Relationship Between Bartleson and Breneman's Brightness vs Luminance Equation and Stevens' Power Law

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Introduction

In the study of brightness perception in complex fields, Bartleson and Breneman observed an interesting relationship between perceived brightness and luminance based on the data collected.[1] This data was submitted to computer analysis, and Eq. 1 was found to adequately describe the relationship between brightness (B) to luminance (L).

$$B = 10^{\alpha} * L^{\beta} / \log^{-1}(\gamma * e^{\delta * \log L}) \quad (1)$$

where α, β, γ, and δ are constants that depend on the experimental conditions.

By transforming to log brightness vs log luminance, a somewhat simpler Eq. 2 resulted.

$$\log B = \alpha + \beta * \log L - \gamma * e^{d * \log L} \quad (2)$$

No explanation was given to the form of the equation except that it fitted the data very well. On the surface, this equation appears to deviate from Stevens' Power Law,[5] which relates psychophysical measurements to physical measurements. However, a closer examination reveals that the brightness equation does not conflict with Stevens' Power Law. In this paper, we start from Stevens' Power Law, make the appropriate brightness perception adjustments due to viewing conditions, and obtain the above stated Bartleson and Breneman's brightness equation.

Stevens' Power Law and Brightness Perception in Dark Surround

Stevens' Power Law relates psychophysical measurements Ψ to physical measurements Φ by Eq. 3:

$$\Psi = a * \Phi^{b} \quad (3)$$

where a and b are constants that denote the scaling and power of the relationship between psychophysical and physical measurements.

In the case of brightness vs luminance, symbols Ψ and Φ can be replaced by B and L respectively, and Eq. 3 can be re-written as Eq. 4.

$$B = a * L^{b} \quad (4)$$

By transforming Eq. 4 to brightness as a function of log luminance, and to log brightness as a function of log luminance, Eqs. 5 and 6 resulted.

$$B = a * (10^{\log L})^{b} = a * 10^{b * \log L} \quad (5)$$

$$\log B = \log(a * 10^{b * \log L}) = \log(a) + \log(10^{b * \log L}) = \log(a) + b * \log L \quad (6)$$

With an appropriate choice of units of brightness and luminance, the constant a can be set to 1. In the case of viewing an object that subtends a viewing angle of 5° in dark surround, b is found to be 0.33 experimentally.[5] Figures 1-3 are graphical illustrations of the relationship between brightness and luminance with a = 1 and b = 0.33. Figure 1 plots brightness vs luminance; Fig. 2 plots brightness vs log luminance; and Fig. 3 plots log brightness vs log luminance.

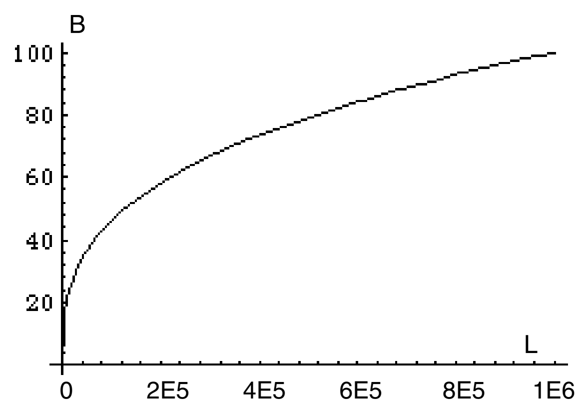

Figure 1. Brightness vs luminance in dark surround $B = a * L^{b} = L^{0.33}$

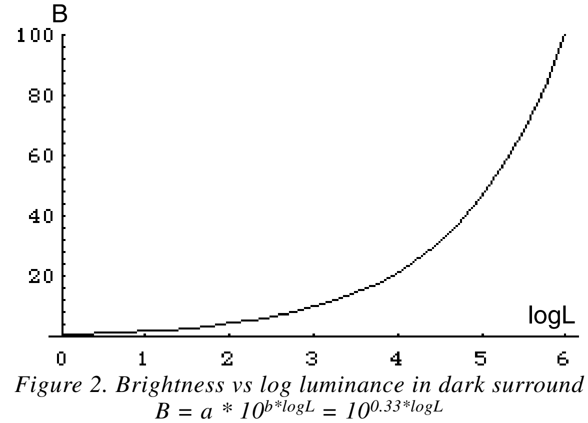

Figure 2. Brightness vs log luminance in dark surround $B = a * 10^{b * \log L} = 10^{0.33 * \log L}$

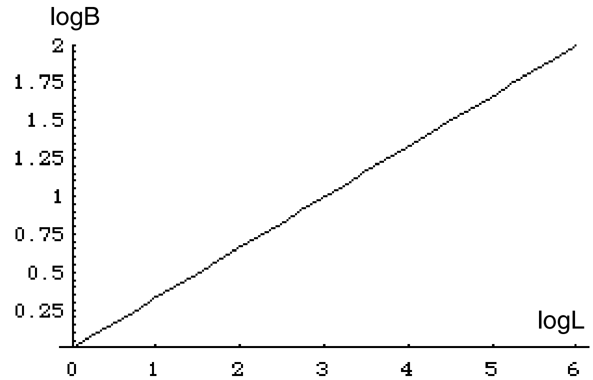

Figure 3. Log brightness vs log luminance in dark surround
$\log B = \log(a) + b*\log L = 0.33*\log L$

Brightness Perception in Light Surround

If objects are viewed in light surround instead of dark surround, all stimuli with luminance less than 1% of the surround luminance will be perceived as black because the human visual system is capable of perceiving only approximately 100 to 1 luminance range simultaneously.[3] Consequently, if the log luminance of the light surround is 6, the brightness of log luminance between 0 and 4 will be zero. Figure 4 gives a qualitative illustration of brightness vs log luminance in light surround, and Fig. 5 is a superposition of Figs. 2 and 4 together.

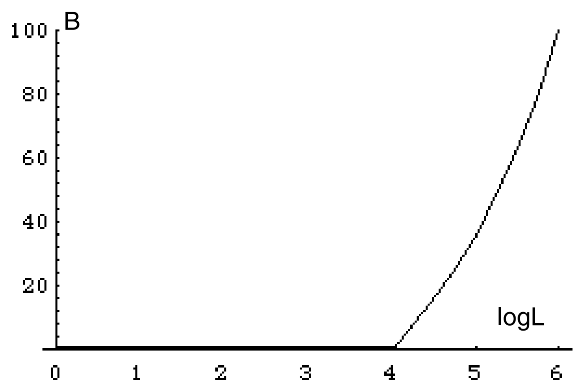

Figure 4. Brightness vs log luminance in light surround

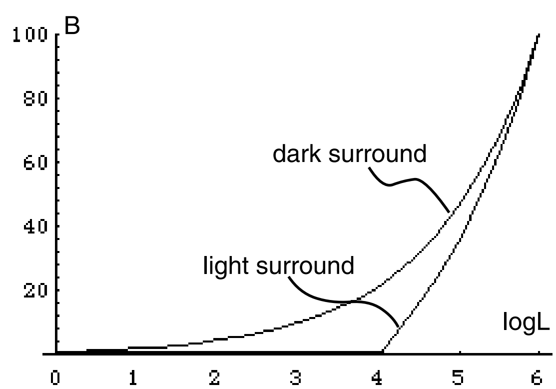

Figure 5. Comparison of brightness vs log luminance in light and dark surrounds

If Fig. 4 is re-plotted in log brightness vs log luminance, we get Fig. 6, whose curve shape is consistent with experimental results described by Bartleson.[2]

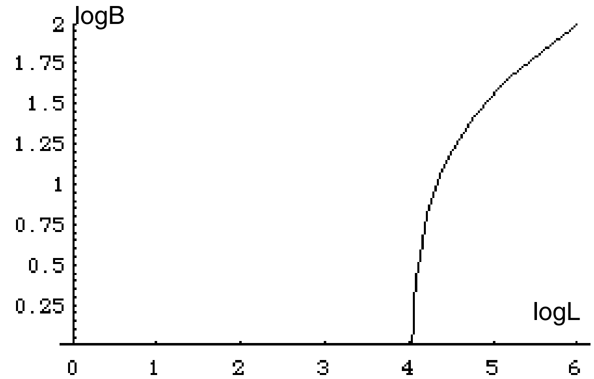

Figure 6. Log brightness vs log luminance in light surround

Note that from Fig. 5, if an image has a certain dynamic range of say 100 to 1, the perceived contrast will be lower when it is viewed in dark surround than in light surround. The corollary of this is that an image should have a higher luminance contrast if it is to be viewed under dark surround. This phenomenon was observed by Breneman in his study of perceived saturation in light and dark surrounds.[4]

If we calculate the brightness difference between the dark surround curve and the bright surround curve in Fig. 5, we get a delta brightness vs log luminance plot as depicted in Fig. 7. This delta brightness function can be interpreted as an brightness adjustment from dark to light surrounds. If an image is to be viewed in an intermediate surround between dark and light, a partial delta brightness adjustment should be made.

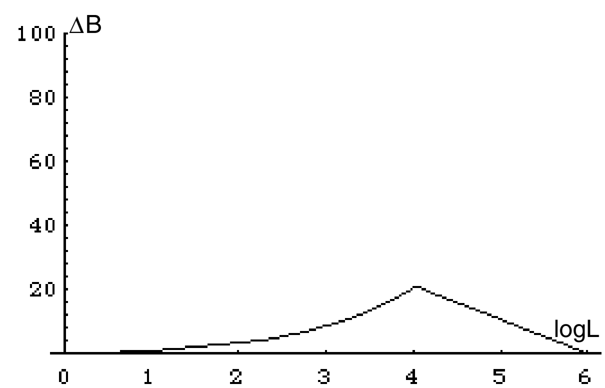

Figure 7. Delta brightness vs log luminance

Many mathematical functions can be used to approximate the delta brightness function in Fig. 7. One such function is that of an exponential function in Eq. 7 with its maximum clipped to the brightness function to avoid negative values. Figure 8 depicts an example of such exponential delta brightness function clipped to the brightness function of Fig. 2.

$$DB = c_1 + c_2 * e^{c_3 * \log L} \qquad (7)$$

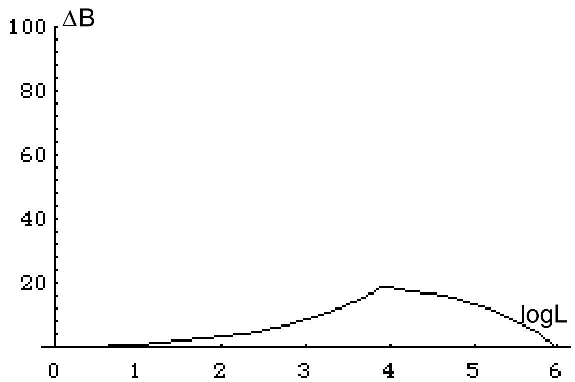

Figure 8. Exponential delta brightness vs log luminance
$\Delta B = \min\left(10^{1.32*(1-e^{\log L-6})},\ 10^{0.33*\log L}\right)$

Now, if we subtract the delta brightness function from the brightness vs log luminance function in dark surround, we will get the brightness vs log luminance function in light surround. Figure 9 is the result of subtracting an exponential delta brightness function in Fig. 8 from the brightness vs log luminance function in dark surround in Fig. 2, and this curve is similar to the brightness vs log luminance function in light surround in Fig. 4.

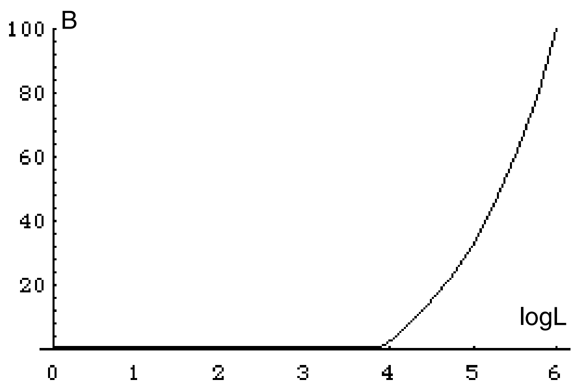

Figure 9. Brightness vs log luminance in light surround resulting from using an exponential ΔB function

Converting Fig. 9 to log brightness vs log luminance, we get Fig. 10, which is similar to Fig. 6 and thus agrees with the observed data of Bartleson and Breneman.

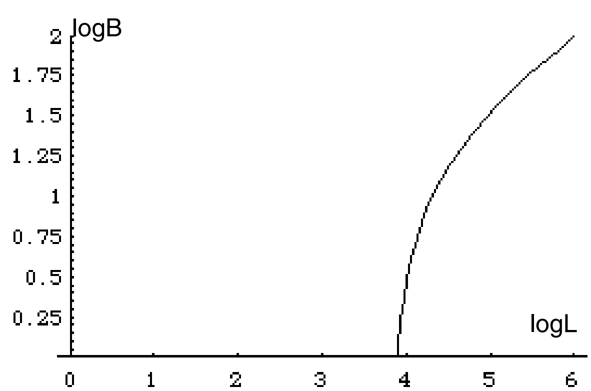

Figure 10. Log brightness vs log luminance in light surround resulting from using an exponential ΔB function

Brightness Perception in Complex Fields

The brightness perception in complex fields is affected by local brightness adaptation due to the brightness of objects immediately surrounding the object of interest. As a result, the curves of brightness perception in dark surround and light surround mark the upper and lower bound for the brightness perception in complex fields.

One attempt to obtain Bartleson and Breneman's brightness vs luminance equation in complex fields is to subtract a partial exponential delta brightness function like Eq. 7 from the brightness vs log luminance function in Eq. 5. This results in Eq. 8.

$$B = a * 10^{b*\log L} - p*\Delta B$$
$$= a * 10^{b*\log L} - (c_1' + c_2'*e^{c_3*\log L}) \qquad (8)$$

where p is a number between 0 and 1, $c_1' = p*c_1$, and $c_2' = p*c_2$.

When Eq. 8 is converted to log brightness vs log luminance, it becomes Eq. 9 which is very complicated and hard to simplify.

$$\log B = \log(a*10^{b*\log L} - (c_1' + c_2'*e^{c_3*\log L})) \qquad (9)$$

However, instead of using a partial exponential delta brightness function that gives a very complicated log brightness vs log luminance function as in Eq. 9, one can use a partial exponential delta log brightness function as in Eq. 10 with its maximum clipped to the log brightness function. This gives similar qualitative results, but the equation is much simpler. Figure 11 is an example of such an exponential delta log brightness function.

$$\Delta\log B = c_1 + c_2*e^{c_3*\log L} \qquad (10)$$

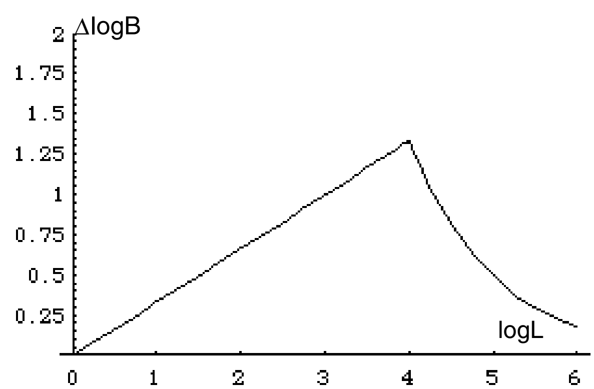

Figure 11. Exponential delta log brightness vs log luminance
$\Delta\log B = \min(1.32*e^{\log L-4},\ 0.33*\log L)$

Subtracting a partial exponential delta log brightness function as in Eq. 10 from the log brightness vs log luminance in dark surround as in Eq. 6, we get Eq. 11.

$$\log B = \log(a) + b*\log L - p*\Delta\log B$$
$$= \log(a) + b*\log L - c_1' - c_2'*e^{c_3*\log L}$$
$$= \log(a) - c_1' + b*\log L - c_2'*e^{c_3*\log L} \qquad (11)$$

Graphically, Eq. 11 can be illustrated by subtracting the delta log brightness function as in Fig. 11 from the log brightness vs log luminance function in dark surround as in Fig. 3.

This results in a log brightness vs log luminance function in complex surround as in Fig. 12, which is similar to Figs. 6 and 10, and agrees with the experimental data of Bartleson and Breneman.

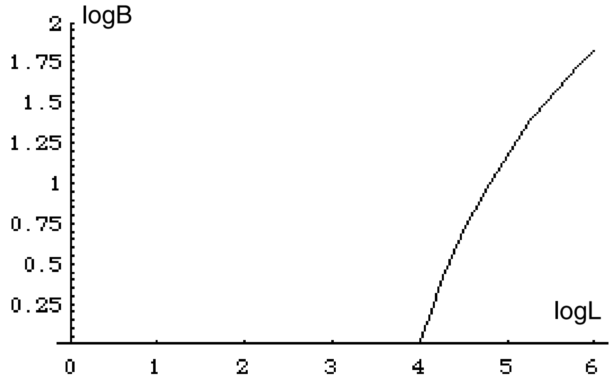

Figure 12. Log brightness vs log luminance in complex surround resulting from using an exponential DlogB function

By letting $\alpha = \log(a)-c_1'$, $\beta = b$, $\gamma = c_2'$, and $\delta = c_3$, Eq. 11 can be re-written as Eq. 12, which is Bartleson & Breneman's brightness vs luminance equation as shown in Eq. 2.

$$\log B = \alpha + \beta * \log L - \gamma * e^{\delta * \log L} \qquad (12)$$

Summary

Brightness perception in complex fields is affected by local adaptation to brightness of the objects immediately surrounding the object of interest, and it is bounded by the limiting cases of brightness perception in light and dark surrounds. Therefore, the brightness vs luminance equation in complex fields can be approximated by subtracting a partial exponential delta log brightness function from the log brightness vs log luminance function in dark surround. As a result, the brightness vs luminance relation in dark surround which follows Stevens' Power Law is transformed to Bartleson and Breneman's brightness vs luminance equation in complex fields.

References

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