition in Version FCG
0.6
0.55
0.5
0.45
0.4
0.35
Response Time (Seconds)
*
*
FCG
Version of Experiment 3
Neutral
Happy
Fearful
Angry
no cue

Figure 8.

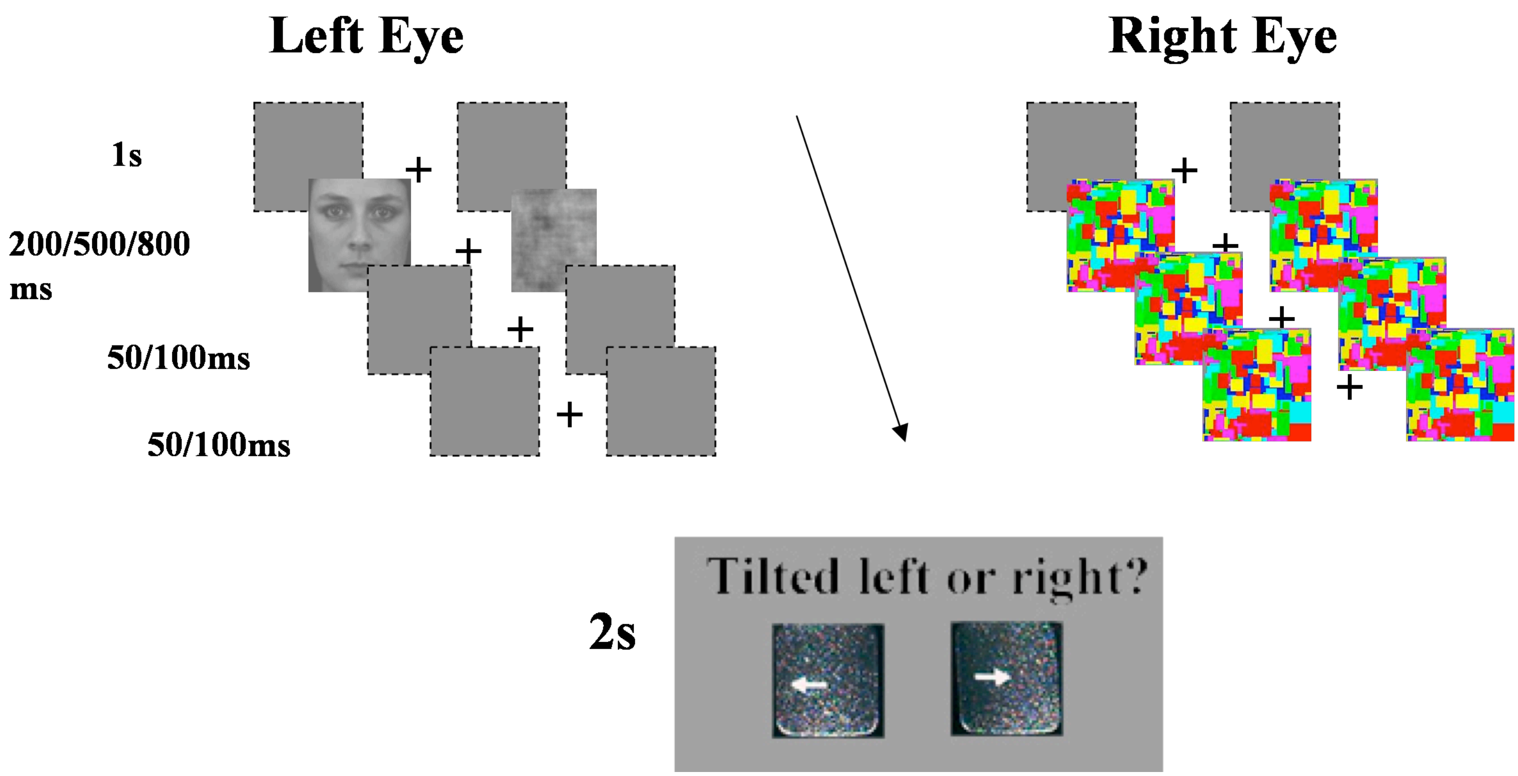
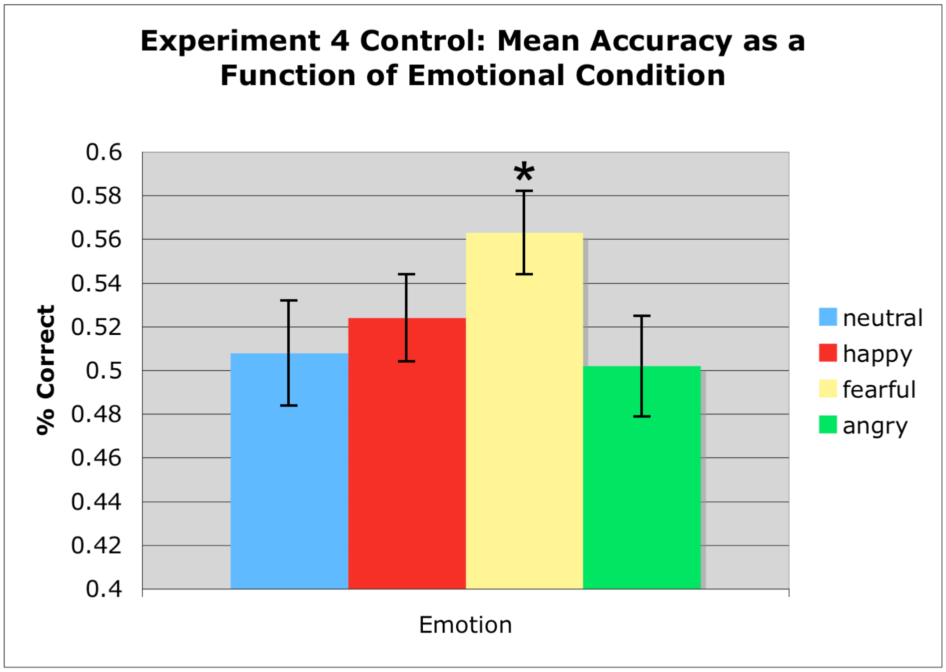

Left Eye
Right Eye
1s
200/500/800 ms
50/100ms
50/100ms
2s
Tilted left or right?

Figure 9.


Experiment 4 Control: Mean Accuracy as a Function of Emotional Condition
0.6
0.58
0.56
0.54
0.52
0.5
0.48
0.46
0.44
0.42
0.4
% Correct
*
neutral
happy
fearful
angry
Emotion