Perceptual Quality of Color Images of Natural Scenes Transformed in CIELUV Color Space

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Abstract

Transformations of digitized color images in perceptually-uniform CIELUV color space and their perceptual relevance were investigated. Chroma variation was chosen as the first step of a series of investigations into possible transformations (including lightness, hue-angle, chroma, etc.). To obtain the information about the perceptual consequences of the chosen transformations, perceptual image quality, naturalness, and colorfulness were measured by means of scaling. The results suggest that in general a more colorful image than the original one is preferred.

Introduction

Every color can be described in terms of hue, colorfulness (chromaticness), and brightness[1]. For an optimal reproduction of natural images on color displays it is important to know the influence theses perceptual attributes may have on perceived quality[2] and naturalness of such images. We are interested in naturalness because it is expected that qualitatively optimal images appear, at least, natural.

This prompts the investigation into the perception of images transformed in a "natural" way. Consequently, global attributes have to be considered.

Changes in global colorfulness due to chroma variations were chosen as the first step in a series of investigations into possible transformations.

Method: Image Transformation

Digitized color images of four natural scenes were described by their color point distributions in the CIELUV uniform color space. For every original image a set of new images was computed by changing the chroma value for each pixel keeping lightness and hue-angle constant. Two methods of changing chroma were used:

1) translation: the chroma value was increased or decreased by adding/subtracting the same number of chroma units to/from the chroma value for every pixel;

2) multiplication: within each image the chroma value for every pixel was multiplied by a constant.

If during the processing of the images calculated r, g, b- grey values were out of the possible range for the grey values of the monitor, the nearest possible value of chroma was used (clipping). For every scene, twenty images were prepared using ten different constants of translation and ten of multiplication. For every image, average chroma value and variability of chroma (standard deviation) were computed.

Procedure

In separate experiments five subjects were asked to rate on a ten point numerical category scale:

1) perceptual quality—degree of excellence of an image;

2) colorfulness—presence and vividness of colors in the whole picture;

3) naturalness - degree of correspondence between the image reproduced on the screen and the reality.

One always corresponded to the lowest strength of an attribute, ten to the highest strength. During one experiment all 84 images were presented four times.

Results: Quality and Colorfulness

The obtained estimations were first rescaled according to the Thurstone model[3] and then averaged over all subjects.

Figure 1 shows quality estimations as a function of average chroma for two scenes: "Fruit" and "Terrasgeel".

The systematic difference between two methods of changing chroma implies that in our experiment average chroma is not the only variable determining perceptual image quality.

To understand the observed discrepancy, subjects were asked to judge colorfulness of the same set of images. Since we changed chroma, colorfulness was expected to be the main attribute underlying perceptual quality. The results of this experiment are presented in Figure 2, where estimated colorfulness is plotted as a function of average chroma for two scenes.

Subsequently, the quality estimations were plotted as a function of judged colorfulness instead of average chroma (Figure 3). The resulting coincidence of the quality estimations for translation and multiplication demonstrates that, in these experiments colorfulness is indeed the main perceptual attribute determining quality. It can be seen that the images of the highest quality are slightly more colorful than the original (unprocessed) ones. This tendency is stable and occurs for all four scenes.

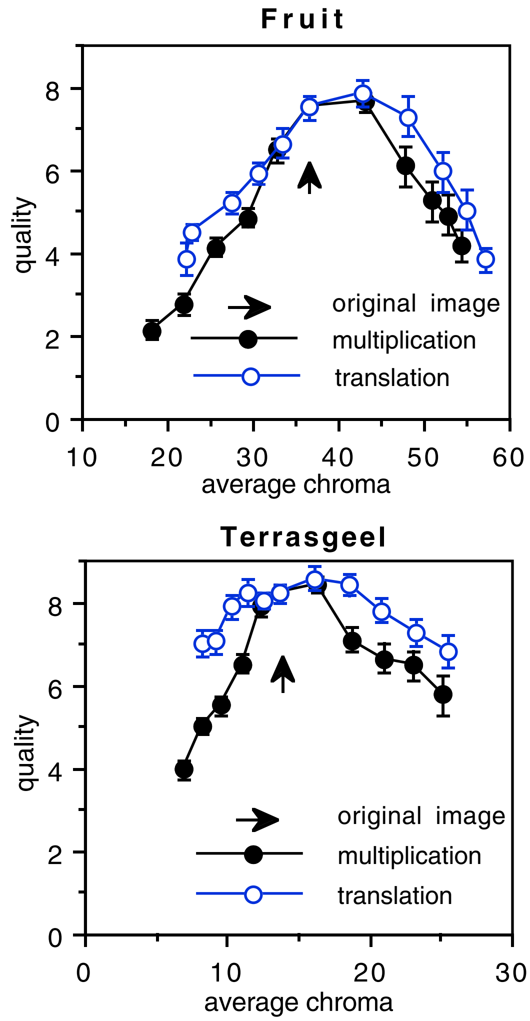

Figure 1. Averaged quality estimations as a function of average chroma for two scenes.

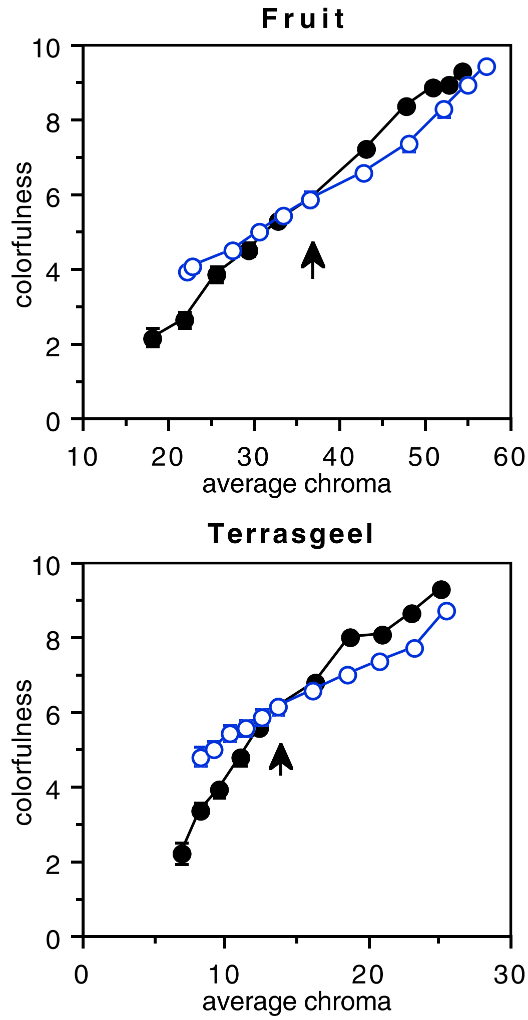

Figure 2. Averaged scaled colorfulness estimations as a function of average chroma for two scenes (symbols: see Fig. 1).

The systematic difference between colorfulness estimations for translation and multiplication indicates that variability of chroma may also contribute to subjective colorfulness. The fact that these values differ in the cases of translation and multiplication follows from the definition of these procedures. In Figure 4 computed standard deviation is plotted versus average chroma. The deviations from predicted values for variability of chroma can be ascribed to clipping.

The dependency of colorfulness on both average chroma and variability of chroma (standard deviation) can be efficiently described by a linear combination of these two variables, or:

colorfulness = A × Average chroma + B × Standard deviation of chroma + C,

where A, B, and C are appropriate constants depending on the rating procedure and scene content. Figure 5 demonstrates the close correspondence between subjective estimations of colorfulness and calculated values for all four scenes used in the experiment. For “Fruit” and “Terrasgeel” the correlation coefficient between estimated and calculated values amounts to 0.993 and 0.977, respectively.

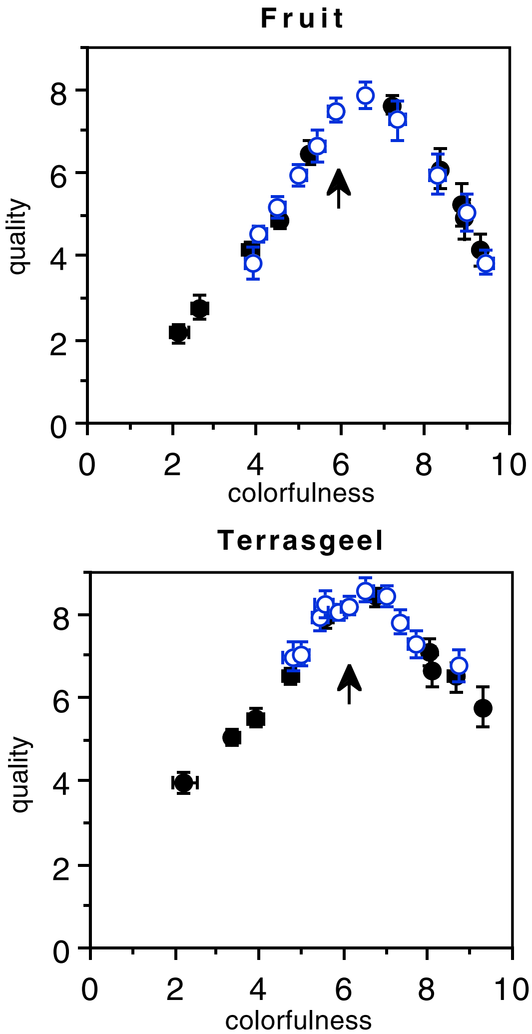

Figure 3. Averaged quality estimations as a function of measured colorfulness for two scenes (symbols: see Fig. 1).

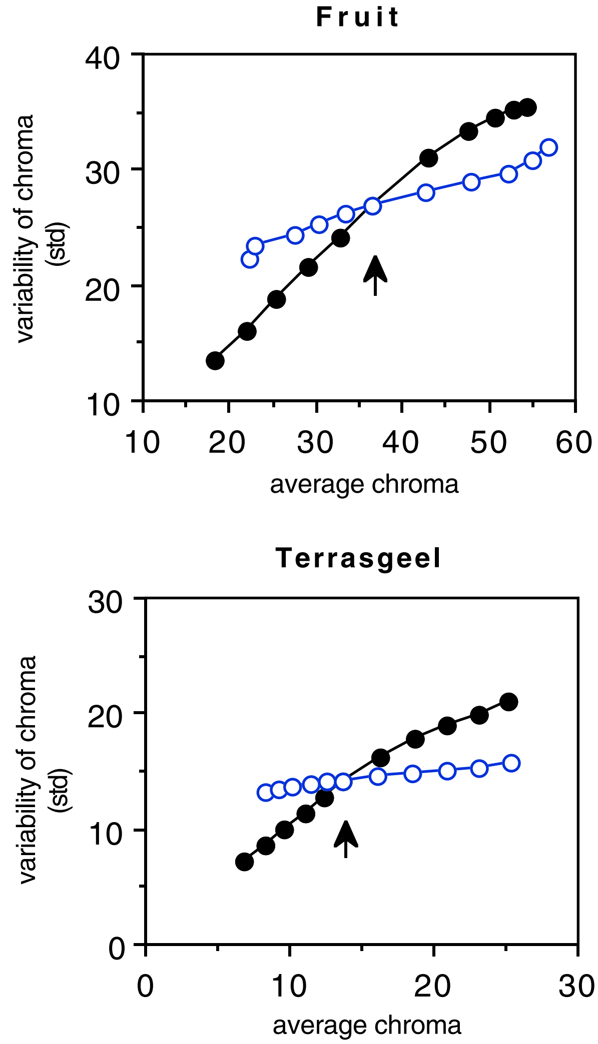

Figure 4. Variability of chroma plotted versus average chroma for two scenes (symbols: see Fig. 1).

Naturalness, Quality and Colorfulness

In the third experiment it was found that naturalness, like quality, is determined by subjective colorfulness: again, a coincidence between translation and multiplication is observed when colorfulness is taken as the independent variable (Figure 6).

The functional relationship between naturalness and colorfulness is comparable to the one between quality and colorfulness. Both attributes are nonlinearly related to colorfulness with an optimum near the original image. The overall coefficient of correlation between naturalness and quality is 0.93 showing their intrinsic connection.

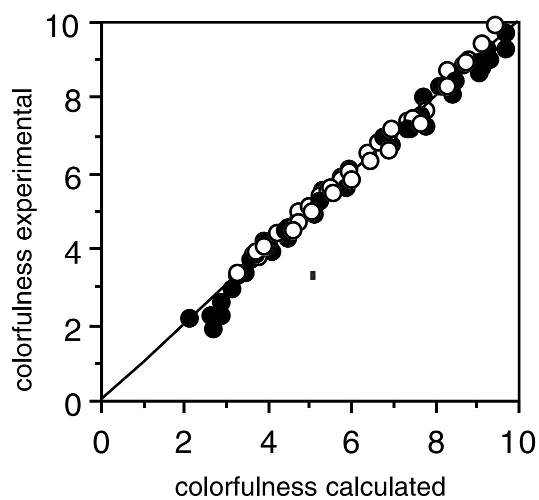

Figure 5. Results of linear regression analysis of colorfulness. Colorfulness as a linear combination of average chroma and variability of chroma plotted versus experimental estimations (symbols: see Fig. 1).

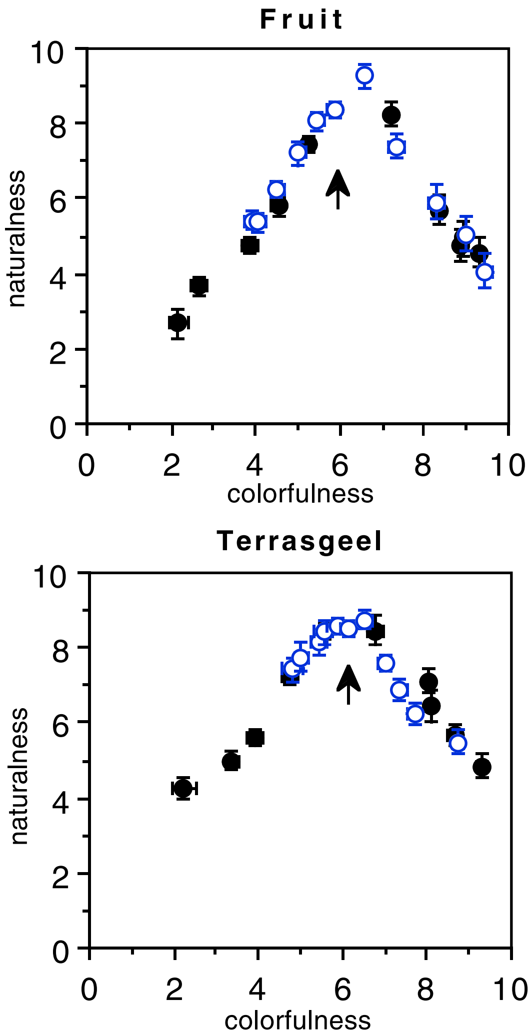

Figure 6. Averaged scaled naturalness estimations as a function of colorfulness for two scenes (symbols: see Fig. 1).

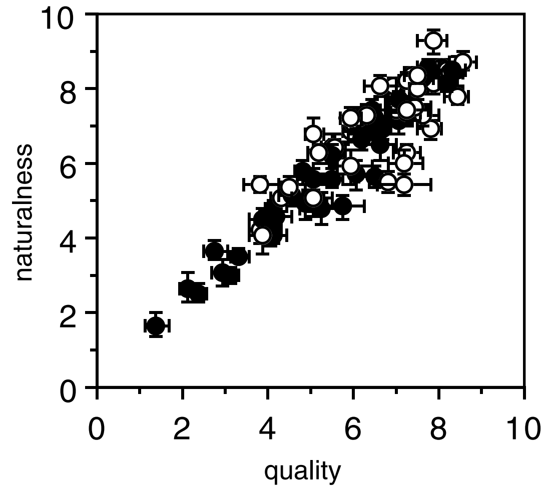

Figure 7. Naturalness estimations plotted versus quality estimations. Data are for all four scenes.

Conclusions

Colorfulness of the whole image in our experiments is a main perceptual attribute underlying image quality and naturalness.

Colorfulness, specified as presence and vividness of colors in the whole picture, depends on both average chroma and variability of chroma as derived from the color point distribution in the CIELUV color space.

Perceptual quality and naturalness are nonlinearly related to colorfulness with an optimum near the original image.

There is a close relation between perceptual image quality and naturalness. The image quality decreases at higher levels of colorfulness because the images become unnatural.

References

1. R. W. G. Hunt, *Measuring Colour*, 2nd ed., Ellis Horwood, Chichester, (1992).
2. J. P. Allebach, Processing Digital Color Images: From Capture to Display, *Physics Today,* **45**, 12, 32-39, (1992).
3. J. A. J. Roufs, Perceptual image quality: concept and measurement, *Philips Journal of Res.,* **47**, 35-62, (1992).
4. W. S. Torgerson, *Theory and methods of scaling*, John Wiley and Sons, New York, (1958).