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# Preference for luminance histogram regularities in natural scenes

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ABSTRACT

Natural scene luminance distributions typically have positive skew, and for single objects, there is evidence that higher skew is a correlate (but not a guarantee) of glossiness. Skewness is also relevant to aesthetics: preference for glossy single objects (with high skew) has been shown even in infants, and skewness is a good predictor of fruit freshness. Given that primate vision appears to efficiently encode natural scene luminance variation, and given evidence that natural scene regularities may be a prerequisite for aesthetic perception in the spatial domain, here we ask whether humans in general prefer natural scenes with more positively skewed luminance distributions. If humans generally prefer images with the higher-order regularities typical of natural scenes and/or shiny objects, we would expect this to be the case. By manipulating luminance distribution skewness (holding mean and variance constant) for individual natural images, we show that in fact preference varies inversely with increasing positive skewness. This finding holds for: artistic landscape images and calibrated natural scenes; scenes with and without glossy surfaces; landscape scenes and close-up objects; and noise images with natural luminance histograms. Across conditions, humans prefer images with skew near zero over higher skew images, and they prefer skew lower than that of the unmodified scenes. These results suggest that humans prefer images with luminances that are distributed relatively evenly about the mean luminance, i.e., images with similar amounts of light and dark. We propose that our results reflect an efficient processing advantage of low-skew images over high-skew images, following evidence from prior brain imaging results.


## 1. Introduction

The distribution of light intensities in the natural world plays a fundamental role in vision. Mechanisms of adaptation evolved to allow species to tune their visual systems to the proportions of different light intensities in the immediate natural environment (see, e.g., Baccus, 2007). However, our perception of natural scenes is also invariant to large changes in luminance distributions, especially with regard to higher order statistical moments. For example, we readily recognize a scene as being the same scene at different times of day or in different weather. We can also recognize a scene whether we see it in person or in a picture. In addition, the example of human-made pictures is particularly intriguing from the perspective of natural vision: Such images "work" despite the fact that typical natural scenes have a far larger dynamic range and more highly skewed histograms than paintings (Graham & Field, 2007, 2008).

Here we examine luminance statistics of natural images, focusing on the skewness (third statistical moment) of luminance distributions. Skewness is of interest for a variety of reasons, but primarily because there is evidence for its role in aspects of natural vision. Higher-order statistics such as skewness and kurtosis appear to be regular in natural luminance distributions. In particular, natural scenes typically have positively skewed luminance distributions (Attewell & Baddeley, 2007; Brady & Field, 2000; Dror et al., 2001; Laughlin, 1981), in part because of natural scenes' high dynamic range. Schemes for efficient neural coding of this regularity have been proposed (Brady & Field, 2000; Richards, 1981).

With regard to aesthetics, basic spatial and luminance statistics relevant to efficient processing can predict significant portions of variance in similarity and preference judgments for paintings (Graham et al., 2010). It has also been shown that artwork tends to have more isotropic orientation spectra (Redies et al., 2007) compared to many types of natural images, due perhaps to a de-emphasis of natural scenes' horizontal structure in paintings at certain scales (Schweinhart & Essock, 2013).

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However, existing data on luminance distribution skewness in images could support one of two possible predictions regarding preference.

First, we might expect preference to be shaped by natural regularities in skewness. Natural scenes' positive skew (Brady & Field, 2000) is due primarily to the heavy-tailed, high-dynamic-range distribution of luminances, which often spans a three or four decade range. We might therefore expect our preferences to simply align with regularities in nature, as has been suggested in relation to other image properties. For example, Redies (2008) argues that we prefer painted portraits that, in the spatial domain, are more like complex natural scenes since portraits tend to have spatial frequency spectra slope closer to those of natural scenes than to those of real faces (Redies et al., 2007). A related argument has been made regarding color, namely that in general we prefer blue over yellow because more positively affective components of our visual ecology are blue than yellow (Palmer & Schloss, 2010). Following this logic, we might therefore expect higher skew to be preferred since it is characteristic of complex natural scenes.

Another line of support for this prediction comes from the finding that skewness is often associated with glossiness in images (Motoyoshi et al., 2007; although high skew does not guarantee glossiness: see Anderson & Kim, 2009). Recent evidence shows that high luminance distribution skewness is a valid cue for freshness of fruits and vegetables[1] (Arce-Lopera et al., 2012; Wada et al., 2010). In addition, infants show preference for glossy objects (with high skew) starting as early as 7–8 months of age (Yang et al., 2011). Thus, if we tend to like shiny and/or fresh things, which tend to generate higher skew in luminance distributions, we may generally also prefer natural images with higher skewness. We term this the *matching nature hypothesis.*

A second hypothesis is that low absolute skew (i.e., skew near zero) would be preferred. In this view, we would take as evidence the fact that artists through the ages have, on average, produced images with low absolute skew. Low skewness in artwork is due in part to the fact that artists are limited in dynamic range compared to natural scenes (Graham, 2011; Graham & Field, 2007, 2008b; Graham et al., 2010), though it is possible produce a low-dynamic range image with high skew by hand. One could hypothesize that preference for low skewness could be partly due to a processing advantage for images with luminance distributions that are relatively evenly distributed about the mean. That is, an image with similar proportions of light and dark may be more aesthetic because it could be more efficiently processed. Such efficiency could sway higher-level cognitive processes associated with aesthetic judgment, or, in less precise terms, it could contribute to the "ease" of cognitive processing (i.e., processing fluency: Reber, Winkielman, & Schwarz, 1998). Thus, if low skewness is indeed efficiently processed by the human visual system, we would expect natural scenes with lower skewness to be preferred. We term this the *matching art hypothesis.*

Thus, we have two reasonable but incompatible hypotheses. Here we aim to address this question by testing human preference for natural images that have been manipulated to possess different higher order statistics, but that are otherwise identical. Following this approach, in Experiment 1, we test artistic photographs of dramatic natural landscapes. In Experiment 2, we test natural landscape images from a calibrated image database. In Experiment 3, we test calibrated natural images of objects. In Experiment 4, we test natural images whose pixels have been spatially randomized.

[1] This result agrees with commercial practice since fruits and vegetables in supermarkets are often sprayed with water to give them a more glossy appearance despite the fact that this can cause them to rot faster.

## 2. General methods

### 2.1. Participants

Participants were recruited from the University of Vienna subject pool in return for course credit (except for Experiment 1a, which employed uncompensated volunteers). All participants had normal or corrected-to-normal visual acuity and were naïve as to the purpose of the experiment. Written informed consent was obtained from all participants prior to participation and the experiment was carried out in accordance with the Declaration of Helsinki.

### 2.2. Stimuli

Adjustments to the source images' luminance distribution skewness were achieved using a gamma transformation. Once images with a range of 8 skew values were achieved for each scene, the 8 images were processed via linear scaling so that the luminance mean and variance was normalized (using the SHINE toolbox; Willenbockel et al., 2010), leaving skew values unaffected. Images were displayed on a black background.

### 2.3. Apparatus

Images were displayed in a darkened room to minimize stray light. In Experiment 1a, we presented the stimuli on a Samsung 2443 24-inch LCD monitor; in all other experiments we used a Samsung SyncMaster S24A300B, 24-inch LED backlit monitor. Both monitors were linearized in software with respect to luminance measured using a photometer (Konica-Minolta LS-100). In all experiments the participant's head position was fixed on a chin rest. Images in Experiment 1 subtended approximately $18^\circ \times 12^\circ$, and in Experiments 2, 3, and 4 they subtended approximately $16^\circ \times 12^\circ$.

### 2.4. Procedure

We used a two-alternative forced choice paradigm with paired comparisons. Each scene's eight versions were presented next to each other in pairs, which produced a total of 28 pairs per scene. Each trial consisted of a comparison of one version of a given scene with another version of the same scene. Presentation of the scenes was blocked and randomized and the presentation of the pairs was randomized to control for anchoring and ordering effects. Participants were instructed in German (except for 3 Erasmus students in Study 1 who received instructions in English) to choose the image in each pair they preferred by pressing the left or right arrow key on the PC keyboard. Stimuli were presented using the PsychToolBox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997) for MATLAB (The MathWorks, Inc.).

## 3. Experiment 1

To investigate the basic effect of skewness on preference, we performed two experiments using artificially manipulated artistic natural images as stimuli. Experiment 1a and 1b involved the same source images and procedure but differed in the number of participants, and the adjusted skew values. This was done to sample a larger variety of skew values and in order to test separate subject pools. The display also differed in the two experiments, as described above.