



EFFECT OF FREQUENCY ON THE SENSITIVITY TO TEMPORAL COLOR TRANSITIONS

Dragan Sekulovski, Ingrid M. Vogels, Maurice van Beurden and Ramon Clout

Philips Research Europe, Eindhoven, The Netherlands

Light and lighting have a large impact on our everyday lives. Advances in lighting, especially in Solid State Lighting, make this impact even larger by enabling new uses and enriching the existing ones. Having improved spatial and temporal resolution, more saturated primaries and lower power consumption, LED based lighting systems can be used to design more complex and attractive lighting atmospheres. One of the largest differentiators of such lighting systems are their dynamic capabilities. However, the produced dynamic lighting atmospheres need certain properties to be attractive to the users. Perceived smoothness is one of those desirable properties. Aside from a limited set of applications, such as for disco lights and concerts, or being used as attention attractors, abrupt changes in environment lighting are hardly perceived as pleasant. Modern lighting applications use discrete control of the light sources, with a limited number of intensity levels. Contrary to the analog systems which have a continuous change in color, in digital systems the smallest distance between two colors, both in color and time, is limited by the resolution of the system. Similar to spatial color perception, an inappropriate distance between successive colors can introduce perceived discontinuities. To compute the required distances between colors that produce spatial patterns which appear smooth, the notions of visibility threshold and just noticeable difference were introduced. The continuation of the work on spatial just noticeable differences led to the development of, among others, the CIE Luv and CIE Lab color spaces. These color models show a relatively good uniformity in the perceived differences, thus predicting the perceived smoothness of spatial color patterns. The work presented in this paper builds upon a previous study [1] of temporal properties of human color vision relevant to dynamic lighting applications. The experiments presented show that existing models of spatial color vision are inadequate in predicting thresholds for smoothness perception for linear color transitions and color flicker. This shows the need for a temporal model that can predict these thresholds. The fact that the perception of the temporal transitions depends on the frequency at which the changes are made, further complicates the representation and smoothness prediction in the temporal case. In this work we characterize the behavior of the smoothness thresholds for different frequencies in terms of the maximum speed of the transition that still appears smooth, i.e. the speed of a temporal color transition with a color difference equal to the smoothness threshold. We define the speed of the transition (v) in terms of the smoothness threshold (s) and the frequency of change (f) as $v = f \times s$. Figure 1 depicts the maximum speed of smooth transitions for a set of frequencies for different directions of the color change (i.e. lightness, chroma and hue), averaged over the base points and participants. The speed is calculated based on the results of the experiment described in the previous study.

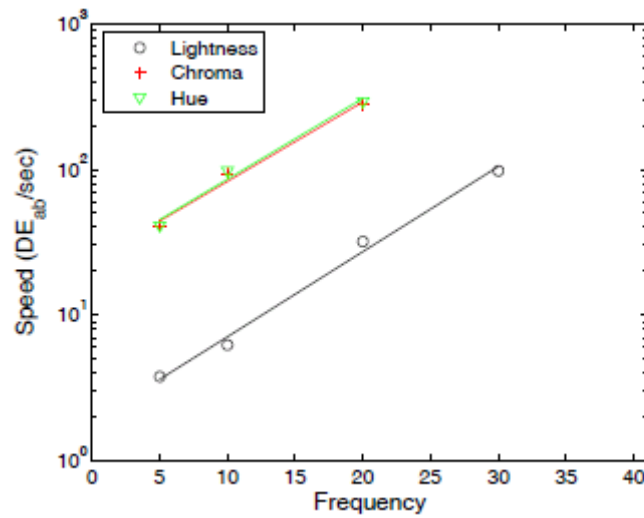


Figure 1: Dependence of the speed of just unsmooth transitions on frequency and a linear fit of the data.

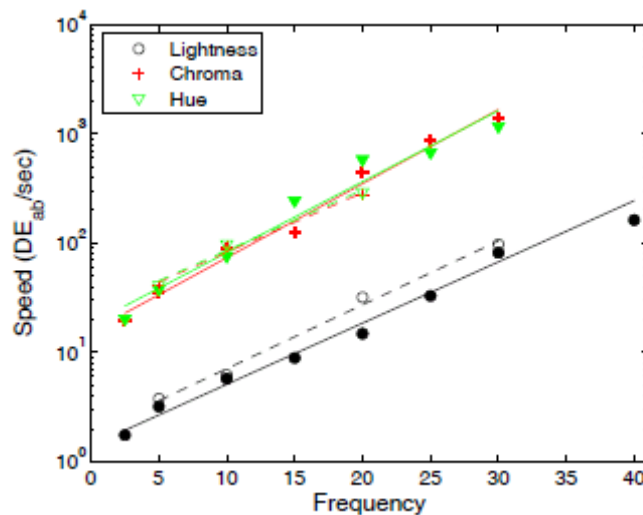


Figure 2: Comparison of the results in the original (dashed lines) and in the validation (solid lines) experiment.

Surprisingly, the results for the natural logarithm of the speed thresholds show a clear linear relationship to the frequency. Furthermore, the fitted lines for the different directions of change all show a similar slope (0.135, 0.125, and 0.128 for lightness, chroma and hue respectively) but differ in their intercept values. The different intercept values account for the absolute difference between the speed thresholds for different directions of change. As interesting as this result is, it is based on a fit of 4 (for lightness) and 3 (for chroma and hue) averaged points, which makes the evaluation of the goodness of the fit hard. To validate the above relationship, an additional experiment was carried out. The additional experiment was a repeated measurement with three participants, the authors of this work IV, RC and DS. As there were no interaction effects of participant to any other factor in the previous experiment, we expect the same trends in the data for a large set of participants in the first experiment and the limited set of participants in the validation experiment. The same experimental setup as in the previous experiment was used. The same color points and directions were tested, but for an extended number of frequencies (2.5, 5, 10, 15, 20, 25, 30, and 40Hz). Figure depicts the results of the validation experiment compared to



the original experiment. The solid lines represent the data from the validation experiment. The results are in accordance with the results from the original experiment with resulting fit slopes of 0.135, 0.141, and 0.145 for lightness, chroma and hue, respectively. Additionally, the higher number of frequency points allows to better estimate the goodness of the fit. The R_2 of the fits was 0.973, 0.978, and 0.944. The absolute value of the speed thresholds is lower in the validation experiment due to participants being expert observers. The results show that for the range of 2.5Hz to 40Hz, the maximum speed of a smooth transition in a direction parallel to the axes of LCh can be determined using a simple exponential law of the form

$$v = a_0 e^{\text{slope}}$$

Analogous to the definition of speed for the linear transitions, we can define the amount of change in one second for flicker as the speed of the flicker and determine its dependence on the frequency. After this transformation, flicker visibility thresholds can be predicted using the same equation.

References

[1] Dragan Sekulovski, Ingrid M. Vogels, Maurice van Beurden, and Ramon Clout. Smoothness and flicker perception of temporal color transitions. In Proc. Of the 15th Color Imaging Conference, November 2007, pp. 112-117.