COMMUNICATIONS AND COMMENTS

Modeling Lightness Perception—Another Point of View

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Received 30 August 2012; revised 12 September 2012; accepted 14 September 2012

Abstract: In a recent note, Brill and Carter propose to revisit the centuries-old disagreement over the relationship between stimuli and perceived lightness or brightness and the mathematical model that best represents it. Here, the answer is offered that the only way to resolve this matter is empirically, with controlled experiments of different kinds that establish statistically meaningful and replicated data for a given set of test conditions and methodology. Given the fact that surround lightness has a very significant effect on the results, including the crispening effect, a model can only be valid for a limited set of conditions, and the likely outcome is multiple models or models with multiple variables. © 2013 Wiley Periodicals, Inc. Col Res Appl, 39, 102–104, 2014; Published online 2 January 2013 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/col.21786

Key words: lightness; difference scaling; just noticeable difference; value scale

In a recent note, Brill and Carter raised the centuries-old issue of which mathematical model most accurately predicts perception of brightness/lightness differences.[1] Depending on one's philosophical world views, mathematics controls the world or it is a very useful tool to describe in a neutral, abstract manner relationships between properties of various kinds. Colors are purely psychological personal mind products. For them, there is no objective information. Representative values can only be the mean results of multiple evaluations by multiple subjects. In most perceptual color experiments of the past, it was not explicitly determined or assured that statistically meaningful mean values were achieved. What is at issue, in this writer's view, is not which mathematical law mean human brightness/lightness perception adheres to but what are solid statistical facts about human lightness perception. Brill and Carter raise the question whether larger lightness differences are sums of just noticeable differences (JNDs). It is evident that only empirical research will provide the answer.

Lightness and brightness scales have a long history; an early illustration of a relevant experiment[2] dates back to 1613. Early experiments are those by Bouguer and Fechner.[3,4] In both of these efforts, JND methodology has been used as a basis for a brightness scale. These and other experimental results provided support for Weber's logarithmic law of 1836, originally proposed for perceptual increments other than those involving light stimuli.[5] In 1873, Plateau developed a lightness step methodology for which he found a power relationship to apply.[6] The argument between supporters of the logarithmic and the power relationship continued and, as the authors of the note show, has not yet abated. Munsell *et al*.[7] presented results for both JND and value step methods using gray samples, finding that for "carefully trained and selected observers" the results were very similar and could be modeled with a power relationship that was later expressed with a cube-root formula. Their work involved use of a white, a black, and a mid-gray surround, and while the functions differed based on the background, their general form was taken to be the same and the results for all three surrounds were averaged. This averaged lightness formula was maintained in the Munsell Renotations[8] of 1943. In the early 1960s, Stevens demon-

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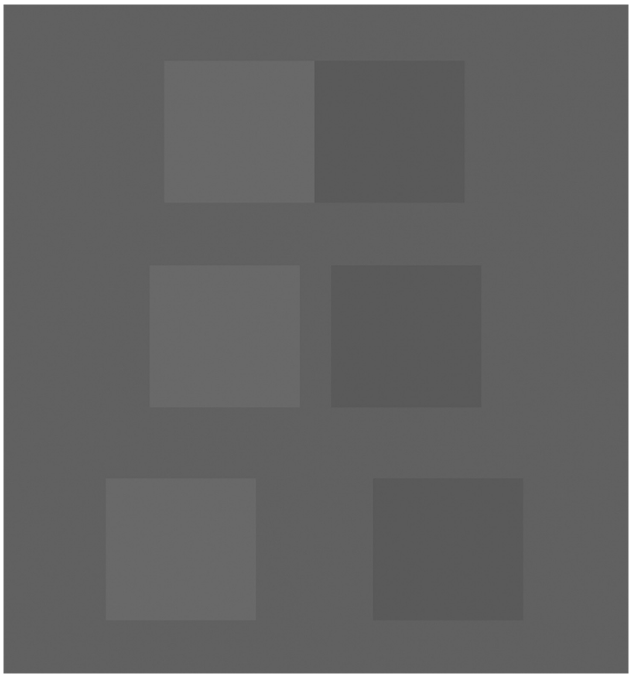

FIG. 1. Example of the crispening effect and related effect of sample distance. The lightness values of the two samples straddle that of the surround. Against a white or a black surround, the samples are seen as having a difference near the JND level. The sample pairs are identical on the same horizontal level where they differ in distance between them.

strated in a series of articles what he believed to be the general applicability of the power law to represent psychophysical relationships.[9] In 1964, Japanese scientist T. Kaneko reported findings of a very significant dependence of perceived lightness difference on surround lightness, particularly strong for samples of lightness near that of the surround.[10] At the time, the Committee on Uniform Color Scales of the Optical Society of America was in the middle of its extended work, and Judd involved Takasaki and Semmelroth to investigate this effect, named "crispening effect," in more detail.[11,12] The outcome was

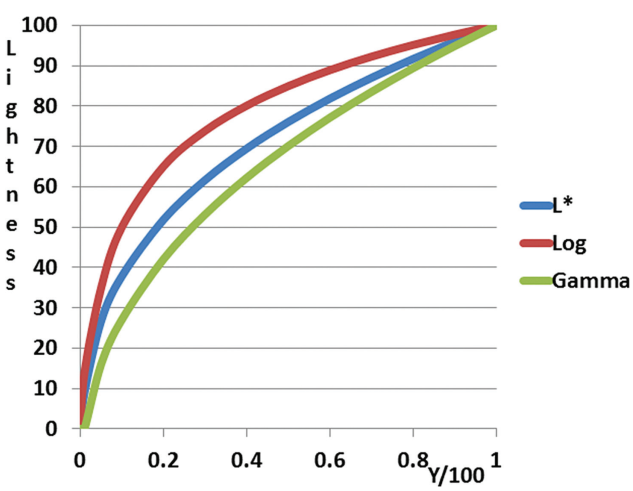

FIG. 2. Luminous reflectance versus lightness functions of the L^*, log 10, and gamma lightness models.

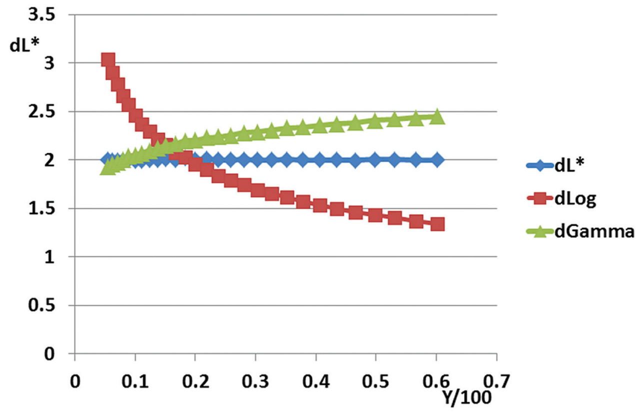

FIG. 3. Comparison of calculated lightness differences for increments in luminous reflectance Y from 4.7 to 60.0 that in the L^* model result in identical differences. The same increments have been used to calculate differences according to the log and the gamma models.

that the OSA-UCS (Optical Society of America Uniform Color Space) lightness formula not only included the Helmholtz–Kohlrausch effect but also the crispening effect.[13] Interestingly, neither of these effects were considered in the International Commission on Illumination (CIE) CIELAB and CIELUV color space and difference formulas, for reasons no longer evident. The crispening effect, a contrast effect, is undoubtedly real. It is itself subject to conditional effects such as the placement of samples (adjoining or separate), the sharpness of the dividing line, the distance between samples, and others, such as sample size. Figure 1 shows an example. Against a black or a white background, the difference between the two samples is very close to a JND. The crispening effect for only the surround lightness of $L^* = 50$ was included in the CIEDE2000 color difference formula.[14] The typical lightness values of the interior of light booths are around $L^* = 70$, however. As the authors report, a considerable number of additional investigations of implicit lightness scaling have been performed in the last quarter century, but a fully detailed model based on statistically meaningful experimental data has not resulted. It is not yet clear if an overarching model of all lightness/brightness effects is possible. Gilchrist has worked for three decades on this issue but agrees that at this time a complete model is still missing.[15,16] Visual illusions of the most amazing kind involving lightness are well known.[17] Then, there is also the idea that personal vision is to some degree influenced by the cumulative statistics of the visual experiences of a subject.[18]

If we limit ourselves to the perception of lightness and lightness increments, it is apparent that, unless the surround is white or black, neither a simple power nor log model can provide generally accurate predictions. What is the difference between the two model types? Figure 2 shows the relationship between luminous reflectance Y from 0 to 100 and implicit perceived lightness for a log 10 relationship, the cube-root relationship of the L^* model, and the power 0.43 relationship of the "gamma" model widely used in electronic color stimulus processing.[19] It is evident that in the log model shown there are relatively more JND or lightness difference steps at low Y values than at high, compared to L^* or gamma. A way of comparing this more specifically is to determine Y-increments across the scale that produce identical L^* differences. The resulting Y-increments are then used to also calculate differences according to the log and the gamma formulas. The results are shown in Fig. 3 for the range of $Y = 4.7$ to $Y = 60.0$. The figure illustrates how differently the three models interpret certain stimulus increments. Assuming a unit of difference represents a JND we can calculate that according to L^* there are 54.0 JNDs between $Y = 4.7$ and $Y = 60$, for the gamma model 60.1 and for the log model 55.4. Although the total number of JNDs for L^* and log is nearly the same, they differ near high and low values of the range quite strongly in terms of the required Y increments. Figure 3 provides a good background for a perceptual experiment. Samples should be prepared at small increments of Y near 5 and near 60. They can then be evaluated against a background producing in both cases little or no crispening effect, that is, near $Y = 30$. One might conclude that the log scale is more closely related to a dark background than to a light one, perhaps as the result of usually dark or black surrounds in optical equipment used in the determination of JNDs. Additional tests could be run also against surrounds of Y near 5 and near 60. For another set of conditions, the same test could be performed by the same group of subjects using display unit stimuli. The results of such test can show under which conditions and in what ranges, if any, a log scale performs better and in what cases a power scale.

An issue as yet not addressed and where there seems to be little or no concrete information in the literature is that of intraobserver and interobserver variability in assessing lightness differences. Considerable interobserver variability in color difference judgments is well established.[20] Finding very low values in case of gray scale JND or lightness step evaluations would be surprising. For meaningful results, the number of subjects needs to be large enough to be statistically solid. They also should be replicated with identical conditions but a culturally different group of subjects.

The results will be applicable to the specific set of conditions used in the experiment. The question arises what conditions should be used to evaluate fully and statistically meaningfully a complete range of stimulus increments across the whole range of lightness. To determine the range of conditions for which the results are valid would require testing of nearby conditions. Such an effort would best be done as an international project with clear, agreed-upon goals. One field of interest is quality control in colored materials. But here one can already expect differences between solid objects and, for example, textiles. Other conditions are display units and those involving various color reproduction processes. Sponsors would need to be found which, given the likely limits of applicability of the findings, might not be easy. The question is if the will exists to determine some facts in this field in a comprehensive fashion or if Brill and Carter's question will be raised again 30 years from now.

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