

Effect of Emotional Primes on Sensitivity to Tilt as a  
Function of Spatial Frequency and Orientation

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### **Abstract**

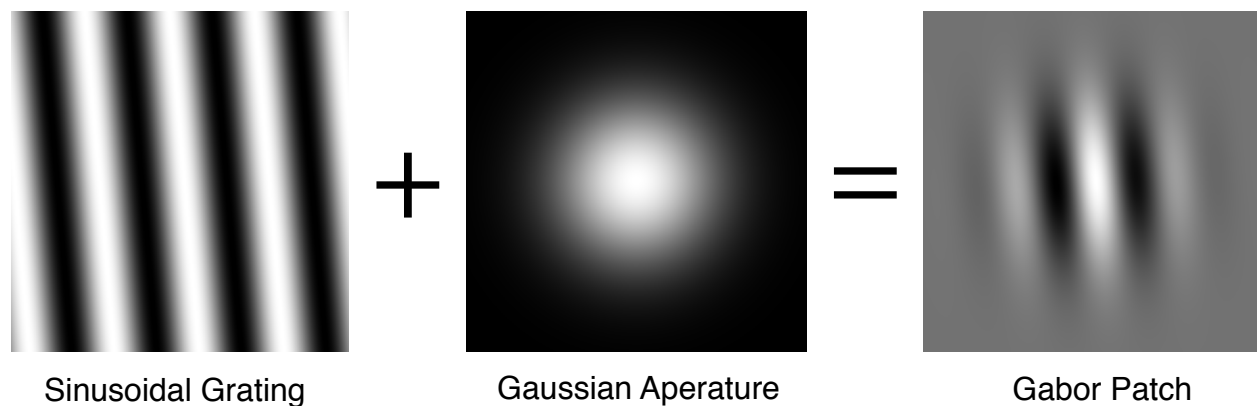
Recent research has uncovered effects of affective priming on early vision. A recent study found that primes consisting of faces from the Ekman Faces Database increased sensitivity to the tilt of vertically oriented low spatial frequency (SF) stimuli, while sensitivity for high SF stimuli decreased. They concluded that this effect was due to heightened arousal facilitating processing in the magnocellular pathway at the expense of the parvocellular pathway. We attempted to generalize these findings to the Radboud Faces Database and to vertical and horizontal gratings and plaids. Our findings for vertical gratings were similar to theirs, but we found no effect for gratings of other orientations or plaids containing multiple orientations. This suggests that the effect is not purely due to differential magnocellular-parvocellular processing, as these systems are not thought to selectively process stimuli based on orientation. That the interaction between emotional valence of primes, SF, and orientation of the test stimuli is anisotropic appears to be a novel aspect of human vision.

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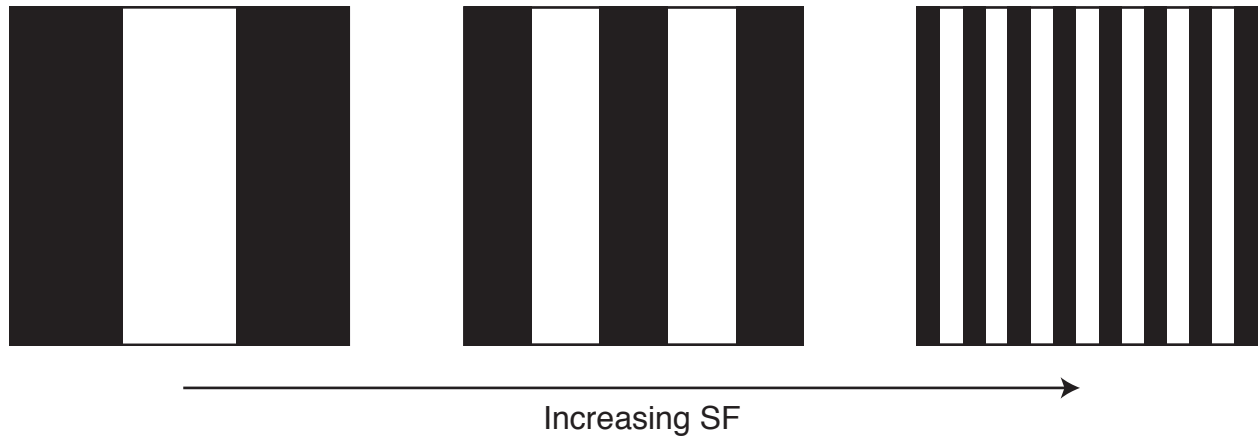
The traditional model of visual processing describes two general dimensions along which processing takes place and to which a neural substrate contributes. “Level” of processing is an indefinite categorization that can be loosely described as the complexity of the features identified, and it generally increases with number of synapses removed from the retina. *Low-level* processing identifies simple features such as points, lines, simple movement, and edges, while *high-level* processing identifies complex features such as faces, objects, complex movement and locations. A second, less fluid categorization is that of parvocellular vs. magnocellular; parvocellular processing analyzes detail and is responsible for object recognition, while magnocellular processing analyzes location, complex motion, and vision for eye-hand-coordination. While initially established at the retinal level, the distinction becomes increasingly important in extra-striate areas, where they separate into the ventral stream (parvocellular; in the temporal lobe) and dorsal stream (magnocellular; in the parietal lobe).

Tilt is a relatively low-level feature first coded in the primary visual cortex, or V1. Earlier feature detectors (in the retina and the thalamus) are *center-surround*; depending on the individual cell, they maximally fire for points of light surrounded by darkness or points of darkness surrounded by light. *Simple Cells* in V1 display the greatest response to bars or edges of a particular orientation. *Gabor patches* model the receptive field of a simple cell, and are composed of a sinusoidal grating windowed by a radial Gaussian

aperture (i.e. fuzzy, parallel, alternating light and dark lines with a circular, blurry edge) (Figure 1). The width of the lines is inversely proportional to their *spatial frequency* (SF), which is measured as cycles-per-degree (cpd) (where a cycle is a dark and light bar, and degrees is a degree of the visual field). The effect of varying SF on a grating can be seen in Figure 2. In addition to an ideal orientation, each simple cell has a preferred SF, which forms an important functional distinction between parvocellular and magnocellular cells in the visual system. While there is no hard cutoff, a rough demarcation can be made at 3 cpd, with magnocellular cells preferring lower SFs and parvocellular cells preferring higher SFs. Note that in this traditional model, all inputs to V<sub>1</sub> arrive from center-surround cells in the LGN of the thalamus, leaving no mechanism for top-down modulation.



*Figure 1.* Structure of a Gabor patch. A Gabor patch is a model of the receptive field of a V<sub>1</sub> simple cell, and is therefore often used as a stimulus. Only a single SF is represented: there are no extraneous high-spatial frequency features such as hard edges, which are found in a square-wave gratings or hard circular apertures. This patch is slightly positively (ccw) rotated.



*Figure 2.* Square-wave gratings of varying spatial frequencies (SF). While SF increases from left to right, exact SF varies with the size of the stimulus and the distance to the viewer.

It has long been established that high-level visual perception is subject to top-down modulation. For example, in 1988, Hansen & Hansen found that angry faces in crowds of neutral faces are more quickly identified than neutral faces in crowds of angry faces. This is consistent with well-demonstrated effects of top-down modulation on higher-order cognitive processing and executive functioning. In contrast, early vision is traditionally considered to be a primarily bottom-up process. Recently, however, physiological and behavioral evidence has uncovered top-down modulation of the early visual system and low-level visual perception, affecting perception of simple features such as tilt and contrast.

In 1998, Lang et al. used fMRI to study physiological responses of the visual cortex to affective primes. Greater activation of both primary and secondary visual regions were observed when a subject viewed pleasant and unpleasant images than when a subject viewed neutral images. While the responses of individual cells may be expected to be different due to structural differences in the images (for example, the up-facing vs. down-

facing contour of the mouth), this would not cause a change in the average activation evidenced by the BOLD signal; it is external modulation due to emotional valence that is implicated in the observed overall increase. This response may, in part, be initiated by projections from the amygdala to the visual cortex, as characterized by Amaral, Behenia, & Kelly (2003).

Emotional modulation of amygdala activity for unperceived angry faces was demonstrated by Morris, Öhman, & Dolan (1998). They sequentially presented two faces – one fearful, and one neutral – to subjects in a PET scanner, and manipulated the order of the faces and whether or not the presence of the fearful face was paired with a negative unconditioned stimulus (100-dB white noise). When the angry face was presented first, the neutral one successfully masked it; subjects had a 0% detection rate. There were thus four conditions: Masked-Conditioned, Unmasked-Conditioned, Masked-Unconditioned, and Unmasked-Unconditioned. The left amygdala showed significantly greater activation for Unmasked-Conditioned than for Unmasked-Unconditioned. The right amygdala showed significantly greater activation for the Masked-Conditioned than the Masked-Unconditioned. Both amygdalae showed significantly greater activation for Conditioned than Unconditioned stimuli, both Masked and Unmasked. Therefore, not only can unattended and unperceived stimuli influence neural activation, but also it is likely that dedicated circuitry and lateralization exist to perform this roll, and the amygdala has the capability to modulate its responses based on past experiences.

Phelps, Ling and Carrasco (2006) uncovered the first *behavioral* evidence of affective primes influencing early vision. They used an orientation discrimination task to

measure contrast thresholds for Gabor patches with an SF of 3 cpd preceded by a fearful or neutral face, either upright or upside-down. Upright fearful faces increased contrast sensitivity relative to neutral faces. Upside-down fearful faces had no effect, establishing affective valence as the causative factor.

Bocanegra & Zeelenberg's 2009 study revealed that affective primes' influence was dependent on the SF of the test stimuli. Tilt sensitivity for Gabor patches with a range of SFs was measured when preceded by a fearful or a neutral face from the Ekman Faces Database. For low SFs (less than 3 cpd), fearful faces increased sensitivity relative to neutral faces; for high SFs (greater than 3 cpd), fearful faces led to decreased sensitivity, as shown in Figure 3. A further experiment utilizing inverted faces found no effect, demonstrating the significance of emotional valence. They suggested that this effect was due to heightened arousal caused by the fearful faces facilitating processing in the magnocellular pathway (which processes low SF information) at the expense of the parvocellular pathway (which processes high SF information).

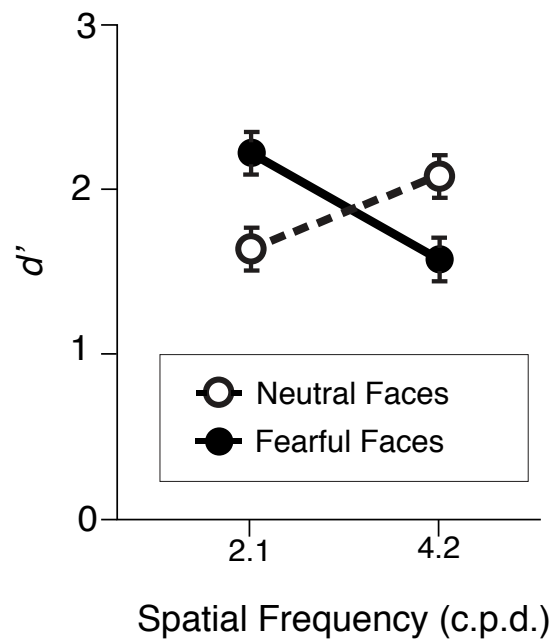
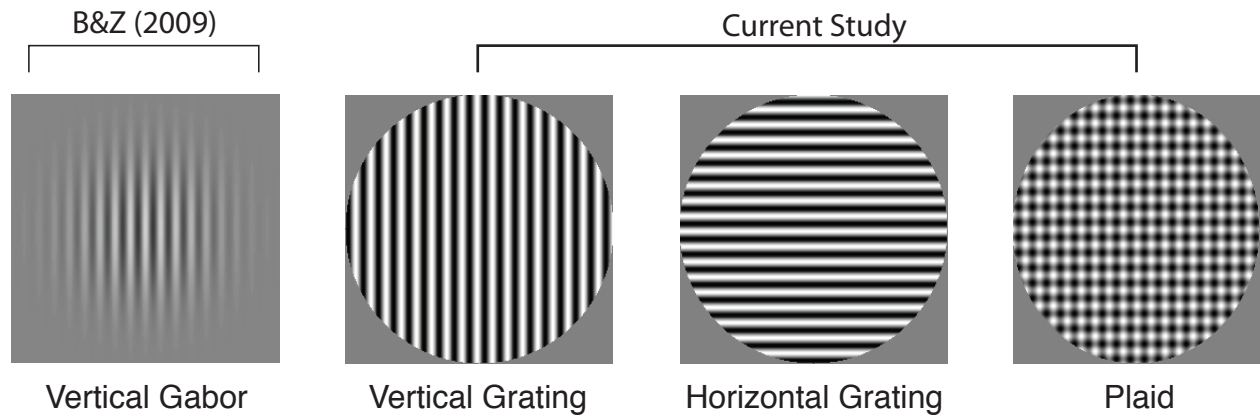


Figure 3. Example of Bocanegra & Zeelenberg's (2009) effect. A fearful prime increases sensitivity to low SF vertical Gabor patches, but decreases sensitivity to high SF vertical Gabor patches. Adapted from Bocanegra & Zeelenberg (2009).

The current study aims to determine whether Bocanegra and Zeelenberg's findings generalize to the Radboud Faces Database (Langner et al, 2010), and to vertical and horizontal gratings, and horizontal-vertical plaids, both with hard (non-Gaussian) circular apertures. The gratings are displayed in Figure 4, and the primes in Figure 5. If the effect is due to emotional valence, a similar effect should be found for the Radboud faces. If the differences seen for low and high SF are due purely to differential parvocellular-magnocellular processing, they should also occur for horizontal gratings and plaids, as these systems are not thought to selectively process stimuli based on orientation.





*Figure 4.* Test stimuli. The vertical Gabor is similar to those used by Bocanegra & Zeelenberg (2009). The vertical and horizontal sinusoidal gratings and plaids were used in the current study. The plaid is the sum of the vertical and horizontal gratings.



*Figure 5.* Emotional Primes. Neutral (left) and fearful (right) faces, modified from the Ekman Faces Database.

## Experiment 1: Influence of Emotion

### Methods

**Apparatus and Presentation.** Stimuli were presented on a calibrated 22 in. Mitsubishi Diamond Pro 2070 flat-screen CRT monitor with a 1024×768 pixel screen at a refresh rate of 100 Hz. It was controlled by a Cambridge Research Systems ViSaGe Visual Stimulus Generator, in turn controlled by a PC running CRS Toolbox for Matlab. Responses were recorded with a CRS CB6 infrared response box.

Observers' heads were positioned by a chinrest 1 m away from the monitor; the center of the monitor was aligned with the observer's eyes. All tasks were performed binocularly. For all conditions, an audio cue was given at the beginning of each session and before each stimulus. Subjects were not instructed as to the existence or nature of this feedback. The experiment took place in a dimly lit room. Observers were allowed to take breaks as they saw fit.

**Stimuli.** The test stimuli were sinusoidal horizontal gratings, vertical gratings and horizontal-vertical plaids, all 250px wide (angular size of  $5.43^\circ$ ) with either a low (2 cpd) or high (4 cpd) SF, for a total of six test stimuli categories. The stimuli were tilted to varying degrees, with positive tilts corresponding to counter-clockwise rotation and negative corresponding to clockwise rotation.

Affective primes consisted of six images from the Radboud Faces Database (Langner et al, 2010). Two images each of three models were selected: one in which the model was holding a fearful expression, the other neutral. The extra-face areas were

occluded by a feathered mask, and the images cropped. The final resolutions (WxH) were 282x338 px, with the faces spanning roughly 4.5° x 6°. All models were male.

**Procedure.** The six conditions each corresponded to a test stimuli category. Each subject observed two conditions: both low and high SF for one orientation, in separate sessions. Sessions were of one of two “stages”: baseline or experimental. Baseline stages measured tilt thresholds in the absence of primes for each subject, while experimental stages measured tilt thresholds in the presence of primes.

Testing began with baseline stages for both SFs. Thresholds were taken for both positive and negative tilts, with images for both presented during a single session but thresholds extracted separately, using the Method of Constant Stimuli.

Subjects were instructed to maintain fixation on a centrally located cross and stimuli were presented in random order, 5° in the periphery, on either the left or right side. Stimuli were presented for 50 ms, after which the subject was to indicate via button press whether or not the stimuli appeared tilted. Both appearance and degree of tilt are relative to the stimulus’ namesake axis. The correct answer for baseline sessions is always tilted: no not-tilted images were displayed. There was a 100 ms interval between a response, and the presentation of the next image. Actual sessions were preceded by a 60 s preadaptation, composed of a mid-grey screen of 54 cd/m<sup>2</sup>; this was absent in practice sessions.

Before the first attempt of a type of session (i.e. combination of condition and stage), a short practice session was given. If the subject demonstrated sufficient

understanding and ability, they were allowed to proceed to an actual session. If they did not, instructions were clarified and/or further practice was allowed.

Typically, two actual baseline sessions were administered for each condition. The first contained images with a range of positive and negative  $1-10^\circ$  in increments of  $1^\circ$ . Actual baseline sessions had ten trials per tilt for a total of 200 trials; practice sessions had three trials per tilt, for a total of 60 trials. In the second actual baseline session, the range and interval were adjusted (but not the number of trials per tilt) to better match the subject's individual abilities, with the number of total trials around 200 (typically 180 – 240). All baseline sessions for a particular subject were administered sequentially, before progressing to any experimental sessions. The trial loop for baseline sessions is illustrated in Figure 6.

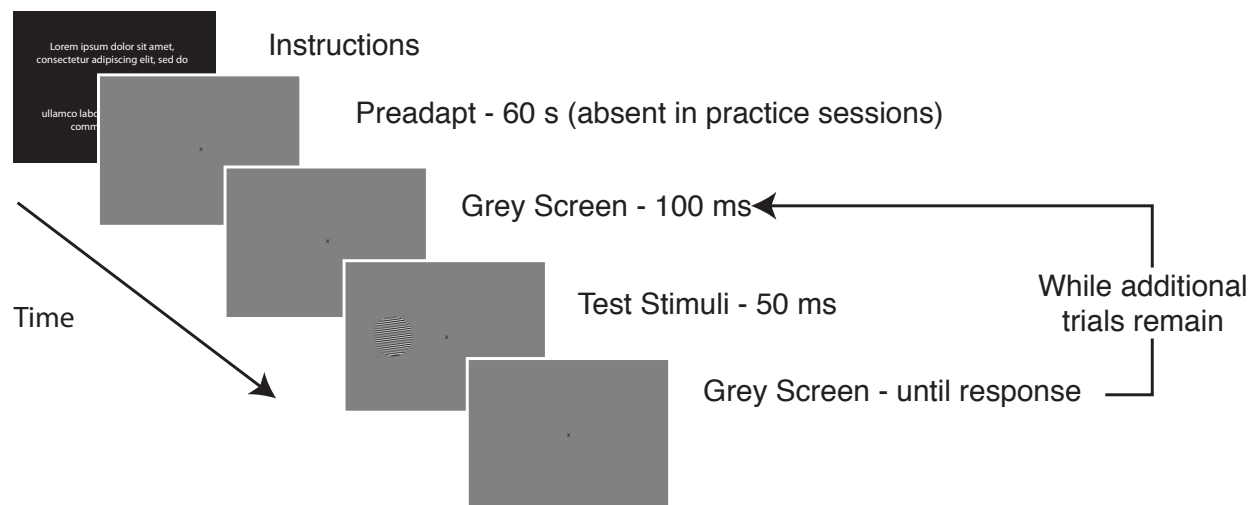


Figure 6. Trial loop for baseline sessions.

Coefficients for a response curve for data from baseline sessions were calculated for a cumulative Weibull distribution from the percent-correct responses for each degree

of tilt using iterative-least-squared estimation and the threshold extracted at 80% correct. If a threshold could not be extracted, another session was run; if a threshold could still not be extracted after several sessions, the subject was dismissed.

Breaks, at the subject's discretion, were allowed between trials and between sessions. Breaks between trials were generally limited to the subject closing their eyes and/or blinking, while between sessions, more extensive activities were allowed (e.g., checking phones, eating, drinking). An additional break of approximately 15 minutes was also mandated between baseline and experimental sessions to allow time to generate individualized stimulus images and to ensure fatigue-free experimentation.

After completion of the baseline sessions, positively and negatively tilted stimuli, tilted at baseline levels (as determined in the baseline sessions) were generated for the experimental sessions, where sensitivity was measured as a function of prime valence and SF. A prime consisting of an image of one of three models holding either a fearful or neutral expression (for six total primes) was presented at 5° in the periphery for 100 ms, followed by a grey screen for 30 ms. The test image was then presented at 5° in the periphery for 40 ms. The four test images consisted of a positively tilted test stimulus, its not-tilted counterpart, a negatively tilted test stimulus, or its not-tilted counterpart. Note that this contrasts with the baseline sessions, in which only tilted images were displayed. Additionally, the same null (not-tilted) stimulus was used for positive and negative; despite being identical, additional presentations must be made because an equal number of tilted and not-tilted images must be displayed for proper data analysis (described below). Figure 7 depicts the trial loop for experimental sessions.

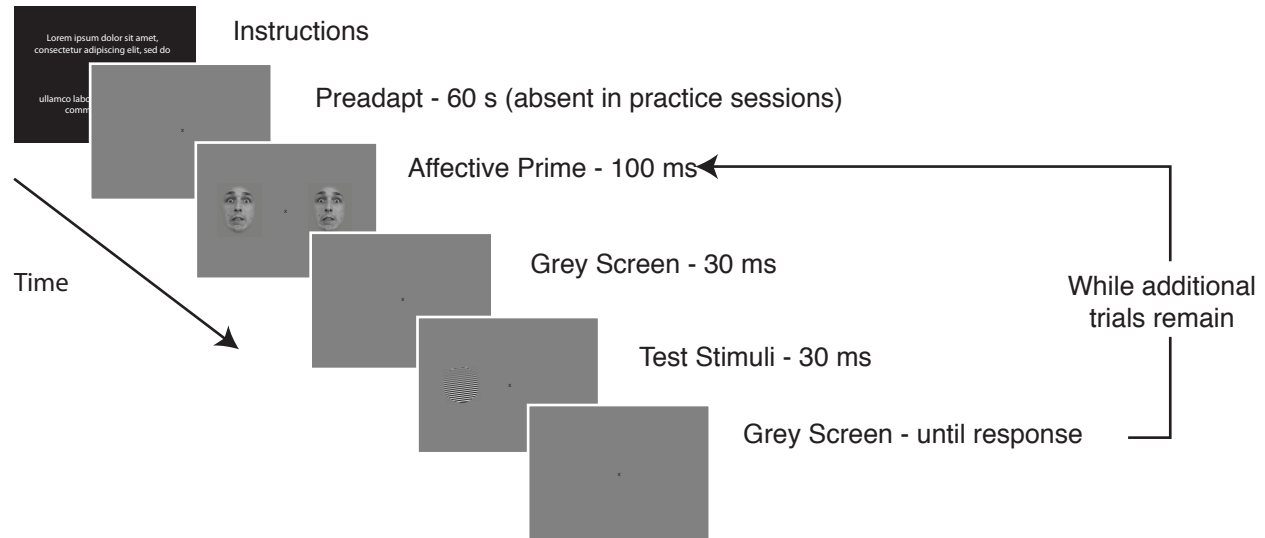


Figure 7. Trial loop for experimental sessions.

Sensitivity was quantified with  $d'$  ( $z[\text{Hits}] - z[\text{False Alarms}]$ ). Scores were calculated separately for positive and negative tilts and averaged for each session, yielding a score for fearful primes and a score for neutral primes. Actual experimental sessions had 12 trials per combination test stimuli and prime, for a total of 288 trials per session; practice sessions had three, for a total of 72.

For the baseline sessions, an additional cue was given after each response to indicate a response had been registered; this cue did not vary across trials. For the experimental sessions, a high-pitched cue indicated that the response was correct, while a low-pitched cue indicated that the response was incorrect.

**Observers and Ethics Statement.** Two authors, six naïve but experienced individuals, and 12 naïve individuals served as observers in the experiment. All observers had normal or corrected-to-normal visual acuity. All research followed the tenets of the World Medical Association Declaration of Helsinki and informed written consent was

obtained from the observers after explanation of the nature of the study. The study was approved by the Queens College Institutional Review Board.

### Results

The results are illustrated by Figure 8. For vertical gratings, there was a significant interaction between SF and prime valence,  $F(1, 17) = 7.38, p = .015$ . There were no significant effects of any kind within horizontal and plaid. There were significant overall effects ( $F(2, 204) = 7.37, p = .015$ ) between vertical and horizontal (Bonferroni,  $p = .039$ ) and horizontal and plaids (Bonferroni,  $p = .008$ ).

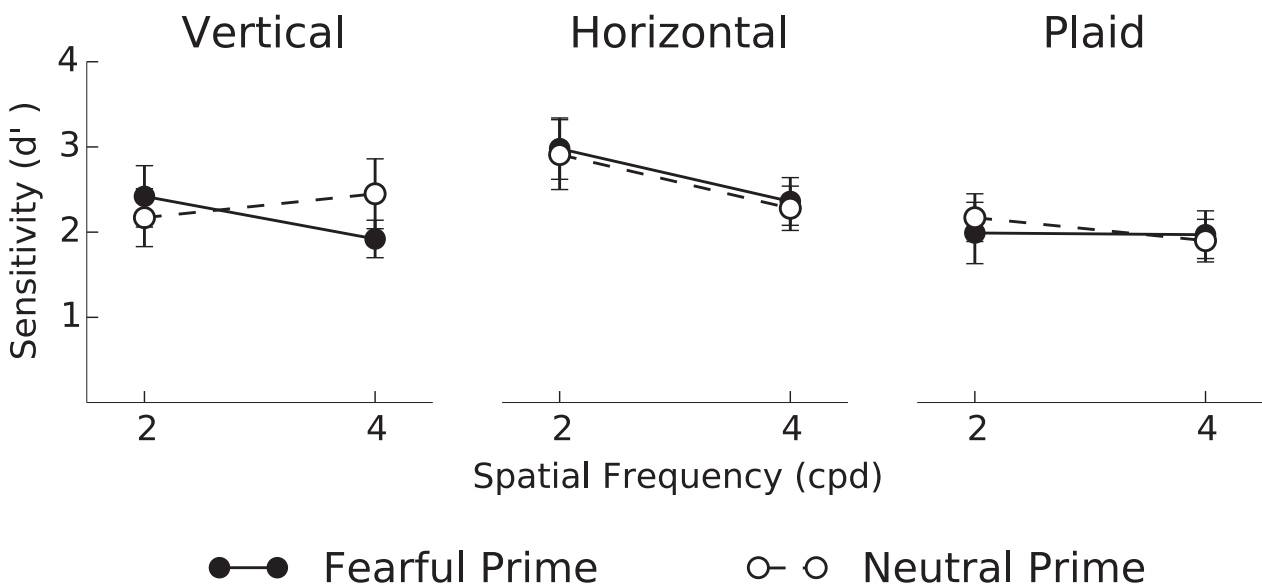


Figure 8. Results for Experiment 1.

The literature on the topic of sensitivity to horizontal vs. vertical gratings is sparse and inconsistent. Furthermore, there may be an effect of the faces themselves, across

emotional expression. In Experiment 2 we examined tilt thresholds around vertical and horizontal between-subjects, and without primes.

### **Experiment 2: Thresholds, Within-Subjects**

#### **Methods**

Methods for the second experiment were similar to the baseline stage of the first experiment; only differences will be detailed.

**Stimuli and Procedures.** Conditions were limited to 2 cpd vertical and horizontal gratings, with each subject observing both orientations in separate sessions. A greater number of sessions per condition (typically between four and ten) were administered, with an increased emphasis on achieving a proper range of tilts. Condition order was chosen randomly.

**Observers.** One author, four naïve but experienced individuals, and eight naïve individuals served as observers. Criteria for dismissal were expanded to include a shifted zero point: a pattern of response in which the subject's maximal frequency of not-tilted responses did not coincide with the least-tilted test stimuli.

#### **Results**

There was a significant correlation between sensitivity to the tilt of vertical and horizontal gratings,  $r(11) = 0.84$ ,  $p < 0.01$  (Figure 9). Thresholds for horizontal gratings ( $M = 1.460^\circ$ ,  $SD = 0.823^\circ$ ) were significantly lower than for vertical gratings ( $M = 1.92^\circ$ ,  $SD = 1.421^\circ$ ),  $t(12) = 1.92$ ,  $p < 0.05$  (Figure 10).



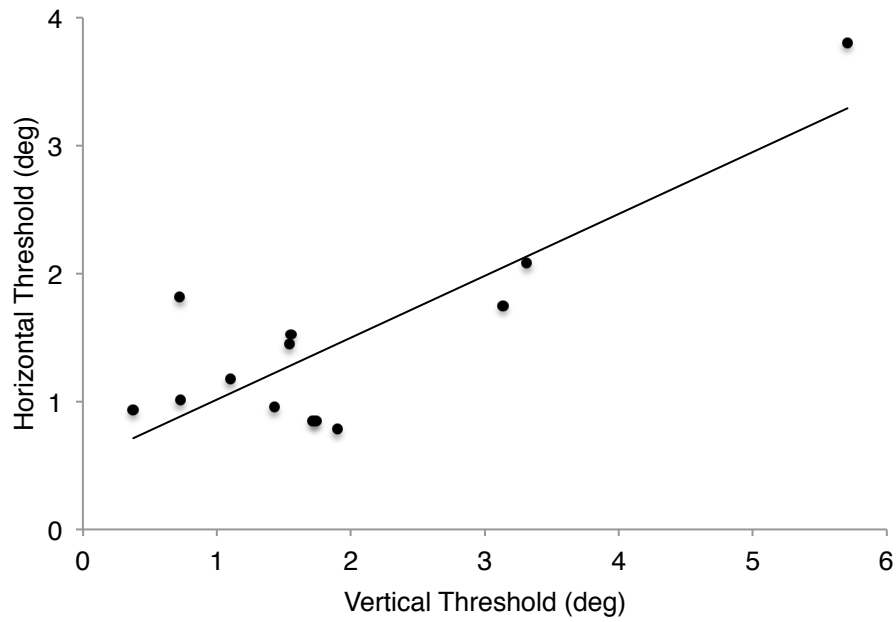


Figure 9. Scatterplot of horizontal and vertical thresholds. In contrast to measurements of sensitivity (as in Experiment 1), a lower threshold indicates increased acuity.

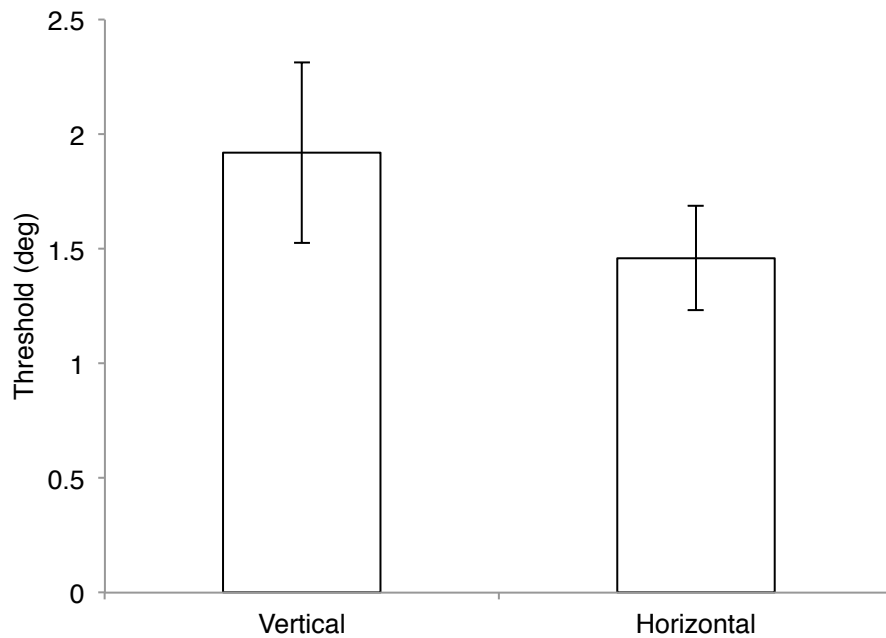


Figure 10. Horizontal and vertical thresholds. Error bars are one SEM. Horizontal's lower threshold corresponds to higher sensitivity, similar to that found in Experiment 1.

### Discussion

In Experiment 1, for vertical gratings, an interaction similar to Bocanegra & Zeelenberg's (2009) was found: for low SFs, fearful primes improved sensitivity, while for high SFs, sensitivity was impaired. The influence of emotional primes on vertical stimuli of varying spatial frequency therefore extends to the Radboud Faces Database and to vertical gratings. No interaction was found for horizontal gratings or plaids. Neither simple nor main effects were found for affect on sensitivity for each SF. Therefore, it appears that affect has no effect on perception of horizontal stimuli. The effect of emotional primes is therefore dependent not only with the test stimulus' SF, but also its orientation; this suggests that the effect is not purely due to differential magnocellular-parvocellular processing, as these systems are not thought to selectively process stimuli based on orientation. The effect on plaids did not resemble that of vertical, horizontal, or any simple combination thereof, suggesting that they are processed as a texture, not a simple combination of vertical and horizontal. The interaction between emotional valence of primes, SF, and orientation of test stimuli appears to be a novel anisotropy of human vision.

Visual anisotropies—differences in perception due to a stimulus' location or orientation in the visual field—have been reported for over 150 years. Fick (*apud* Finger & Spelt, 1946) first reported that vertical lines appear slightly longer than horizontal lines of the same length in 1851; this became known as the *horizontal-vertical illusion*. Another well-characterized anisotropy is the *oblique effect*, in which sensitivity to the tilt of

vertical or horizontal stimuli is higher than for oblique stimuli, as noted by Ernst Mach in 1861 (Westheimer, 2003).

*Meridional anisotropies* are a well-characterized effect of some relevance. A meridian is a line that passes through the center of vision. Humans show increased sensitivity to stimuli aligned to meridians than those not so aligned; the effect is therefore based both on a stimulus's orientation and position (Mannion, McDonald & Clifford, 2010). Due to the stimuli's lateral positioning, our horizontal gratings benefit from this effect, while vertical ones do not, providing a potential confound. However, while certainly relevant, meridional anisotropies probably do not significantly impede interpreting our results. The stimulus eccentricity was relatively small at 5°; meridional anisotropies are more prevalent further to the periphery. For example, Rovamo, Virsu, Laurinen & Hyvärinen (1982) found that meridional anisotropies only overshadowed the oblique effect when stimuli were located further than 20° to the periphery.

Less is known about the inherent differences between tilt perception of horizontal and vertical stimuli, independent of position. Reviewing the literature for traditional stimuli (for example, gratings), Hansen and Essock (2004) report both a behavioral and physiological bias in V1 for horizontal over vertical, but concluded that research was lacking, and some studies failed to find significant differences.

Indeed, the anisotropy may not even arise in V1. Aspell et al. (2010) used fMRI to gauge neural response to various "form coherence stimuli". These stimuli have a global structure, but locally resemble noise. A simple prompt-response task was used to maintain attention. Significantly higher activation for vertical over horizontal stimuli was

found in V<sub>2</sub> and V<sub>3</sub>, but not in V<sub>1</sub>. In a separate mini-study (n=2), no difference between vertical and horizontal tilt thresholds was found.

Inherent differences between perception of horizontal and vertical lines—including the influence of affective primes—may be related to the prevalence of such orientations in the natural world and cortical mechanism that account for them. Studying perception of stimuli with natural-like noise, Hansen and Essock (2004) found a trend that was opposite that of traditional stimuli's oblique effect: they reported *highest* sensitivity for oblique, followed by vertical, then horizontal. In congruence with the oblique effect, they termed this trend the *horizontal effect*. They used stimuli composed of oriented noise, as well as actual photographs modified to prominently contain only a single orientation. The task was to determine whether or not a particular orientation was present. They then quantified prevailing orientations in natural scenes, and found that horizontal orientations were most common, followed by vertical, then oblique. This led them to hypothesize that the visual system's sensitivity bias is a mechanism to increase salience of objects (which would contain a different set of orientations than the background) and decrease salience of the background.

While the stimuli in the current study are sinusoidal, there was no mask and only a short inter-stimulus-interval separated the primes and test stimuli; the prime's afterimage may serve the same purpose as the noise and introduce a similar effect as Hansen and Essock's background noise (barring an effect of the faces' prominent orientations). If this mechanism is related to our differing findings for horizontal and vertical gratings, oblique gratings should show a greater interaction of prime valence and

SF than vertical gratings, and gratings, when preceded by faces of unvarying valence, should show a horizontal effect. The particular mechanisms and evolutionary advantages involved remain to be elucidated.

There are several limitations in the current study. The sample sizes were small. Only three models were used for the primes (3 models x 2 expression = 6 primes total). Finally, the Method of Constant Stimuli does not account for bias, and is generally finicky. Future studies may examine whether the anisotropy is based on perceived (i.e. gravitational) vertical or retinal vertical, use a wider variety of primes, models, and stimuli, and include use of physiological techniques. We are currently examining the effect of emotional prime on a variety of 3D stimuli.

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