Seeing the World Through Target-Tinted Glasses: Positive Mood Broadens Perceptual Tuning

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Research shows that positive mood can serve to broaden the scope of attention at both the perceptual and conceptual level (e.g., increasing the size of spatial attentional focus and semantic access to remote associates). We investigated whether this relaxation of attentional filters by positive affect reduces their selectivity for basic visual features. We induced positive, neutral, or negative affect and asked observers to identify a target motion direction in a series of rapid random moving dot displays. Using a reverse correlation method, we examined the differential effects of emotion on observers' perceptual tuning curves for motion direction. Here we find that positive affect reduces selectivity for motion direction by broadening observers' perceptual tuning relative to both neutral and negative affect conditions. These findings provide the first behavioral evidence that positive emotion influences selectivity for basic visual features through modulation of tuning properties.

Keywords: attention, positive emotion, perceptual tuning, motion reverse correlation

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Converging evidence suggests that our emotions can influence our thoughts, actions, and even basic perceptions. Specifically, it has been proposed that positive and negative affect have opposing influences on cognition and perception: Whereas negative mood can narrow or sharpen our attentional selection and cognitive resources (Curby, Johnson, & Tyson, 2012; Easterbrook, 1959; Nobata, Hakoda, & Ninose, 2010), positive emotional states can do the opposite, in that they may broaden, diffuse, or even increase our powers of attention and cognition (Estrada, Isen, & Young, 1994; Fredrickson & Branigan, 2005; Rowe, Hirsh, & Anderson, 2007; Sakaki & Niki, 2011; Schmitz, De Rosa, & Anderson, 2009; for reviews, see Fredrickson, 2004; Friedman & Förster, 2010). For example, several studies on global-local processing bias demonstrated that positive mood results in a shift toward a global visual processing bias, allowing one to better see the "forest over the trees," with induced negative emotion evoking a corresponding local feature bias (Fredrickson & Branigan, 2005; Gasper & Clore, 2002).

Crucially, these opposing functions of positive and negative affect are not only found in cognitive biases, but are also shown in perception through the modulation of attentional scope. Attention enables us to select a subset of information relevant to our current behavioral goals while inhibiting others. Prior studies show that negative affect contracts and positive affect expands the scope of attentional selection. It has been shown that negative emotion results in the narrowing of the focus of attention through the "weapon focus effect," in which a threatening central stimulus captures attention and inhibits the encoding of peripheral details (Christianson, 1992; Easterbrook, 1959; Loftus, Loftus, & Messo, 1987). Similarly, viewing task-irrelevant negative emotional stimuli can restrict one's functional field of view (Nobata, Hakoda, & Ninose, 2010). In contrast to negative affect's constriction of attention, Rowe et al. (2007) demonstrated an expansion of "attentional spotlight" by positive affect, showing that positive emotion decreased one's ability to ignore distractors further away from a central target than both neutral and negative emotions. Consistent with these behavioral findings, a later neuroimaging study revealed neural correlates of an increased attentional focus under positive affect where positive mood increases, and negative mood decreases, neural activity in brain regions processing unattended peripheral stimuli surrounding a central attended stimulus (Schmitz, De Rosa, & Anderson, 2009).

Expansion of the "breadth" of attention by positive affect also extends to the conceptual space. Positive affect has been associated with improved performance on creative problem solving tasks, such as the Remote Associates Task (RAT) and the Duncker candle task, by increasing access to remote word associations or through overcoming functional fixedness (Duncker, 1945; Isen, Daubman, & Nowicki, 1987). Furthermore, Rowe et al. (2007) revealed that not only does the scope of spatial attentional spotlight increase under positive mood, but this increase is correlated with the increased breadth of semantic access, measured by the RAT. These findings suggest that both perceptual and conceptual expansion because of positive mood share a common underlying mech-

anism in the form of reduced inhibitory control (Friedman & Miyake, 2004).

Although positive emotion leads to a multilevel broadening of the scope of attentional selection from the perceptual to the conceptual level (Rowe et al., 2007; but see Huntsinger, 2012), it is not clear whether this expansion of attentional scope is restricted to the spatial domain or if it also elicits a general relaxation of attentional filters for basic visual features of stimuli. It is well-established that attention can be deployed to nonspatial visual features, such as orientation, color, and direction of motion as well as spatial locations (for reviews, see Carrasco, 2011; Maunsell & Treue, 2006). Previous studies on feature-based attention showed that attention increases the selectivity for features of an attended stimulus at the single-neuron level as well as at the population response level (Ling, Liu, & Carrasco, 2009; Martinez-Trujillo & Treue, 2004; Spitzer, Desimone, & Moran, 1988). If positive affect diffuses or broadens attentional filters for a given feature, then it would lead to the opposite effect, decreasing the selectivity along a relevant feature dimension.

Preliminary evidence for this hypothesis comes from a color categorization study in which subjects were instructed to group randomly ordered colored swatches into as many or as few distinct categories as they pleased (Isen & Daubman, 1984). Under positive affect, subjects were more inclusive in their categorizations of color, dividing them into fewer groups than did subjects in the neutral condition, which may be interpreted as reduced selectivity along the color dimension. However, in this study, it remains unclear whether this inclusive categorization results from changes in subjects' cognitive biases or from changes in their color perception.

Here we directly test whether positive affect leads to decreased perceptual selectivity for features by examining observers' response profiles in a demanding motion direction discrimination task under positive, neutral, and negative affective states. Specifically, we obtained perceptual tuning curves using a reverse correlation method, in which observers identify occurrences of a target motion direction embedded within a series of coherent moving dot displays that rapidly change their direction of motion. Cross-correlating observers' responses with the presented motion sequence allowed for the reconstruction of their tuning curves for motion direction. We then compared observers' tuning curves across three emotional conditions.

If positive emotions impact our visual perception along a given feature dimension by broadly relaxing attentional filters, hence reducing selectivity for that feature, positive affect would lead to broader perceptual tuning for motion direction compared with neutral and negative affect. We suggest that this decreased selectivity for features at the perceptual level may be the basis for the increased attentional breadth at the conceptual level under positive affect, which enhances cognitive flexibility, creativity, and holistic processing as reported previously (Fredrickson & Branigan, 2005; Isen & Daubman, 1984; Rowe et al., 2007).

Method

Subjects

Twelve naïve subjects with normal or corrected-to-normal vision were recruited from Dartmouth College to participate in the

experiment. Written, informed consent was obtained from each subject before the experiment.

Apparatus

The experiment was performed in a dimly lit testing room. Visual stimuli were presented on a 17-inch Mitsubishi CRT monitor (1,024 × 768; 60 Hz) at a viewing distance of 57 cm. Subjects' heads were stabilized using a chin-rest. Auditory stimuli were presented using a secondary computer and Acoustic Noise Cancelling headphones (Bose QuietComfort). Visual stimulus presentation, response recording and data analysis were performed using MATLAB, the Psychophysics Toolbox (Brainard, 1997) and the EzyFit toolbox (Moisy, 2010).

Stimuli and Procedure

We used a dual task paradigm in which subjects performed a luminance change detection task at the central fixation point and a motion direction discrimination task in the periphery concurrently (see Figure 1), adapted from a study by Busse, Katzner, Tillmann, & Treue (2008). The central task was used to control the level of attention allocated to the motion discrimination task while ensuring the subjects maintained fixation and refrained from foveating on the peripheral motion stimuli. For the luminance change detection task, subjects were asked to maintain fixation on a central white square ($0.5° × 0.5°$) presented on a black background (0.14 cd/m^2) and report the number of times it blinked at the end of the trial using the number keys on the keyboard. The fixation square dimmed at random for 150 ms between 0 and 3 times on a given trial. Subjects received feedback at the end of every trial.

While performing the central luminance change detection task, subjects simultaneously performed the motion direction discrimination task in the periphery by directing their covert attention toward a stationary circular aperture (diameter = 3.75°) containing gray dots (density: 15 dots/°^{2}). On each trial, the dots moved within the aperture in a rapid series of 107 motion bursts (speed: 12°/s). The duration of each burst was 100 ms and a blank fixation screen was presented for 50 ms between the bursts. At each burst, all the dots underwent fully coherent motion in a single direction.
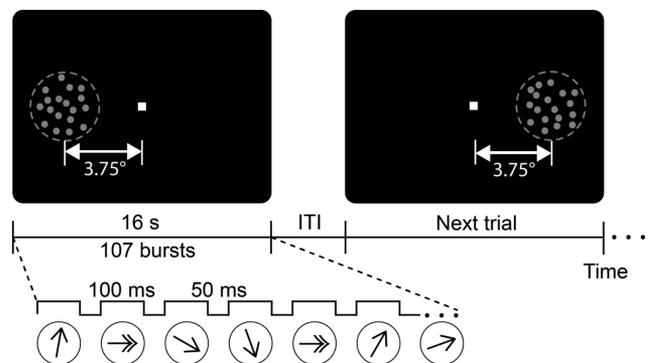

Figure 1. A schematic illustration of the stimuli and example trials. Subjects performed a central luminance change detection task and a peripheral motion direction discrimination task simultaneously. In this example, the target direction is rightward motion, as depicted by the doubled arrows above.

The direction of motion was chosen at random from a set of 17 possible directions, sampling a 160° range in 10° increments, centered on the target direction (either horizontal leftward or rightward motion, counterbalanced between subjects). Each of the possible motion directions was equally likely to be presented from burst to burst, such that on average, each direction was presented six or seven times per trial. Subjects were instructed to press "M" as soon as they detected motion in the target direction. The aperture was centered 3.75° to the left or right of the fixation square, alternating between trials so as to minimize adaptation effects.

Before each block of 34 trials, subjects underwent a musical mood induction procedure for 7 min, in which they listened to sad/negative, neutral, or happy/positive music through headphones and were instructed to enter the mood in question by generating matching thoughts. A shorter, 2 min-long version of this procedure was performed at the half-way point within a given block, so as to reinforce the relevant mood induction. Subjects continued to listen to the relevant music passively as it played on repeat softly in the background during the task. For the happy mood induction, subjects listened to Bach's *Brandenburg Concerto No. 3* and *Mazurka* from "Coppélia" by Delibes. Kraftwerk's *Home Computer* and *Kling Klang* were utilized in the neutral condition. The sad mood was induced using Prokofiev's *Alexander Nevsky: Russia Under the Mongolian Yoke* played at half-speed and Albinoni's *Adagio in G Minor* (Martin, 1990; Rowe, Hirsh, & Anderson, 2007). Subjects rated their current self-perceived valence and arousal separately on a scale of 1 to 9 (1 = *very unpleasant* or *very unaroused*, 9 = *very pleasant* or *very aroused*, respectively) using the Self-Assessment Manikin (SAM) (Lang, Bradley, & Cuthbert, 2008) before each session began, and at the end of each block.

The experiment consisted of two sessions, each of which was conducted on a separate day. Each session lasted approximately 1.5 hr, and consisted of 10 practice trials and three main experiment blocks of 34 trials each, one for each of three mood induction conditions (sad/negative, neutral, and happy/positive). Subjects went through all three mood conditions in each session and the order of the mood conditions was counterbalanced both across sessions within subjects, and between subjects.

Data Analysis

Task performance. Accuracy on the luminance change detection task was measured for each subject by dividing the number of correct responses by the total number of trials. Incorrect trials from this blink task were excluded from further data analysis for the motion discrimination task. In the motion direction discrimination task, we computed d', an index of discrimination sensitivity of the target direction separately in each emotion condition for each subject (Macmillan & Creelman, 2005). A target motion burst to which a response was made between 200 and 1,000 ms after its onset was regarded as a "hit" and a nontarget motion to which a response was made within that time window was regarded as a "false alarm." Hit rate was calculated by dividing the number of hits by the total number of target motion bursts, whereas false alarm rate was calculated by analogously dividing the number of false alarms by the number of nontarget motions. Sensitivity (d') was calculated by subtracting the z-transformed false alarm rate from the z-transformed hit rate. Criterion was found by summing the z-transformed hit and false alarm rates, and dividing the result by −2.

Correlograms and tuning curves. To examine the effects of emotion on observers' behavioral profiles, we have adopted a reverse correlation method (Busse et al., 2008; Ringach, 1998; Tadin, Lappin, & Blake, 2006). We obtained the tuning functions of individual observers' response by plotting the probability that an observer's response was to a given direction of motion. This method is used to determine the degree of perceptual selectivity for a given feature, as represented by the width of the tuning curve.

Using 50 ms bins, all motion bursts occurring between 1,000 ms before and 300 ms after each response were grouped by direction of motion and binned according to temporal onset relative to the response. The totals in each bin for each direction of motion were then divided by the aggregate number of button presses across the three emotional conditions, to normalize the correlograms and allow for comparison of the curves across mood conditions (Busse et al., 2008).

To remove high frequency noise, the correlograms were then low-pass filtered using a cutoff frequency of 4 Hz. We computed the correlograms for each emotion condition separately using only trials in which the luminance change detection task was performed correctly. The incorrect trials were excluded as subjects may not have fixated as instructed, and may have devoted varying levels of attention to the peripheral motion display.

Perceptual tuning curves for motion direction were plotted separately for each emotion condition in each observer using only those probability values of the correlograms corresponding to the time of the peak value of the target motion direction's correlogram (see Figure 2).

These curves had a single peak centered on the target direction. They were then fitted with a Gaussian function using the Nelder-Mead method (Nelder & Mead, 1965). The equation used is as follows:

$$p(x) = B + Ae^{-0.5\left(\frac{x-C}{\sigma}\right)^2}$$

Where B is the baseline, A is the amplitude of the curve, C is the peak, and σ gives us the full width at half maximum (FWHM) or tuning width by the equation $2\sqrt{2\ln2}\sigma$. Tuning width of the curve, which is the index of the response selectivity, as well as other parameters of the tuning curve, such as the amplitude, peak shift, and baseline, were compared across three emotion conditions.

Results

Mood induction. Subjects' self-reported valence ratings differed significantly across all four time points (initial pretest and after each of the three induction conditions), as revealed by a repeated measures analysis of variance (ANOVA) with a Greenhouse-Geisser correction, $F(1.708, 18.790) = 24.781$, $p < .001$, $\eta_p^2 = .693$ (see Figure 3). Pairwise comparisons revealed that pretest valence ratings were generally positive ($M = 6.08$, $SD = 1.08$), and were greater than those collected after both negative ($M = 3.83$, $SD = 1.63$), $t(11) = 5.420$, $p < .001$, $d = 1.627$, and neutral inductions ($M = 5.38$, $SD = 1.25$), $t(11) = 2.429$, $p = .033$, $d = .607$. However, pretest ratings were significantly lower than those obtained after the positive mood induction phase ($M =$
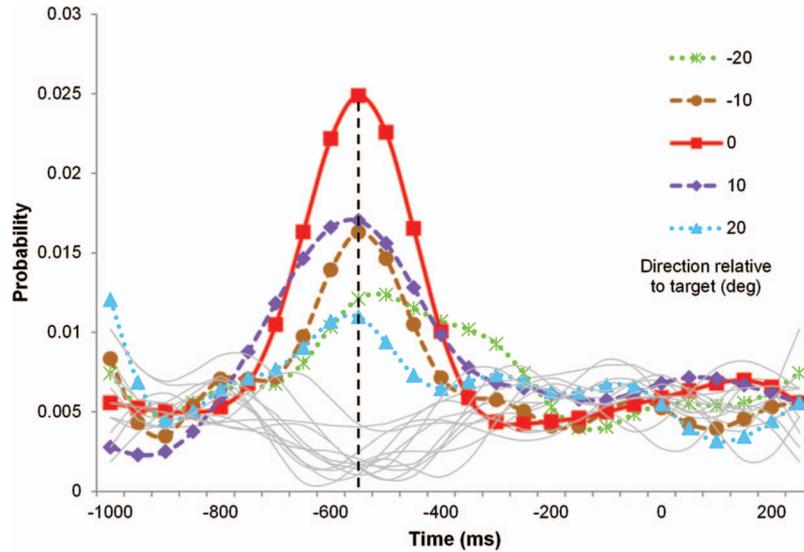
Figure 2. Example correlogram (taken from a representative subject's positive mood results). The probability values for each motion direction (depicted as separate lines) obtained at the time of the peak of the target direction (demarcated by the vertical dashed line) were used to produce the tuning curves. Thin gray lines (without markers) indicate nontarget directions offset more than 20° from the target direction. See the online article for the color version of this figure.

6.96, $SD = 1.42$), $t(11) = -2.434$, $p = .033$, $d = -.692$. Additionally, sad mood ratings were significantly lower than both neutral, $t(11) = -5.407$, $p < .001$, $d = -1.063$, and happy ratings, $t(11) = -5.708$, $p < .001$, $d = -2.045$. Finally, participants' positive mood reports were significantly higher than those after neutral mood induction, $t(11) = 5.636$, $p < .001$, $d = 1.184$. These results indicate that the musical mood induction procedure was effective in inducing the relevant valence.

Figure 3. Self-reported measures of valence. Dashed line shows average preinduction ratings. Error bars represent ± 1 *SE* of the mean.

Subjects' arousals also significantly differed across mood-induction conditions, $F(3, 33) = 12.010$, $p < .001$, $\eta_p^2 = .522$. Pairwise comparisons revealed that pretest arousal ratings ($M = 6.25$, $SD = 1.46$) did not differ significantly from happy ratings ($M = 6.38$, $SD = 1.58$), $t(11) = -0.561$, $p = .586$, $d = -.082$, but were higher than both neutral ($M = 5.71$, $SD = 1.70$), $t(11) = 2.600$, $p = .025$, $d = .341$, and negative arousal ratings ($M = 4.92$, $SD = 1.76$), $t(11) = 4.690$, $p = .001$, $d = .824$. Neutral ratings were also significantly higher than sad ratings, $t(11) = 2.656$, $p = .022$, $d = .458$. This shows that subjects were able to maintain a moderate level of arousal throughout the study, although our neutral and negative mood induction procedures slightly lowered arousal levels compared with pretest.

Behavioral performance. Average performance in the central luminance change detection task was 86.4% ($SD = 14.1\%$), 86.3% ($SD = 12.6\%$), and 88.5% ($SD = 13.9\%$) for the negative, neutral, and positive mood conditions, respectively. Accuracy on this task did not significantly differ across three emotion conditions, $F(2, 22) = .927$, $p = .401$, $\eta_p^2 = .078$, which suggests that the level of subjects' attention deployed to the motion stimulus remains the same regardless of the mood they experienced.

On the motion direction discrimination task, subjects' accuracy in detecting target motion as measured by hit rate did not differ significantly across conditions (positive: $M = 30.8\%$, $SD = 9.1\%$; neutral: $M = 30.0\%$, $SD = 10.4\%$; negative: $M = 30.3\%$, $SD = 9.4\%$), $F(2, 22) = .240$, $p = .788$, $\eta_p^2 = .113$. However, false alarm rate did in fact differ significantly across mood conditions, $F(2, 22) = 6.276$, $p = .007$, $\eta_p^2 = .363$. Positive mood induction ($M = 2.5\%$, $SD = 1.3\%$) led to significantly higher false alarm rates relative to sad ($M = 2.0\%$, $SD = 1.2\%$), $t(11) = 3.096$, $p = .010$, $d = .402$, and neutral conditions ($M = 2.1\%$, $SD = 1.1\%$), $t(11) = 3.233$, $p = .008$, $d = .352$. There was no difference between

neutral and negative mood periods, $t(11) = .472$, $p = .646$, $d = .071$, indicating that only positive mood yields greater susceptibility to false alarms compared with neutral mood.

Differences in discrimination sensitivity (d') across conditions trended toward significance, $F(2, 22) = 2.847$, $p = .079$, $\eta_p^2 = .206$. Planned pairwise comparisons revealed that positive mood ($M = 1.50$, $SD = .21$) led to lower sensitivity relative to negative mood ($M = 1.60$, $SD = .28$), $t(11) = -2.482$, $p = .030$, $d = -.397$, but did not differ in sensitivity from neutral mood, ($M = 1.56$, $SD = .25$), $t(11) = -1.750$, $p = .108$, $d = -.258$. Sensitivity under the neutral condition also did not differ from that of the sad condition, $t(11) = .790$, $p = .446$, $d = .147$. These results are consistent with the observed higher rates of false alarms under positive mood.

Criterion (C) also differed significantly across mood conditions, $F(2, 22) = 4.701$, $p = .020$, $\eta_p^2 = .299$, such that positive mood induction ($M = 1.27$, $SD = 0.25$) resulted in lower criterion values than either negative ($M = 1.34$, $SD = 0.28$), $t(11) = -2.440$, $p = .033$, $d = -.251$, or neutral moods ($M = 1.33$, $SD = 0.29$), $t(11) = -2.784$, $p = .018$, $d = -.217$. The difference between negative and neutral conditions was nonsignificant, $t(11) = 0.355$, $p = .729$, $d = .028$. These data indicate that positive mood increases tuning curve width through a combination of sensitivity reduction and criterion shift.

To ensure that reaction times (RTs) for false alarms did not differ from RTs for hits, we compared RTs for target directions to those RTs for critical nontarget directions (i.e., those directions offset from the target direction by no more than 20°) across all three mood conditions. RTs to motion directions offset over 20° from the target direction were not included because they could not be reliably estimated because of a dearth of responses to them. This 2 (target vs. nontarget) × 3 (mood condition) repeated-measures ANOVA revealed that there was no effect of mood condition, $F(2, 22) = 2.887$, $p = .077$, $\eta_p^2 = .208$, nor was there

an effect for motion direction (target vs. nontarget directions), $F(2, 22) = .873$, $p = .370$, $\eta_p^2 = .074$ (see Table S1 in Supplementary materials for relevant means and SDs). The interaction between the two factors was also nonsignificant, $F(2, 22) = 1.266$, $p = .302$, $\eta_p^2 = .103$. These results confirm that false alarm responses are taken into account in our data analysis equally well even though we analyzed tuning curves at the peak time for hits.

Correlograms and tuning curves. Figure 2 shows the smoothed correlograms for a representative observer in the positive mood condition. As seen on the figure, the observer's responses were based on motion bursts between 350 and 700 ms before the response was made. Although most responses were made to the target direction, the observer was also likely to respond to motion directions adjacent to the target direction (±20°).

The resultant tuning curves derived from such correlograms were then fitted to a Gaussian as discussed in the Data Analysis section. The goodness of fit (R^2) was high and did not differ across mood conditions (positive: $M = 91.7\%$, $SD = 8.1\%$; neutral: $M = 92.9\%$, $SD = 5.2\%$; negative: $M = 92.6\%$, $SD = 5.1\%$), $F(2, 22) = .455$, $p = .641$, $\eta_p^2 = .040$. The average tuning curves across all subjects for each mood condition are shown in Figure 4.

The main research question of this study is whether positive affect can modulate the selectivity for visual features by broadening perceptual tuning. If positive emotions reduce selectivity by broadening the scope of featural selection, we would observe increases in the width of the tuning curves in the positive affect condition compared with neutral and negative conditions.

Indeed, the width of the tuning curves did differ significantly between conditions, $F(2, 22) = 5.617$, $p = .011$, $\eta_p^2 = .338$ (see Figure 5). Happy curves ($M = 41.6°$, $SD = 12.4°$) were wider than both sad ($M = 34.8°$, $SD = 13.4°$), $t(11) = 2.621$, $p = .024$, $d = .530$, and neutral tuning curves ($M = 34.4°$, $SD = 9.7°$), $t(11) = 3.012$, $p = .012$. $d = .650$, whereas sad and neutral curves did not
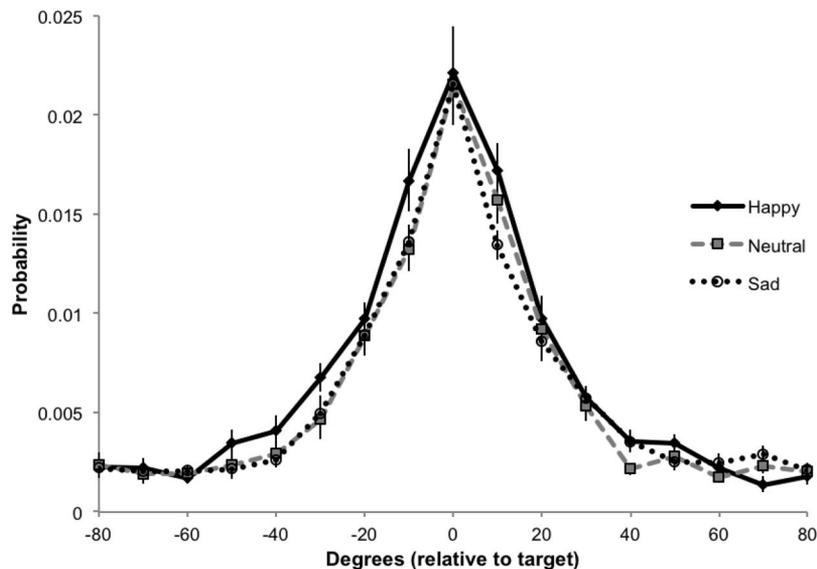

Figure 4. Average perceptual tuning curves across subjects in three emotion conditions. Note that the lines shown above only connect the data points, and do not represent fitted curves. Error bars represent ±1 *SE* of the mean. See Figure S1 in supplemental materials for fitted curves.
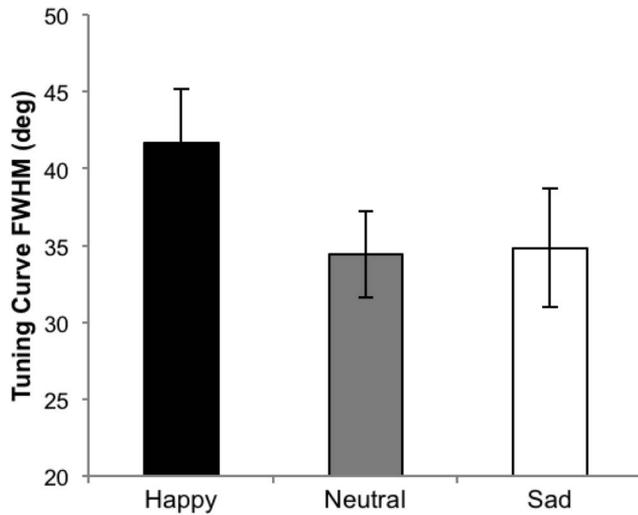
Figure 5. Average tuning curve width across conditions. Error bars represent ±1 *SE* of the mean.

differ from one another, $t(11) = .173$, $p = .866$, $d = .033$. These results indicate that positive mood resulted in decreased featural selectivity relative to neutral and negative mood conditions by broadening perceptual tuning. None of the other properties of the curves, such as the amplitude, $F(2, 22) = .255$, $p = .778$, $\eta_p^2 = .023$, peak direction, $F(2, 22) = .131$, $p = .878$, $\eta_p^2 = .012$, or baseline, $F(1.292, 14.210) = .340$, $p = .625$, $\eta_p^2 = .030$, differed between emotional inductions, and will not be discussed further (see Table S2 in Supplementary Materials for relevant means and *SD*s).

The results remain qualitatively unchanged when a narrower response window size (800 ms before and 300 ms after each response) is used and when the average of correlogram probability values across three time points, including the peak and the two neighboring time points around the peak is used (see Supplementary Data Analysis). This suggests that our observed results are robust and are not specific to the choice of parameters in our analysis.

Discussion

In this study we demonstrate that positive affect decreases the selectivity for directions of motion, relative to both neutral and sad moods. This decreased perceptual selectivity was exhibited by the increased width of the tuning curves without being accompanied by changes in other characteristics of tuning. The perceptual effect of positive mood on sensitivity to motion signals was amplified by an attendant reduction in criterion; thus, leading observers to more readily classify incoming stimuli as targets, even though they were now less discriminable. Broadened perceptual tuning for a basic visual feature under the influence of positive affect represents a novel finding which, to our knowledge, shows that positive emotion can modulate perceptual tuning for low-level visual features for the first time.

Broadened featural tuning may serve as a common mechanism that potentiates other observed effects of positive mood, such as more inclusive color categorization (Isen & Daubman, 1984) and improved other-race face discrimination (Johnson & Fredrickson, 2005). Reduced selectivity for basic visual features, such as color and motion direction, could function as the perceptual basis for general category-broadening as a result of positive mood.

Previous research has found that global-happy and local-sad processing bias with Navon letters and simple geometric figures (Fredrickson & Branigan, 2005; Gasper & Clore, 2002) extends to face perception. Positive emotion is associated with more holistic processing of facial stimuli, therefore improving other-race recognition and even eliminating the own-race bias (Johnson & Fredrickson, 2005). When coupled with an expanded field of view under positive affect (Rowe et al., 2007), coarser featural tuning might allow for better extraction of personally identifying information in other-race faces by reducing the selectivity of attentional filters that are fine-tuned to own-race facial features.

Positive mood can also be associated with analogous reduction in selectivity in memory. One seminal study by Storbeck and Clore (2005) demonstrated the differential effects of positive and negative mood on memory using the well-worn Deese-Roediger-McDermott (DRM) paradigm (Deese, 1959; Roediger & McDermott, 1995). In this paradigm, participants are presented with several lists of words (e.g., *bed*, *rest*, and *awake*) and asked to recall them later. Crucially, each list is strongly associated with one nonpresented lure (e.g., *sleep*), which participants often falsely recall as having been presented originally. The authors showed that positive mood led to greater false recall of lures relative to negative mood (Storbeck & Clore, 2005). Similarly, participants in a positive mood have been shown to be more susceptible to memory intrusions from misleading information (Forgas, Laham, & Vargas, 2005).

These outcomes have often been interpreted in light of the affect-as-information theory, which posits that negative affect leads to greater item-specific processing and positive mood results in more relational processing (Clore et al., 2001). However, these results are also consistent with a reduced selectivity interpretation; the threshold for a related item's entry into memory may have been lowered when observers were in positive mood states, or raised for negative affect conditions (Storbeck, 2013; Storbeck & Clore, 2005; Storbeck & Clore, 2011; but see Brainerd, Stein, Silveira, Rohenkohl, & Reyna 2008; Van Damme, 2013). Extending the affect-as-information framework (Clore et al., 2001), Huntsinger (2013) suggests that the link between positive affect and broadened attentional scope may not be fixed, but flexible in nature, and that it critically depends on the participant's dominant attentional orientation at the time (Clore & Huntsinger, 2007, 2009; Huntsinger, 2012). This theory would also predict lowered perceptual selectivity under happy mood if a broad attentional state in the feature domain is the default attentional orientation. To directly test this hypothesis, future studies may prime broad or narrow featural attention modes while manipulating mood.

Furthermore, positive mood has been shown to modulate thresholds for decisions. Positive mood is robustly associated with more optimistic risk assessments (e.g., Johnson & Tversky, 1983; Lerner & Keltner, 2001) and increased gambling behaviors relative to negative mood (Stanton, Reeck, Huettel, & LaBar, 2014). These previous studies on the effects of positive mood on decision-making frame their results mainly in terms of changes to decision biases used to evaluate given options, as opposed to differences in participants' sensitivities to discriminate between similar alterna-

tives. The current study critically differs from this past research in that the positive mood condition led not only to lowered response criterion, but lowered sensitivity relative to negative mood. Our finding shows that positive affect's impact on behavior does not end at merely influencing response biases. By modulating attention, it can also reach down into low-level perceptual processes and reduce the discriminability of visual features.

Our findings are consistent with the view that positive affect leads to a generally broadened state of attention affecting both perceptual and conceptual processes (Fredrickson, 2004; Rowe, Hirsh, & Anderson, 2007) and are in line with the theorized adaptive functions of positive and negative emotions on attention (Derryberry & Tucker, 1994; Fredrickson, 2004; Tucker & Williamson, 1984). Whereas negative affect promotes concentration of attentional and cognitive resources on the task at hand or the target of main interest under threatening situations that require immediate action, positive affect can expand individuals' thought-action repertoires, thereby increasing their cognitive flexibility and exploratory behaviors when a demand for immediate resolution is alleviated (Fredrickson, 2004; Fredrickson & Branigan, 2005).

If we consider that one purpose of positive mood may be to enhance exploratory behaviors, then reduced featural selectivity/ broadened featural tuning is an efficient method of evincing such patterns of behavior. By allowing near-target feature values to reach threshold more often, the observer becomes more open to a broader range of stimulus values in the environment. This broadened perceptual tuning can also be accomplished by a change in attentional control setting, which was originally proposed to account for contingent involuntary attentional capture (Folk & Remington, 1998, 2008; Folk, Remington, & Johnston, 1992). If happy moods weaken the attentional control settings for the target feature value it can lead to greater perceived similarity between directions of motion surrounding the target direction. This interpretation also predicts that happy moods should lead to exacerbated attentional capture (relative to negative mood) for near-target feature distractors within visual search and spatial attentional cuing paradigms, which may require further testing to confirm.

Conversely, it is worth noting that it is also possible for negatively valenced material to broaden perceptual tuning. In their recent study, Resnik, Sobel, and Paz (2011) classically conditioned participants to associate an initially neutral tone with either a pleasant or unpleasant odor, and subsequently measured their auditory discrimination thresholds for the affect-laden tones in the absence of any odor. Strikingly, aversive conditioning led to lowered discriminability for the paired tone, whereas reward conditioning improved sensitivity. This pattern of behavior would be most likely to allow us to attain maximal rewards (by more accurately identifying pleasant targets among distractors) and suffer minimal punishment (by erring on the side of producing false alarms for anything resembling the aversive stimulus). Similar outcomes have also been found in the memory domain using the DRM paradigm, as negative semantic material results in greater false memory intrusions than does positive material (Brainerd et al., 2008; Dehon, Larøi, & Van der Linden, 2010; Gomes, Brainerd, & Stein, 2013).

How might these seemingly contradictory results be reconciled with our findings? One answer can be found in the distinction between attentional effects for particular sets of emotionally charged stimuli (as for aversive tones or negative words) and

effects of mood on attention *in general.* Whereas affective conditioning may alter the discriminability of a conditioned tone to the exclusion of others, and negatively valenced lists can lead to more false memories for only their associated lures, we demonstrated here that positive tonic mood can alter the discriminability of target items in general. Thus, the observed modulation of attentional scope should apply regardless of where in feature-space the target may lie (e.g., 90°, 270°, etc.) and may reflect a distinct mechanism from that observed in the aforementioned studies.

Although positive mood is robustly associated with cognitive broadening in myriad respects, these findings may also be contingent on the motivational nature of the moods. In the recent motivational dimensional model of affect, motivational intensity is a key dimension of mood that can potentiate the observed broadening or narrowing effects of emotion on cognition (Gable & Harmon-Jones, 2010a; Harmon-Jones, Price, & Gable, 2012). According to this theory, both positive and negative moods that are low in motivational intensity (e.g., happiness, sadness) can lead to broadened attention, whereas such moods that are high in motivational intensity (e.g., desire, disgust) can result in attentional narrowing relative to neutral conditions (Gable & Harmon-Jones, 2008; Gable & Harmon-Jones 2010b; Harmon-Jones & Gable, 2009). As the moods used in our study were low in motivational intensity, we cannot differentiate the relative contribution of motivation here. However, despite the fact that all our mood conditions were low-motivation, tuning differences between positive and negative mood persisted. Further, by this theory one would expect melancholic mood induction to broaden attention relative to neutral mood, which was not observed in the present study (Gable & Harmon-Jones, 2010a). Future studies can incorporate moods with differing levels of motivational intensity to more directly test its effect on perceptual tuning.

Another possible interpretation of our results would be that the difference in arousal between conditions led to differences in curve widths. Attentional response profiles can be affected through two distinct and sometimes co-occurring neural mechanisms: multiplicative gain and altered tuning width (Martinez-Trujillo & Treue, 2004; McAdams & Maunsell, 1999). Elevating the gain increases the population response multiplicatively (leading to higher amplitudes) whereas sharpening tuning leads to attenuated responses at neighboring nontarget values. It is well-known that moderate increases in arousal can lead to better performance on simple tasks through greater allocation of attention (Yerkes & Dodson, 1908). Given that neither an increase in multiplicative gain nor sharpened tuning was found as arousal increased from negative to neutral to positive affect, but rather the opposite was the case, where only broadening of tuning occurred, it is unlikely that the observed pattern of results can be attributed to differences in self-reported arousal across mood conditions (Busse et al., 2008; Ling, Liu, & Carrasco, 2009). Further, subjects' accuracy on both the central blink detection task and the peripheral motion discrimination task was below ceiling and equivalent across conditions, suggesting that they had deployed equivalent levels of attention.

Furthermore, while the central fixation task motivates fixation, it is still possible that subjects could have made occasional eye movements which differed across mood conditions in terms of frequency or gaze pattern. Although this is a possibility, it is unlikely that differing patterns of eye movements in the different mood conditions would selectively increase only false alarms near

the target direction while leaving hits unaffected. For example, if subjects were to make more eye movements or biased fixations toward the peripheral motion stimuli in the positive mood condition, this would both increase hits and decrease false alarms, which was not observed. On the other hand, if there were more blinks and exploratory eye movements to other locations, this would result in lower hits as well as higher false alarms, which was also not the case.

Finally, while we did not observe a corollary narrowing of attentional filters as a result of sad mood induction, this is consistent with prior research's difficulty in finding a narrowing effect because of sadness (a low-arousal negative emotion) and reflects the fact that more aversive, high-arousal negative states such as anxiety and fear may be necessary to induce narrowing of attention (Fredrickson, 2004; Friedman & Förster, 2010; Gable & Harmon-Jones, 2008; Rowe, Hirsh, & Anderson, 2007). Additionally, this null result could be because subjects in musically induced dysphoric states may have experienced a bittersweet sorrow with positive, cathartic undertones (Salimpoor, Benovoy, Longo, Cooperstock, & Zatorre 2009).

While the precise neural mechanisms underlying positive emotion's broadening effect on perception and cognition remain unclear, one neuropsychological theory linked the pattern of increased creativity and cognitive flexibility under conditions of positive mood with the attendant release of dopamine from the mesocorticolimbic system to the prefrontal cortex (PFC) (Ashby, Isen, & Turken, 1999). Long-range feedback projections from PFC to early visual areas such as MT and V1 present a feasible mechanism through which such perceptual effects as broadened featural tuning might manifest themselves (Clavagnier, Falchier, & Kennedy, 2004; Ruff et al., 2006).

In conclusion, our results provide the first behavioral evidence that positive affect can impact early visual processing through reducing selectivity for visual features. This change may reflect a broader, more exploratory perceptual mode adopted to take advantage of weaker but potentially lucrative signals in the environment. This featural expansion is similar in quality to the broadening found in the disparate cases of creative problem-solving and expansion of spatial attention. A positive mood appears to fundamentally change the way we view the world into one inviting inclusive and exploratory processing in our perceptions, though at the expense of accuracy.

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