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## How emotional arousal and valence influence access to awareness

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### ABSTRACT

The effect of emotion on visual awareness is largely unknown. Pairs of natural images were presented side by side on a screen in a binocular rivalry setup. The amount of time that each image of a pair dominated perception was computed. Our results showed:

(A) A main effect of arousal: Dominance durations of the more arousing picture of iso-valence pairs were longer. (B) No effect of valence: Dominance durations of pleasant and unpleasant pictures of iso-arousal pairs were similar. (C) An interaction between arousal and valence: The more pleasant picture of iso-arousal pairs of low arousal level dominated conscious perception. The less pleasant picture of iso-arousal pairs of high arousal level dominated conscious perception. Our findings suggest that the emotional content of a stimulus affects the extent to which it dominates awareness. While arousal and valence interactively affect access to awareness, only arousal exerts an independent control of such access.

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### 1. Introduction

Recent studies have found that emotion modulates perception. For instance, emotional stimuli often attract attention (Most, Chun, Widders, & Zald, 2005). Aversive stimuli can modulate attention to such a degree that they impair the perception of subsequently presented neutral, or non-emotional, targets. Not only that, temporary visual deficits can be induced by otherwise neutral distractors whose aversive associations have only recently been learned (Smith, Most, Newsome, & Zald, 2006). Emotion potentiates the effect of attention on sensitivity to stimulus contrast (Phelps, Ling, & Carrasco, 2006): Performance on an orientation discrimination task, is modestly but significantly better when the oriented target at near-threshold contrast follows a fearful face cue rather than a neutral face cue.

Research on the neural mechanisms underlying the emotional modulation of attention implicates the amygdala, a medial temporal lobe structure known to be involved in the enhanced perception of emotional events (Anderson & Phelps, 2001). The amygdala responds to the emotional content of an event rapidly (LeDoux, 2002). Not only that, the amygdala is known to respond to emotional content prior to awareness (Whalen et al., 1998). There is now behavioral evidence indicating that emotional content alters contrast processing, a feature of low-level vision (Phelps et al., 2006). In light of recent neural evidence that the amygdala projects

to visual cortex (Kapp, Supple, & Whalen, 1994; LeDoux, 2002) and evidence that awareness does not arise in the primary visual cortex (Crick & Koch, 1995; He & MacLeod, 2001; Jiang, Zhou, & He, 2007), we hypothesize that the emotional content of a visual stimulus is capable of affecting its processing even before it reaches awareness.

This hypothesis has been previously tested using a classical binocular rivalry paradigm (Alpers & Gerdes, 2007; Alpers & Pauli, 2006; Yang, Zald, & Blake, 2007). In this paradigm, two disparate images are presented simultaneously to the corresponding location in each of the two eyes. Under this condition of ambiguous visual input, the observer is more likely to see one image rather than a superposition of the two. That is to say, exactly one image of the pair will be consciously perceived at a given time. After a few seconds, the previously suppressed image will be perceived (or become dominant) and then the two rival images will continue to cycle between suppression and dominance in a quasi-regular fashion. Using this paradigm, Coren and Russell (1992) showed that faces with extreme emotions dominated over faces without. Ogasawa and Suzuki (2000) reported that fusion in this paradigm depended on the similarity of emotions in the two images: Fusion was easier to obtain with images of similar emotions. More recently, Alpers and Pauli (2006) extended these results to non-facial images and showed that emotional images significantly dominated relative to neutral images. The same pattern of results has been reported by Alpers and Gerdes (2007) and Yang et al. (2007). In sum, several studies have shown that, emotional images predominate over unemotional or neutral ones.

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It is important to note that emotion is not a monolithic process but rather has long been known to consist of multiple dimensions (Mehrabian & Russell, 1974; Tellegen, 1985; Wundt, 1896). For instance, valence (affect) is a separate dimension of emotional content from arousal (Lang, Bradley, & Cuthbert, 1999; Osgood, Suci, & Tannenbaum, 1957): Pleasant images can be either non-arousing (e.g.s, pictures of a young girl reading a book, a flock of parrots, or a school of brightly colored fish) or highly arousing (e.g.s, pictures of a romantic or erotic couple, a roller-coaster, or people playing and enjoying a sport such as windsurfing or skiing). Similarly, unpleasant images can be either non-arousing (e.g.s, pictures of a cemetery, a hospital, or an arguing couple) or highly arousing (e.g.s, pictures of a baby with a tumor, severed hand, or a burn victim). The studies cited above did not address how these two dimensions separately or jointly influence access to visual awareness. This study was designed to specifically address this question.

Observers in the study dichoptically viewed pictures selected from the International Affective Picture System, or IAPS, an image-base whose pictures have been pre-rated for emotional arousal and valence (affect) (Lang et al., 1999). Specifically, we asked if the arousal level of a picture (arousing vs. non-arousing) influences its access to visual awareness. We expect arousing images to suppress non-arousing ones and have higher priority access to visual awareness. We also asked if the valence of an image influences its access to awareness. In our opinion, unpleasant pictures ought to have higher priority to awareness than pleasant ones because potentially, objects of negative valence negatively affect one's biological fitness or even threaten one's very survival; furthermore, studies of visual search have shown that unpleasant facial expressions are easier to find than pleasant ones (Hansen & Hansen, 1988).

## 2. Materials and methods

### 2.1. Participants

Participants were eighteen healthy volunteers (9 female) from the University of Houston (age:  $21.6 \pm 0.6$  years, age range: 18–27) with normal or corrected-to-normal vision, who were naïve as to the purpose of the study. Data from six observers were discarded because of a computer glitch discovered later. The study was approved by the local human studies committee of the University of Houston, and participants provided written informed consent.

### 2.2. Stimuli

Images were selected from the International Affective Picture System (IAPS) database (Lang et al., 1999), which provides ratings of affect for a large set of emotionally evocative, internationally accessible, color photographs that includes contents across a wide range of semantic categories. Pictures were selected and paired such that either (a) the pictures comprising a pair were very similar in image content but differed dramatically in arousal and valence rating, or (b) the pictures comprising a pair were tightly matched for valence or arousal, but not both. IAPS mean valence ratings of the pictures constituting a given iso-valence pair could not differ by more than 0.2 points on a 9-point valence rating scale. Similarly, IAPS mean arousal ratings of the pictures constituting a given iso-arousal pair could not differ by more than 0.2 points on a 9-point arousal rating scale. Fifty four picture pairs were created that satisfied one of the two criteria. Each picture ( $108 = 54 \times 2$  pictures total) belonged to just one pair. The picture pairs were presented in two sessions, typically separated by a week. Observers had never seen any of the pictures prior to their run.

### 2.3. Procedure

Picture pairs were presented on a NEC MultiSync LCD 2090UXi monitor ( $1600 \times 1200$  pixels resolution, 75 Hz refresh) viewed through a mirror stereoscope for a continuous duration of 60 s (1 min). Pictures subtended  $1.78^\circ \times 1.34^\circ$  of visual angle at a viewing distance of 78 cm, and each picture was bordered by a thin, high contrast, oriented border in order to rapidly help bring the two eyes into alignment. Observers sat comfortably in a chair and viewed the monitor through a careful arrangement of mirrors adjusted individually for each observer so that the left picture on the screen projected exclusively to the left eye and the right picture to the right. The monocular images stimulated corresponding areas of the retinae and therefore converged upon the same portion of the binocular field. The participant's head was stabilized by a chinrest (Headspot). Software was programmed and presented using MATLAB (Mathworks, Inc.) and the Psychophysics toolbox extensions (Brainard, 1997; Pelli, 1997). Every 15 s of the 60-s. long trial, the two pictures switched location, so that both eyes saw each picture of the pair for an equal 30 s. This design constraint, in addition to the constraint that the initial picture locations were counterbalanced across our observer set, effectively reduced whatever bias arising from eye preference that could have existed in the data. Participants continually reported, by hitting the corresponding key on a computer keyboard, their ongoing conscious percept throughout the 60-s display period, and in particular, as soon as a transition occurred in their perception. They could also report a superposition of both pictures, or mixed dominance, and were explicitly encouraged to report as such unless one of the pictures thoroughly dominated perception. Therefore, at all times, the observer had *three* choices—total dominance of either picture or a superposition of both. The relatively small size of the pictures reduced the possibility that the observer would perceive a superposition (Logothetis & Schall, 1990). Observers reported mixed dominance for over more than one third of the total display duration on 55% of trials.

### 2.4. Data analysis

For each comparison, we analyzed two variables – (a) predominance, or total dominance duration and (b) initial image percept. We explain their meanings using a high vs. low arousal image pair for illustration. Predominance, or total dominance duration, is the total time during the course of the trial that an observer reports perceiving a particular image of the pair (say, the low arousal image). Averaging across all high vs. low arousal image pairs, we obtained low vs. high arousal dominance durations for each individual observer. Second, we kept track of the initial picture perceived of the pair, which corresponded to the first key in the response sequence. Summing this across all high vs. low arousal image pairs, we calculated the probability that a given observer initially perceived the low arousal picture or the high arousal picture. All pairwise statistical comparisons used a two-tailed paired student's *t*-test.

### 2.5. Image analysis

For each picture used in the study, we computed the value of key low-level stimulus measures using custom software scripted in MATLAB. Specifically, we measured local (contrast) as well as global (mean, kurtosis, entropy, and spectral composition) image properties.

(a) *Mean luminance and kurtosis of luminance distribution*: To our knowledge, there is no widely accepted standard way to characterize the distribution of pixel luminance values across a complex, natural scene. We measured two features of the luminance

distribution – the mean and kurtosis. The luminance (in  $\text{cd}/\text{m}^2$ ) of each RGB intensity level was measured using a photometer and from that, the calibrated luminance of each pixel was computed. In this way, we measured the average of the distribution of calibrated luminances across all the pixels of a given image. To quantify variability in the luminance distribution, we measured its kurtosis, which is the ratio of the fourth central moment of the distribution of pixel intensities and the standard deviation to the fourth power (Pearson, 1905). Kurtosis measures the degree of peakedness of a distribution (a normal distribution has a kurtosis of zero; a uniform distribution has negative kurtosis), and is sensitive to extreme deviations in luminance in any local part of an image.

(b) *Entropy*—This is Shannon entropy in bits/pixel of the distribution of pixel intensities. It is a quantitative measure of image complexity.

(c) *Contrast*—Natural images of reasonable complexity have unclearly delineated, heterogeneous figure and ground. Therefore, classical measures of image contrast (Weber contrast, Michelson contrast) cannot be applied to our images. Instead, we used a measure derived from (Sonka, Vaclav, & Boyle, 2007) to compute image contrast: At each inter-pixel distance ([1, 5] pixels), a histogram of contrast, viz. difference in intensity between all pairs of pixels, was computed along the two cardinal and two oblique orientations. The mean contrast at a given inter-pixel distance by the sum of all levels of contrast at that distance weighted by the proportion of pixel pairs at each level of contrast. Next, three separate directionally isotropic measures were derived—(i)  $\text{contrast}_{\text{nearestneighbor}}$ , which is the mean difference in intensity of adjacent pixels, (ii)  $\text{contrast}_{\text{weighted}}$ , which is a weighted sum of the difference in intensity of neighboring pairs of pixels 1 → 5 pixels apart. The weights linearly decrease with inter-pixel distance, (iii)  $\text{contrast}_{\text{max}}$ , which is the maximum difference in intensity among pairs of pixels between 1 and 5 pixels apart.

(d) *Spectral composition*—Amplitude spectra in the range 0–10 cycles per degree or cpd (Robson, 1966) were computed for each image. Although all our images subtended the same viewing area, each had a variable number of pixels (note that the images comprising a given pair were required to have the same number of pixels) and thus variable spatial sampling frequency. In order to standardize across images, a uniform frequency resolution of 0.5 cpd was used for computation of the amplitude spectra.

### 3. Results

We first inquired if there was a difference in the conscious perception of pairs of images that differed significantly along both dimensions—arousal and affect (valence)—of emotional content (Table 1). Observers ( $n = 12$ ) viewed seven pairs of pictures for 1 min each and, during this period, continually reported what they perceived. The two pictures of the pair were largely similar to each other but differed in a single detail (e.g. identical face either smiling or bloodied). The difference in stimulus content between the two pictures is what caused the valence and arousal ratings of the otherwise similar pictures to diverge: One picture of the pair

had a low arousal rating and high valence rating, which respectively signify non-arousing and pleasant; the other had a high arousal rating and low valence rating, which respectively signify arousing and unpleasant. We sought to determine if variation in emotional content affected access to conscious awareness, namely if the high arousal, low valence picture or the low arousal, high valence picture of the test pair predominated, i.e. was exclusively visible over a larger proportion of the 60-s long viewing period.

Observers reported seeing the arousing, unpleasant image of the pair (Fig. 1A, red bar) for a significantly longer duration than the non-arousing, pleasant image over the 60-s total viewing period (Fig. 1A, black bar; 25.95 s vs. 19.63 s,  $p = 0.007$ ; Table 1; During the remaining viewing period, observers reported a mixture of both pictures, termed piecemeal rivalry; mixtures were not analyzed any further). In order to understand how the difference in predominance between the two image classes evolves over time, we re-sampled the data at 1 s. intervals and re-plotted the time courses of predominance, or total dominance duration, of the two image classes in Fig. 1B. Fig. 1B shows that the difference in total duration of perceptual dominance did not begin until 15 s or so into the presentation, and the difference gradually increased over the remainder of the 60-s viewing period. The arousing, unpleasant picture was not necessarily the initial one perceived (56% of trials across all observers; Table 1). Thus, the initial period of rivalry did not exclusively determine perception in subsequent epochs; this result is also in accord with the claim that onset rivalry and sustained rivalry are different from, and perhaps independent of, one another (Carter & Cavanagh, 2007). In sum, arousal and/or valence—two different dimensions of emotion—control access to awareness during the sustained period of rivalry.

We isolated each of the two dimensions one by one. First, we inquired if there was a difference in the conscious perception of pairs of images that differed significantly in level of arousal but negligibly along the other dimension of affect (iso-valence pairs; Table 2). We reasoned that if arousal were the dimension that governed access of the previous image set to visual awareness, observers would report seeing highly arousing images more often and over a longer duration than less arousing images. We used a new set of iso-valence images (17 pairs) for this test. The variation in valence across iso-valence pairs in the set was relatively low (see Table 2). Observers reported perceiving the more arousing image of the iso-valence pair for a significantly longer duration (22.93 s vs. 18.24 s,  $p < 0.0001$ ; Fig. 2A, Table 2). The difference in dominance duration first appeared 10–15 s following image pair onset and monotonically increased with time (Fig. 2B). High and low arousing pictures were each perceived first on the same proportion (50%) of trials (Table 2); therefore, for iso-valence image pairs as well, perception in the initial phase of the rivalry had little control over perception in the sustained period of rivalry.

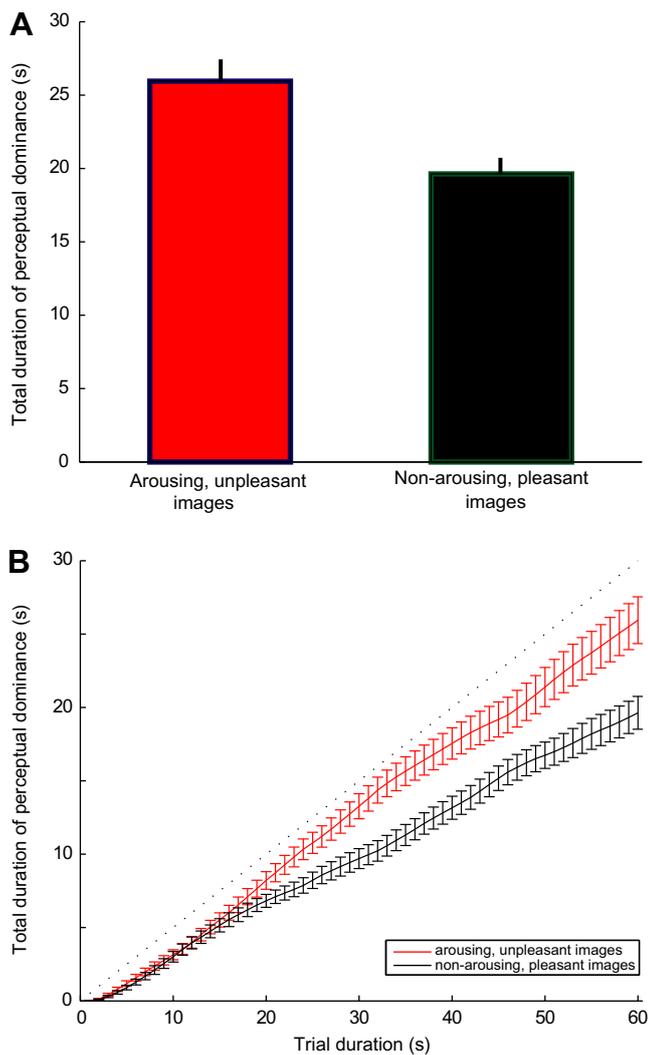
Next, we inquired if there was a difference in the conscious perception of pairs of images that differed significantly in affect (valence) but negligibly in arousal level (Fig. 3A, Table 3). Valence did not appear to play a role in perceptual dominance: Observers reported seeing the unpleasant versus pleasant images of the pair (30 image pairs total) for about the same amount of time (17.86 s

**Table 1**

Arousing, unpleasant images vs. non-arousing, pleasant images—perception measures, emotion ratings

| Measures of conscious perception (observer means, $n = 12$ ) | Arousing, unpleasant images mean $\pm$ 1 SEM<br>A | Non-arousing, pleasant images mean $\pm$ 1 SEM<br>B | $p$ -Value A vs. B |
|--|---|---|--------------------|
| Duration of perceptual Dominance (s)                         | 25.95 $\pm$ 1.52                                  | 19.63 $\pm$ 1.07                                    | 0.007*             |
| First image perceived (fraction of trials)                   | 0.56 $\pm$ 0.04                                   | 0.44 $\pm$ 0.04                                     | ns                 |
| Emotion ratings (image means, $n = 7$ )                      | Mean $\pm$ 1 SD                                   | Mean $\pm$ 1 SD                                     |                    |
| Valence ratings (IAPS)                                       | 2.3 $\pm$ 0.5                                     | 6.2 $\pm$ 0.9                                       | <0.0001*           |
| Arousal ratings (IAPS)                                       | 5.8 $\pm$ 0.9                                     | 4.7 $\pm$ 0.3                                       | 0.007*             |

\*, statistical significance; ns; not significant.



**Fig. 1.** Combined effect of arousal and valence (affect) on the duration of conscious perception. (A) Group mean durations of perceptual dominance of the set of arousing, unpleasant images (red bar) versus non-arousing, pleasant images (black bar). Each pair of pictures was simultaneously presented for a total of 60 s. Each bar represents the time duration in which the corresponding picture category was exclusively perceived. A combination of both was perceived over the remainder of the duration. Error bars represent one SEM. (B) Group dynamics of perceptual dominance as a function of ongoing trial duration (0 → 60 s) are shown. Red and black solid lines, respectively, represent the evolution of perceptual dominance of the set of arousing, unpleasant images and the set of non-arousing, pleasant images. The dotted line represents a 50–50 duty cycle. Dominance durations are cumulative over the 60-s viewing period. Error bars represent one SEM. (For interpretation of the references in colour in this figure legend, the reader is referred to the web version of this article.)

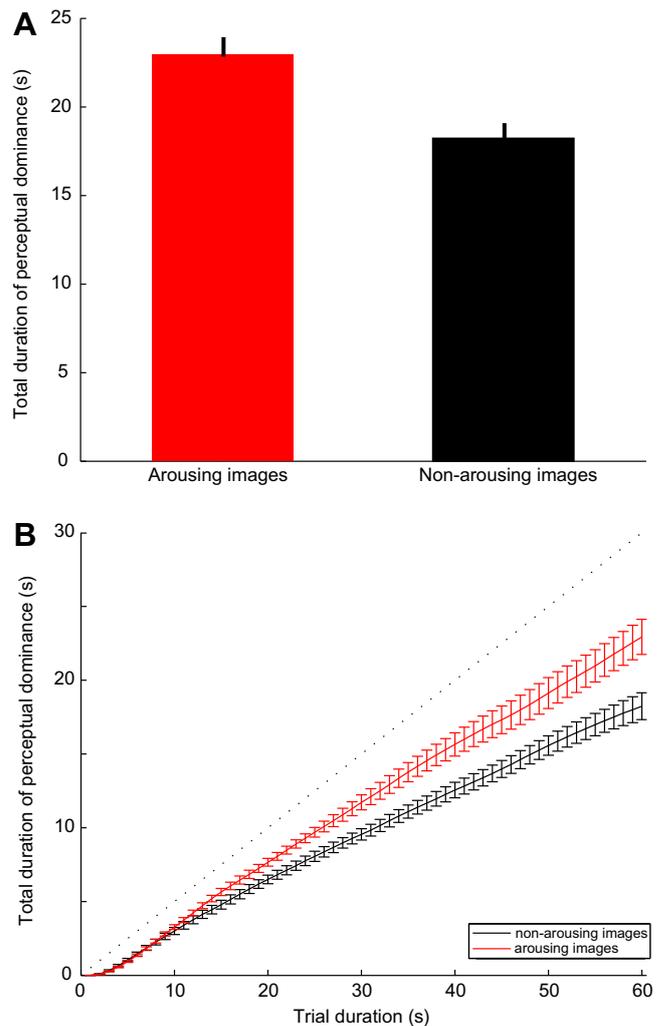
vs. 18.41 s,  $p > 0.4$ ; see Table 3 for other measures). A closer look at the dynamics of perceptual dominance revealed that the lack of difference was consistent across time following stimulus onset (Fig. 3B). In other words, it was not the case that a difference in duration between low (unpleasant) and high valence images was

**Table 2**

Arousing images vs. non-arousing (low arousal) images—perception measures, emotion ratings

| Measures of conscious perception (observer means, $n = 12$ ) | Arousing images mean $\pm 1$ SEM A | Non-arousing images mean $\pm 1$ SEM B | $p$ -Value A vs. B |
|--|------------------------------------|--|--------------------|
| Duration of perceptual Dominance (s)                         | 22.93 $\pm$ 1.14                   | 18.24 $\pm$ 0.86                       | 0.0001*            |
| First image perceived (fraction of trials)                   | 0.50 $\pm$ 0.04                    | 0.50 $\pm$ 0.04                        | ns                 |
| Emotion ratings (image means, $n = 17$ )                     | Mean $\pm$ 1 SD                    | Mean $\pm$ 1 SD                        |                    |
| Valence ratings (IAPS)                                       | 5.7 $\pm$ 1.3                      | 5.7 $\pm$ 1.3                          | 0.28, ns           |
| Arousal ratings (IAPS)                                       | 6.5 $\pm$ 0.5                      | 2.8 $\pm$ 0.6                          | <0.0001*           |

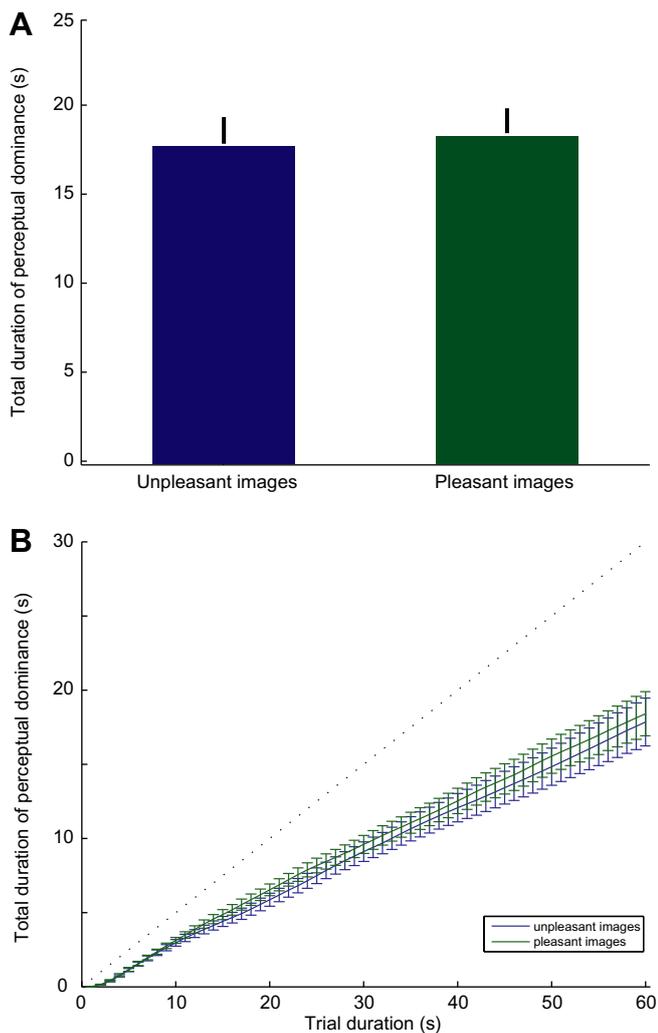
\*, statistical significance; ns; not significant.



**Fig. 2.** Effect of arousal on the duration of conscious perception. (A) Group mean durations of perceptual dominance of the set of arousing (red bar) versus non-arousing images (black bar). The two image sets were equated for affect, and differed significantly in arousal level. Error bars represent one SEM. (B) Group dynamics of perceptual dominance are shown as a function of ongoing trial duration (0 → 60 s). The red solid line represents the evolution of perceptual dominance of the set of arousing images, and the black solid line the evolution of dominance of the set of non-arousing images. (For interpretation of the references in colour in this figure legend, the reader is referred to the web version of this article.)

present at some early time following onset, but then dissipated with sustained exposure.

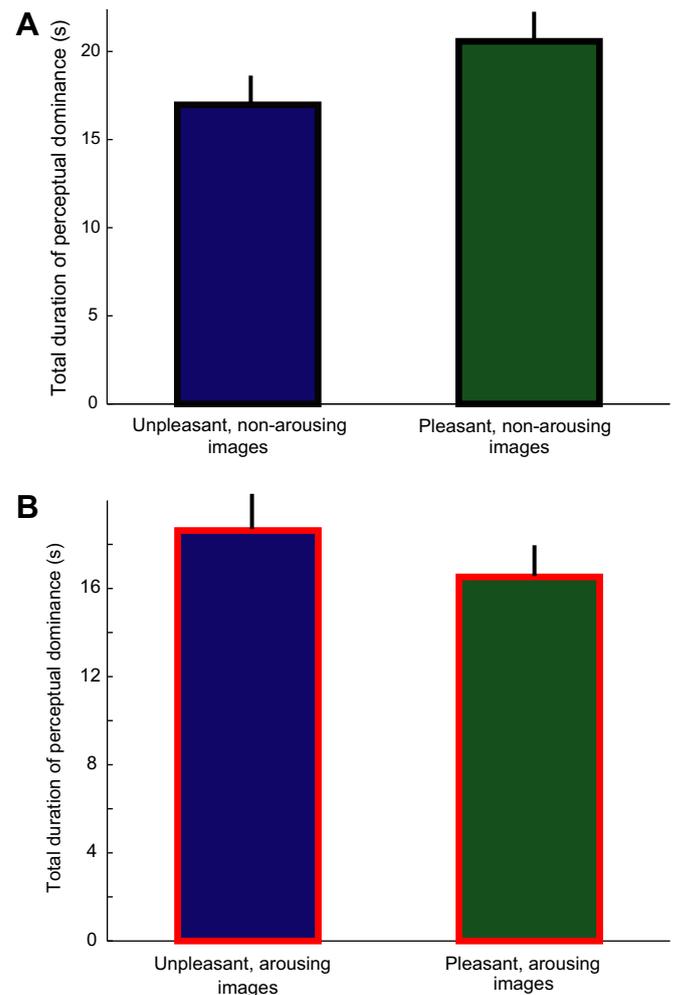
Given that there is a significant effect of arousal on total dominance duration (see Fig. 2), we reasoned that if any effects of valence (affect) on conscious perception were present, they would be subsumed by the more powerful effect of arousal. Note that the iso-arousal pairs had relatively high between-pair variance in arousal rating (see Table 3), which facilitated study of the



**Fig. 3.** Effect of valence (affect) on the duration of conscious perception. (A) Group mean durations of perceptual dominance of the set of unpleasant (blue bar) versus pleasant images (green bar). The two image sets were equated for arousal level, and differed significantly in valence (affect). Error bars represent one SEM. (B) Group dynamics of perceptual dominance are shown for the unpleasant (blue solid line) and pleasant (green solid line) images as a function of ongoing trial duration (0 → 60 s). (For interpretation of the references in colour in this figure legend, the reader is referred to the web version of this article.)

interaction between the effects of valence and arousal on perceptual dominance (see Fig. 4). In a *post-hoc* analysis, we classified the thirty iso-arousal image pairs into two categories—low or high arousal level, and measured the effect of valence on each arousal-based category separately.

On the low arousal level iso-arousal image pairs, observers reported perceiving the more pleasant image of the pair over significantly longer total durations (unpleasant vs. pleasant—16.97 s vs. 20.57 s,  $p = 0.004$ ; Fig. 4A, Table 4). On the other hand, on the high



**Fig. 4.** Interaction between arousal and valence (affect). (A) Group mean durations of perceptual dominance of the set of unpleasant, non-arousing images (blue bar) versus pleasant, arousing images (green bar). The two image sets were equated for low arousal levels and differed significantly only in affect. Error bars signify one SEM. (B) Group mean durations of perceptual dominance of the set of unpleasant, arousing images (blue bar) versus pleasant, arousing images (green bar). The two image sets were equated for high arousal levels and differed significantly only in valence (affect). (For interpretation of the references in colour in this figure legend, the reader is referred to the web version of this article.)

arousal level iso-arousal image pairs, observers reported perceiving the more unpleasant image of the pair over significantly longer total durations (18.63 s vs. 16.52 s,  $p = 0.043$ ; Fig. 4B, Table 4). Valence (affect) had opposite effects for low and high arousal iso-arousal image pairs, which is probably why there was no main effect of valence.

### 3.1. Effect of low-level stimulus measures on rivalry

Manipulation of stimulus variables such as luminance (Fox & Rasche, 1969; Kakizaki, 1960), contrast (Hollins, 1980a; Whittle,

**Table 3**  
Unpleasant images vs. pleasant images —perception measures, emotion ratings

| Measures of conscious perception (observer means, $n = 12$ ) | Unpleasant images mean $\pm 1$ SEM A | Pleasant images mean $\pm 1$ SEM B | $p$ -Value A vs. B |
|--|--------------------------------------|------------------------------------|--------------------|
| Duration of perceptual dominance (s)                         | 17.86 $\pm$ 1.54                     | 18.41 $\pm$ 1.42                   | >0.4, ns           |
| First image perceived (fraction of trials)                   | 0.48 $\pm$ 0.02                      | 0.51 $\pm$ 0.02                    | ns                 |
| Emotion ratings (image means, $n = 30$ )                     | Mean $\pm 1$ SD                      | Mean $\pm 1$ SD                    |                    |
| Valence ratings (IAPS)                                       | 3.3 $\pm$ 1.1                        | 7.0 $\pm$ 1.1                      | <0.0001*           |
| Arousal ratings (IAPS)                                       | 4.7 $\pm$ 1.9                        | 4.7 $\pm$ 1.9                      | >0.6, ns           |

\*, statistical significance; ns; not significant.

**Table 4**  
Unpleasant, low/high arousal images vs. Pleasant, low/high arousal images—perception measures, emotion ratings

| Measures of conscious perception (observer means, $n = 12$ ) | Unpleasant, low arousal images mean $\pm 1$ SEM A | Pleasant, low arousal images mean $\pm 1$ SEM B | $p$ -Value A vs. B | Unpleasant, high arousal images mean $\pm 1$ SEM A | Pleasant, high arousal images mean $\pm 1$ SEM B | $p$ -Value A vs. B |
|--|---|---|--------------------|--|--|--------------------|
| Duration of perceptual dominance (s)                         | 16.97 $\pm$ 1.63                                  | 20.57 $\pm$ 1.63                                | 0.004*             | 18.63 $\pm$ 1.57                                   | 16.52 $\pm$ 1.39                                 | 0.043*             |
| First image perceived (fraction of trials)                   | 0.42 $\pm$ 0.03                                   | 0.58 $\pm$ 0.03                                 | 0.02*              | 0.54 $\pm$ 0.04                                    | 0.45 $\pm$ 0.03                                  | >0.2, ns           |
| Emotion ratings (image means)                                | Mean $\pm 1$ SD                                   | Mean $\pm 1$ SD                                 |                    | Mean $\pm 1$ SD                                    | Mean $\pm 1$ SD                                  |                    |
| Valence ratings  | 3.9 $\pm$ 0.9                                     | 7.1 $\pm$ 0.6                                   | <0.0001*           | 2.7 $\pm$ 0.8                                      | 7.0 $\pm$ 1.3                                    | <0.0001*           |
| Arousal ratings  | 3.7 $\pm$ 0.5                                     | 3.7 $\pm$ 0.5                                   | > 0.4, ns          | 5.6 $\pm$ 0.8                                      | 5.6 $\pm$ 0.8                                    | >0.9, ns           |

\*, statistical significance; ns; not significant.

1965), contour density (Levelt, 1965), spatial frequency (Andrews & Purves, 1997; Fahle, 1982a, 1982b; Hollins, 1980b), image complexity (Alais & Melcher, 2007), size (O'Shea, Sims, & Govan, 1997), velocity (Blake, Yu, Lokey, & Norman, 1998; Breese, 1899; Wade, de Weert, & Swanston, 1984) and retinal eccentricity (Fahle, 1987) can produce pronounced variations in stimulus predominance. As a general rule, a “stronger” rival target (e.g., one that is of higher contrast, larger, closer to fixation, more sharply focused, flickering or dynamically changing versus one that is not) dominates conscious perception. An important question is whether any of these low-level stimulus measures rather than emotional content predicts predominance during rivalry.

The short answer is ‘no’: An extensive analysis of image statistics found little difference in low-level stimulus measures between pictures of discrepant emotional content. The pictures constituting a given pair were of the exact same size, displayed at the same eccentricity and were static natural scenes with no flicker or other dynamic properties or differences. Thus, the following three stimulus measures—size, retinal eccentricity, and stimulus velocity—had no role to play at all in our study. The results of our analysis of some of the remaining stimulus measures—image contrast, interestingness or image complexity, mean image intensity, image kurtosis, and spectral composition—as a function of image class are given in Table 5. On each of the stimulus measures, our approach was the same: Calculate the values of each stimulus measure for each image and statistically compare between relevant image classes (low vs. high arousal, low vs. high valence, and so on). Overall, differences among image classes in these formal stimulus measures failed to explain the corresponding differences in total dominance duration. For instance, high arousal images had significantly longer total dominance durations than low arousal ones; however, there was no significant difference in low-level stimulus measures between the two classes. Similarly, pleasant, low arousal images were perceived for significantly longer total durations than unpleasant, low arousal images of similarly low arousal value, but there was not a significant difference in low-level stimulus measures between them. The measures are briefly described below and results are shown in Table 5.

We calculated three different measures of image contrast (Sonka et al., 2007) (see Section 2.5) and computed the mean value of contrast for each class of pictures (low arousal, high arousal, negative valence, and so on). Irrespective of measure, differences in image contrast failed to account for the differences in total dominance duration (Table 5). Another stimulus factor we investigated was luminance; we wondered if there were differences in luminance statistics as a function of image class that might explain our findings. For this purpose, we derived two statistics for each of our images from its luminance distribution—mean (and median) and kurtosis, which measure, respectively, the average (median) luminance across a given image, and extreme deviations in local luminance within the given image (see Section 2.5). As before, we did not observe a significant difference in mean (or median) luminance ( $p > 0.1$  for each pairwise comparison; see Table 5) or image kurtosis as a function of arousal or valence. Yet another stimulus factor in rivalry is the level of interestingness (Smets,

1975) or complexity (Alais & Melcher, 2007; Rogers, Rogers, & Tootle, 1977)<sup>1</sup>. Whereas interestingness is subjective and therefore hard to quantify, entropy is a reasonable proxy for image complexity (Shannon & Weaver, 1949). Again, image entropy did not differ significantly between arousing vs. non-arousing pictures or across any of the other relevant pairwise comparisons (Table 5). The final stimulus measure we examined was spectral composition. It has been shown that blurred patterns are suppressed by sharply focused ones, and stimuli of limited spatial frequency (sf) range are suppressed by patterns consisting of the whole sf-spectrum (Fahle, 1982a, 1982b). For each of the five comparisons (arousing, unpleasant images vs. non-arousing, pleasant images, pleasant vs. unpleasant images, arousing vs. non-arousing images, and so on), we conducted a two-way repeated measures ANOVA with frequency and image class as main factors. The difference in spectral content between the image classes being compared in each case was not statistically significant (Table 5; all  $ps > 0.1$ ). That is to say, there were no significant differences in spectral power between image classes that could account for the observed differences in predominance. In brief, there were few, minor differences in the low-level stimulus properties between image classes of different valence or arousal value and none that could account for the observed differences in predominance.

### 3.2. Mean period of dominance phase

On a related but different note, arousal and valence do not behave like low-level stimulus measures in other important ways. Consider the mean period of each dominance phase (predominance, or total dominance duration, is the sum of all the periods of dominance). First, if both rival targets are bilaterally increased in strength, the two targets will alternate in dominance more rapidly, leading to shorter periods of dominance, e.g. when two high contrast gratings are viewed during rivalry, the periods of dominance are shorter than when two low contrast gratings are viewed (Levelt, 1965). If arousal and low-level stimulus measures affect predominance similarly, then the mean period of dominance when a pair of arousing images is viewed should be reduced relative to a pair of non-arousing images. However, across our observers, the mean dominance periods did not differ between our non-arousing (8.93  $\pm$  1.33 s) and arousing (8.54  $\pm$  1.31 s) image pairs ( $p > 0.4$ ). Second, “stronger” stimuli tend to stay suppressed for shorter periods of time while not necessarily staying dominant for longer periods of time [e.g., (Fox & Rasche, 1969; Levelt, 1965); but see (Bossink, Stalmeier, & De Weert, 1993; Mueller & Blake, 1989) for evidence pointing to longer mean dominance periods, too]. However, for our iso-valence image pairs, the dominance period of the arousing image of the pair was significantly longer (10.57  $\pm$  1.28 s) than that of the non-arousing image of the pair (8.07  $\pm$  0.91 s;  $p = 0.006$ ). Similarly, for the low arousal image pairs, the dominance period of the “stronger” (see Fig. 4A) more pleasant image of the pair was significantly longer (8.96  $\pm$  1.27 s) than that

<sup>1</sup> It is worth pointing out that Alais and Melcher (2007) showed that it is not image complexity *per se* or the difference in complexity between the images of a pair, but the level of shared complexity that governs predominance.

**Table 5**  
Image statistics

|   | Arousing, unpleasant vs. Non-arousing, pleasant        | Arousing vs. Non-arousing                             | Unpleasant vs. Pleasant                               | Unpleasant vs. Pleasant (low arousal)                  | Unpleasant vs. Pleasant (high arousal)                |
|---|--|---|---|--|---|
| Mean intensity mean $\pm$ 1 SD ( $\text{cd/m}^2$ ), p-Value                     | 23.0 $\pm$ 17.1 vs. 21.9 $\pm$ 17.1<br>$p > 0.5$ , ns  | 28.9 $\pm$ 20.2 vs. 21.4 $\pm$ 14.3<br>$p > 0.2$ , ns | 23.9 $\pm$ 14.8 vs. 25.1 $\pm$ 17.2<br>$p > 0.7$ , ns | 23.3 $\pm$ 14.9 vs. 21.2 $\pm$ 10.9<br>$p > 0.6$ , ns  | 24.5 $\pm$ 14.6 vs. 28.4 $\pm$ 20.7<br>$p > 0.6$ , ns |
| Kurtosis mean $\pm$ 1 SD, p-Value   | 7.8 $\pm$ 14.7 vs. 9.0 $\pm$ 18.4<br>$p > 0.5$ , ns    | 28.3 $\pm$ 51.7 vs. 30.0 $\pm$ 62.5<br>$p > 0.9$ , ns | 42.8 $\pm$ 61.5 vs. 70.4 $\pm$ 83.0<br>$p > 0.1$ , ns | 29.0 $\pm$ 35.8 vs. 88.4 $\pm$ 92.3<br>$p > 0.05$ , ns | 54.8 $\pm$ 75.2 vs. 54.7 $\pm$ 70.2<br>$p > 0.9$ , ns |
| Entropy (bits/pixel) mean $\pm$ 1 SD, p-value                                   | 7.4 $\pm$ 0.4 vs. 7.2 $\pm$ 0.4<br>$p > 0.05$ , ns     | 7.2 $\pm$ 0.7 vs. 7.2 $\pm$ 0.8<br>$p > 0.9$ , ns     | 7.2 $\pm$ 0.6 vs. 7.0 $\pm$ 0.8<br>$p > 0.2$ , ns     | 7.1 $\pm$ 0.8 vs. 7.0 $\pm$ 0.9<br>$p > 0.6$ , ns      | 7.3 $\pm$ 0.4 vs. 7.0 $\pm$ 0.6<br>$p > 0.1$ , ns     |
| Contrast <sub>nearest-neighbor</sub> mean $\pm$ 1 SD ( $\times 10^2$ ), p-value | 0.15 $\pm$ 0.13 vs. 0.12 $\pm$ 0.13<br>$p > 0.05$ , ns | 0.15 $\pm$ 0.18 vs. 0.24 $\pm$ 0.19<br>$p > 0.2$ , ns | 0.20 $\pm$ 0.31 vs. 0.19 $\pm$ 0.18<br>$p > 0.8$ , ns | 0.24 $\pm$ 0.43 vs. 0.17 $\pm$ 0.12<br>$p > 0.5$ , ns  | 0.17 $\pm$ 0.12 vs. 0.20 $\pm$ 0.23<br>$p > 0.5$ , ns |
| Contrast <sub>weighted</sub> mean $\pm$ 1 SD ( $\times 10^2$ ), p-value         | 0.49 $\pm$ 0.39 vs. 0.40 $\pm$ 0.38<br>$p = 0.036^*$   | 0.51 $\pm$ 0.61 vs. 0.71 $\pm$ 0.60<br>$p > 0.3$ , ns | 0.64 $\pm$ 0.80 vs. 0.61 $\pm$ 0.49<br>$p > 0.8$ , ns | 0.70 $\pm$ 1.08 vs. 0.59 $\pm$ 0.37<br>$p > 0.7$ , ns  | 0.59 $\pm$ 0.40 vs. 0.62 $\pm$ 0.57<br>$p > 0.8$ , ns |
| Contrast <sub>max</sub> mean $\pm$ 1 SD ( $\times 10^2$ ), p-value              | 1.1 $\pm$ 0.74 vs. 0.89 $\pm$ 0.73<br>$p = 0.038^*$    | 1.13 $\pm$ 1.23 vs. 1.44 $\pm$ 0.89<br>$p > 0.4$ , ns | 1.34 $\pm$ 1.35 vs. 1.33 $\pm$ 0.95<br>$p > 0.9$ , ns | 1.38 $\pm$ 1.81 vs. 1.34 $\pm$ 0.81<br>$p > 0.9$ , ns  | 1.31 $\pm$ 0.74 vs. 1.33 $\pm$ 1.07<br>$p > 0.9$ , ns |
| Spectral power F statistic, p-value   | $F(1,514) = 1.477$<br>$p > 0.2$                        | $F(1,1304) = 0.044$<br>$p > 0.8$                      | $F(1,2331) = 2.692$<br>$p > 0.1$                      | $F(1,1067) = 1.741$<br>$p > 0.1$                       | $F(1,1225) = 1.094$<br>$p > 0.2$                      |

\*, statistical significance; ns; not significant.

of the less pleasant one ( $7.38 \pm 1.12$  s;  $p = 0.007$ ); for the high arousal image pairs, the dominance period of the “stronger” (see Fig. 4B) unpleasant image of the pair was significantly longer ( $8.55 \pm 1.31$  s) than that of the pleasant one ( $7.25 \pm 1.13$  s;  $p = 0.001$ ). In sum, the findings above suggest that the mechanisms in the brain by which low-level stimulus measures and emotional content affect stimulus predominance and access to visual awareness differ.

#### 4. Discussion

Consistent with other studies, our study finds that the emotional content of an image is an important factor guiding the transition from unconscious to conscious perception. That is to say, in addition to differences in formal stimulus measures such as luminance, contrast, and complexity, differences in the emotional content of rivaling images also influence which image ends up dominating perception. Specifically, the arousal level of an image determines the level of its access to visual awareness—the more arousing image of an iso-valence image pair dominates conscious perception. Arousal also interacts with valence (affect): For images of identical, low arousal level, the more pleasant image of the iso-arousal pair dominates perception, whereas for images of high arousal value, the less pleasant image of the iso-arousal pair dominates perception. The effects were remarkably consistent across observer (e.g. the more arousing image of the iso-valence pair dominated the conscious perception of 11/12 observers).

##### 4.1. Response bias

An issue concerning research on the relationship between emotion and perception is response bias, which is the proposal that observers are, for whatever reason, biased to favor the reporting of emotional percepts. A list of causes of response bias include the use of self-report (Blake, 2001), the use of large images that are prone to piecemeal rivalry (Blake, 2001), judgments that are binary in nature (Blake, 2001), brief presentation of images resulting in dichoptic masking (Alpers & Gerdes, 2007), reporting after brief binocular presentation (Coren & Russell, 1992) which is prone to memory and response biases, verbalization of subjective perception which could bias results in favor of emotional pictures (Alpers & Pauli, 2006), a tendency to label ambiguous percepts as emotional (Alpers & Gerdes, 2007), a tendency to favor the initial (emotional) percept, a tendency to favor the more emotional percept, and awareness of researchers’ hypotheses (Alpers & Gerdes, 2007). Our study did use self-report to measure predominance. However, we did not pair an emotional stimulus with a neutral one unlike previous studies; in all cases, we paired an emotional image with another emotional image (even the non-arousing images were either pleasant or unpleasant, and not of neutral valence), and images were carefully paired to be nearly equal along a dimension of emotional (or stimulus) content. Moreover, our images were small (see Section 2), judgments were ternary in nature (in addition, observers were strongly and explicitly encouraged to report a mixture if either one of the images was not exclusively dominant, see Section 2), each pair was shown for a long time, viz. 1 min., reports were concurrent with presentation, percepts in our study were not verbalized but reported by key press, the initial percept did not predict predominance [e.g. the more arousing image was reported to be perceived first on exactly 50% of trials; also see (Carter & Cavanagh, 2007)] in our study, all of our observers were naïve as to the researchers’ hypotheses and what’s more, the study yielded at least one result that we failed to hypothesize. Finally, our experimental design by and large precludes criterion shifts. For instance, presentation of low arousal image pairs and high arousal image pairs was intermixed. As we showed (Fig. 4),

the more pleasant image of low arousal pairs is predominant, whereas the less pleasant pair of high arousal pairs is predominant. This means that the observer would have to switch criterion from trial to trial, which is extremely difficult (Wixted & Stretch, 2000). Therefore, from all of the above, it appears that response bias cannot be a plausible account of our findings. Of interest, when Alpers et al. corrected for bias in a later study (Alpers & Gerdes, 2007), their conclusions did not change much from before, suggesting that the effect of emotional content is quite robust and insensitive to variations in experimental paradigm [see also (Yang et al., 2007) for a similar conclusion].

There does remain one possibility (this does not fall under the category of response bias): The observer prefers looking at a particular class of image and controls what (s)he consciously perceives. This potential shortcoming is something the present study shares with many, perhaps most, studies of rivalry. However, this shortcoming is not of serious concern, as Most researchers agree that the rate of alternation in rivalry is not controllable by normal viewers; for a study on Tibetan monks, see (Carter et al., 2005). To quote Blake (2001), "Aside from deploying oculomotor "tricks", observers seem unable willfully to trigger immediate switches from suppression to dominance or to hold one stimulus dominant indefinitely (Blake, 1988)". In sum, the preponderance of evidence argues against the notion that response bias is a plausible account of our findings.

#### 4.2. Different views of binocular rivalry

For simple rival stimuli such as orthogonal gratings, the proportion of time in which either stimulus is exclusively visible, termed rivalry coherence, is typically much smaller (~25–30%) than that for complex rival stimuli (~60–80%) (Alais & Melcher, 2007). In this study, we observed a high degree of rivalry coherence: Mean coherence across the different pairwise comparisons was 60–76%. Thus, the stimuli used here, which were small ( $1.78^\circ \times 1.34^\circ$ ) but notable for having strong emotional content, rivaled like coherent visual objects of low emotional content (Alais & Melcher, 2007).

Our findings are thus concordant with the recent view of rivalry that stimuli, and not just the two eyes, compete (Logothetis, Leopold, & Sheinberg, 1996) for visual awareness. Over the years, there have been a number of studies of binocular rivalry showing that in addition to low-level stimulus primitives, meaning, context, and other aspects of global organization of the stimulus strongly influence predominance. For instance, it has been shown that upright faces dominate over inverted faces (Engel, 1956), figures one has seen before dominate over novel figures (Goryo, 1969), and Jewish (Catholic) religious symbols dominate for Jewish (Catholic) observers (LoSciuto & Hartley, 1963). Thus, meaning, context, and other aspects of global organization of the stimulus strongly influence dominance duration.

Within the context of the present study, there is another way of comparing the relative merits of the eye rivalry and stimulus rivalry views: Examine transitions in dominance resulting from the interchange of images between the eyes every 15 s in our experiment (Blake, Westendorf, & Overton, 1980; Logothetis et al., 1996). If a given pattern were dominant in rivalry, moving that pattern to the other eye should have no effect on its duration of dominance, which normally lasts at least several seconds. But if a region of a given eye is dominant during rivalry, swapping the orientations should produce an immediate transition in dominance, for the previously suppressed pattern would now be imaged in the currently dominant eye (Blake et al., 1980). Regards to the present study, we counted the number of transitions that resulted from the interchange of images between the two eyes. Specifically, we computed the fraction of (a) reversals, or trials in which one image of the pair was exclusively visible before the interchange and the second, previously suppressed image became exclusively

visible following the interchange, and (b) transitions, or trials in which one image of the pair was exclusively visible prior to the interchange but was replaced by the second picture of the pair or by a mixture of both (piecemeal rivalry). For this analysis, we obtained the proportions across all 54 image pairs for each observer. The analysis revealed relatively small proportions of reversals and transitions: Across observers,  $3.5 \pm 0.9\%$  and  $6.0 \pm 1.1\%$  of interchanges at the time of coherence respectively resulted in reversals and transitions within 500 ms of the interchange; the respective proportions were  $13.3 \pm 2.9\%$  and  $18.9 \pm 3.5\%$  within 1 s. of the interchange. Thus, our results are apparently more in accord with the stimulus rivalry view.

This does not mean that our findings contradict the eye rivalry view. Different aspects of rivalry are likely to be governed by different processes (Alais & Blake, 2005; Blake, 2001; Blake & Logothetis, 2002). For example, the stimulus determinants of the temporal dynamics of rivalry are not necessarily those governing the spatial extent of rivalry. Similarly, the processes responsible for initiation of rivalry and selection of one eye's input for dominance are now believed to be different from the processes responsible for the implementation and maintenance of dominance. Our findings are in agreement with the above view: As far as the initiation of rivalry is concerned, the more dominant stimulus is not perceived any more at the onset of rivalry than the less dominant one. But as far as the maintenance of dominance is concerned, the stronger stimulus of the two along the emotional dimension dominates over longer durations.

#### 4.3. Emotion influences perception: A brief history, and our contribution

Emotion affects the perception of low-level visual features (Phelps et al., 2006) and modulates attention (Most et al., 2005). Of critical importance is the fact that emotion is not a single monolithic concept but consists of several related but different dimensions. How these different dimensions affect perception at conscious and unconscious levels of processing remains, by and large, unexplored.

At the biological level, these issues are now beginning to be explored. There is a known connection between the amygdala, a brain structure critical for emotional processing, and visual cortex (Kapp et al., 1994; LeDoux, 2002; Vuilleumier, Richardson, Armony, Driver, & Dolan, 2004), brain areas critical for visual stimulus processing. Of particular interest to the present discussion is the finding that amygdala activation does not often differ for positively and negatively valenced stimuli (Garavan, Pendergrass, Ross, Stein, & Risinger, 2001; Hamann & Mao, 2002): Relative to neutral words, positive and negative emotional words elicited greater fMRI activity in the left human amygdala; relative to a low arousal and neutral valence picture baseline, both positively and negatively valenced pictures elicited greater fMRI activity in the left human amygdala and these responses did not differ from each other (it bears mention that neither study used stimuli that were balanced in one dimension of emotion and variable in the other as we did). Given the established fact that the amygdala is strongly responsive to emotional stimuli (LeDoux, 1996), the above findings indirectly argue that rather than valence, other dimensions of emotion, e.g. arousal, drive amygdala response. On the basis of our behavioral finding indicating, perhaps for the first time, that valence does not have access to awareness independent of arousal, one is tempted to speculate that earlier studies may have confounded the two variables—arousal and valence—in examining amygdala response: Negatively valenced, or unpleasant, stimuli can be highly arousing. However, valence and arousal are not one and the same (all arousing stimuli are not unpleasant).

Previous studies have examined the effects of stimulus valence on conscious perception but have rarely tried to tease apart the effects of valence from those of arousal. For instance, spotting a negative stimulus (angry face) among positive stimuli (happy faces) has been shown to be easier than the other way around (Hansen & Hansen, 1988), indicating that negatively valenced (unpleasant) stimuli dominate over positively valenced (pleasant) ones. On the other hand, other studies using the rivalry paradigm have shown that both positive and negative facial expressions predominate over neutral ones (Alpers & Gerdes, 2007). The effect with face stimuli is consistent with our findings on emotionally laden natural scenes, but differs in a few important ways over and above the obvious difference in choice of stimuli. In this and other previous studies (Alpers & Gerdes, 2007; Alpers & Pauli, 2006), negative and positive arousing stimuli were pitted against neutral, non-arousing ones, whereas in our study, stimuli of negative and positive valence of nearly identical arousal level were directly pitted against each other. Furthermore, stimuli of high and low arousal of nearly identical valence were directly pitted against each other in our study. This controlled experimental design allowed us to argue for the predominance of arousal over valence in driving access to visual awareness. Arousing images predominate, regardless of valence—the more arousing the image, the greater is its likelihood to be perceived longer. Valence also has an effect on perception, but, as we show here, only within an overarching context of arousal. Thus, our study generalizes and extends previous findings by teasing apart the influence of two distinct dimensions of emotion—arousal and valence—on visual perception and access to visual awareness.

#### 4.4. Biological fitness

The issue is if we can reasonably explain how the predominance of arousal on visual perception, and the opposite effects on visual perception of stimulus valence depending on low or high stimulus arousal level, benefit the organism. An arousing stimulus, by definition, is one that awakens, alerts, and stimulates the nervous system. An alert individual is one who is aware of the environment. It is therefore reasonable for the sensory system to have evolved to grant early 'privilege' to an arousing stimulus. One might also reasonably posit that the arousing stimulus is processed just enough for one to realize that but that it is arousing, but that it needs to be processed further still in order to evaluate its effect on survival. This would imply that it is imperative to process the more unpleasant stimulus more thoroughly, because the consequences of not processing a noxious stimulus are direr than the consequences of not processing a pleasing one. Our finding, viz. the more unpleasant picture of a high arousal pair is perceived for longer durations dovetails nicely with the above arguments. On the other hand, if the stimuli are not arousing and therefore, not critical to one's fitness, the more pleasant stimulus is obviously more pleasurable. With this backdrop, it is not surprising that the more pleasant picture of a low arousal pair tends to be perceived longer, as we observed.

In sum, our study teases apart the relative effects of the arousal versus valence levels of a stimulus on one's awareness of it. We propose that the arousal level of a stimulus provides the initial, automatic, pre-conscious route to awareness; once triggered by arousal, awareness is further modulated by stimulus valence, but the effect of valence depends on the level of arousal. On the basis of our findings, it is tempting to speculate that stimulus valence is processed at a more conscious level as compared to arousal. That there might be a dimension of emotion that can be processed with little consciousness, while another requires more consciousness before being processed, is an exciting idea. It would be instructive to explore how these two dimensions of emotion are represented

in the brain, how they interact in the brain, and how each affects access to consciousness.

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#### Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.visres.2008.07.013.

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