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A Review of Lamp Spectrum and Spatial Brightness

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Light sources are available with a wide variety of spectral power distributions (SPD), which are defined by the relative amounts of optical radiation versus wavelength, within the visible range of approximately 380–780 nm. Previous work has demonstrated that SPD influences perceived brightness of room interiors (or, spatial brightness) in a manner that is not predicted by photometric quantities that are derived from the Standard Photopic Observer. The ability to change the impression of spatial brightness through careful variation of lamp spectrum provides a route to acceptable reduced illuminances in offices [1] and thus potentially to energy savings, but we are not yet able to identify the spectral characteristic that best correlate with impressions of spatial brightness. Over 70 past studies of SPD and spatial brightness have been reviewed with the objectives of firstly identifying studies that give reliable evidence of the effect and secondly identifying the trends found.

A first look shows that some studies suggest SPD affects brightness [2] while others conclude that it does not [3]. These different findings may be explained by the fact that each study has tended to use a unique methodology (procedure, evaluation mode, field size and visual objective) in addition to a unique set of stimuli (light sources and illuminances). This review has used experimental methodology to screen and collate the most convincing data from within this body of work [4-7].

One common procedure is side-by-side matching, in which a critical requirement is that the spatial locations (e.g. left and right) of the two stimuli are balanced across trials. Unfortunately, this has not always been done, leading to potentially erroneous estimates of the effect of SPD on brightness: it is possible to explain the results of some studies as an effect of spatial location rather than as an effect of lamp SPD. Null condition trials with the potential to detect bias in methodology or human responses are unfortunately a rare find in past studies.

Category rating is another procedure commonly employed to evaluate spatial brightness. Where a repeated measures design is used, a critical requirement is that the stimuli are observed in a randomised order: in some cases this was not done.

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One pervasive problem is incomplete reporting, meaning that the report does not provide sufficient descriptions of the methodology, sufficient description of the stimuli, nor sufficient numeric data for the test results. Such deficiencies should be considered when assessing the credibility of the conclusions. For example, many studies report mean values of judgements (e.g. illuminance ratios at equal brightness or ratings of brightness) but do not report measures of dispersion (such as standard deviation), nor do they provide statistical analyses of whether apparent differences between the means are real or chance occurrences. The lack of standard deviations means it is not subsequently possible to carry out a statistical analysis.

Table 1 shows some past studies that we believe provide reliable evidence of lamp spectrum and brightness: these tend to suggest that SPD affects spatial brightness perceptions. We propose to divide these data into two categories according to the level of chromatic adaptation permitted by the procedure, either complete or mixed adaptation. These data are being used to screen potential metrics to explain the SPD effect on brightness, with the aim of identifying one or more light source SPDs that yield exceptional brightness per watt of optical radiation.

Potential tools for correlating SPD with spatial brightness fall into two classes. The first class consists of measures that are used in lighting practice today that give simple descriptions of an SPD such as Correlated Colour Temperature (CCT), Colour Rendering Index, gamut area, the S/P ratio and the SWS/P ratio. Such metrics have been suggested in previous studies: Vienot et al [8] proposed a model of brightness using CCT; Boyce [9] found that gamut area predicted judgements of visual appearance of a lit scene using a matching task; Berman et al [2] suggested that the S/P (scotopic/photopic) ratio provides a metric for brightness at photopic levels and it has also been found to correlate well with brightness judgements at mesopic levels [10]. Two studies have suggested a model based upon the short wavelength sensitive cones [11,12].

The second class of potential brightness prediction tools consists of the metrics that are based on visual physiology such as prime-colour theory [13] and colour appearance models [14]. All of the above metrics have limitations. Metrics in the first class do not fully describe light source SPD, as they reduce a complex spectral distribution to a single index, but they are established characteristics and widely used and so would be simple to implement. Metrics in the second class are likely to be the most accurate, and more defensibly rooted in vision science, but they will be more complex. They are based on the characteristics of the photoreceptors over a limited range of conditions such as field size, which is an important variable when applying the results to real rooms; they are also the most complicated to implement and complexity is an important criterion because it may be a barrier to implementation.

Figure 1 shows mean illuminance ratios of lamp pairs at equal brightness plotted against the ratios of their CCT, and these data are the results of the matching and discrimination studies in Table 1. While previous studies may have suggested, from a limited set of data, that CCT provides good prediction of brightness, it does not provide a good prediction of this larger set of data. It is clear that a new metric for spatial brightness is required.

Table 1. Summary of studies considered to give reliable evidence of the impact of lamp spectrum on spatial brightness

Chromatic Adaptation	Method	Study	Does SPD affect brightness?
mixed	Sequential discrimination of two stimuli	Berman, 1990; Houser, Fotios & Royer, 2009; Vrabel, Bernecker & Mistrick, 1998	Yes
mixed	Simultaneous (side-by-side) discrimination of two stimuli	Houser, Tiller & Hu, 2004; Houser, Fotios & Royer, 2009	Yes
mixed	Simultaneous (side-by-side) matching of two stimuli	Boyce, 1977; Fotios & Gado, 2005; Fotios & Levermore, 1997, 1995; Hu, Houser & Tiller, 2006	Yes
complete	Field survey in work places.	Akashi & Boyce, 2006;	Yes
complete	Semantic rating of lighting in a laboratory test environment	Boyce, 1977; Boyce, Akashi, Hunter & Bullough, 2003; Boyce & Cuttle,1990, (experiment 2); Davis & Ginthner, 1990; Flynn & Spencer, 1977; Han & Boyce, 2003; Piper, 1981; Vienot et al, 2009; Vrabel, Bernecker & Mistrick, 1998	Yes (except No for Davis & Ginthner, 1990)

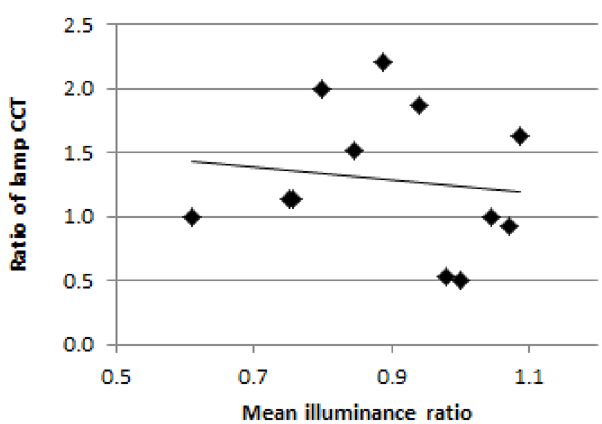

Figure 1. Mean illuminance ratios of lamp pairs at equal brightness plotted against the ratio of their CCT (R2=0.02)

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