Square Law Dimming: Presumed Perception or Reality?

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The principle of "Square Law Dimming" has been used by lighting controls manufacturers for a number of years to predict the relationship between the perceived brightness of a lighting system and the actual level of dimming provided by that system. However, there does not appear to be a specific research basis for this principle or relationship in the lighting literature other than an extrapolation of the Munsell system's representation of the reflectance based upon the square of a color's value designation. The 9th Edition of the IES Lighting Handbook (and prior versions), where this is cited, refer to square law dimming as a "presumed relationship" between perceived illuminance and measured illuminance, also suggesting the lack of a research basis for this principle. Moreover, the 10th Edition of the IES Lighting Handbook does not reference the square law dimming curve at all, further reinforcing the conclusion that a strong research basis does not exist for square law dimming.

Research on brightness perception, on the other hand, suggests that the relationship between luminance and brightness perception is more of a power law. Specifically, Stevens' Power Law is often cited in the literature as a fundamental principle of psychophysics, and much of his work was done relative to brightness perception. The 10th Edition of the IES Lighting Handbook also references a power law relationship between luminance and brightness perception in complex visual fields.

Given the growing importance of lighting controls in lighting system energy savings, including mandates for the use of controls in several lighting energy codes, as well as the explosion in lighting technologies with solid state lighting (LED's) enabling sophisticated connected lighting and control systems, understanding the relationship between the light being delivered and the perception of the light

delivered within an environment takes on an increasingly important role in being certain these systems are being effectively designed.

As a result, this study is a first step to systematically explore the perceived level of light relative to dimming of light sources in real spaces. This first study focuses on the brightness–luminance relationship with a uniform field of luminance.

The study was conducted in the School of Constructed Environments Light Lab at Parsons School of Design (New York, NY). The light lab afforded the opportunity to set up a uniform luminance field controlled by a dimming control system. Two ETC Source 4 LED Daylight theatrical luminaires with 50 degree lens were mounted approximately twenty-five feet from a diffuse neutral color surface (approximately 50% reflectance). The theatrical luminaires afforded the opportunity to precisely "frame" the wall with overlapping beams to maximize uniformity and minimize any shadows. Black drapes were hung on each side to limit the assessment to the font wall. An ETC Programmable Console was used to precisely control the level of light delivered by the luminaires. Participants were seated at a fixed location approximately ten feet from the wall and asked to focus at a marked spot on the wall when making their judgments. Each subject, tested individually, was exposed to lighting at its full intensity (100%) and then asked to rate subsequent levels as a percentage of the initial level. Subjects judged fifty different lighting levels divided into two sets of randomized presentations. At the beginning of each set they were exposed to the base level of 100% as the basis for comparison

Twenty-eight subjects were drawn from the student population at The New School -- 18 female and ten male – with an average age of 26, ranging from 18 to 32. Ten subjects were American with the remainder of various other nationalities.

Luminance measurements were taken of the wall for each dimming setting from two locations with Konica Minolta Digital luminance meters. Color temperature measurements were also taken to ensure that the color of light was consistent throughout the presentations.

The data clearly presented a non-linear relationship between luminance and perceived level of light (judged as a percentage of initial level) when plotted on a scatter diagram and a non-linear regression analysis was conducted to determine a more specific representation of the relationship. It is clear from the data that a simple representation such as a square law relationship is not adequate to describe perceived level of light versus actual level.

As mentioned, this first study focuses on the brightness–luminance relationship with a uniform field of luminance. In itself it should be repeated with a wider range of luminances and, perhaps allowing subjects to adjust the luminance as a percentage of a benchmark. Subsequent studies should explore the influence of other variables in the dimmed environment, such as:

- Position of the dimmed surface, e.g., overhead or in front.
- Uniformity of light, i.e., uniform versus non-uniform.

- Surface luminance(s) versus luminance of source versus luminance of task.
- Color of light (warm versus cool) and/or interaction of color of light and color of surfaces.