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Lighting Research Center
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877 25th Street, Watervliet
New York 12189

Museum Lighting Protocol Project

Grant #MT-2210-7-NC-014

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Report submitted to
The National Center for Preservation Technology and Training
Northwestern State University
NSU Box 5682
Natchitoches, Louisiana 71497

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Executive Summary

This project examines a proposal to reduce the exposure of museum exhibits to incident radiant power without reducing the level of visual satisfaction for museum visitors. Many types of museum exhibits are susceptible to damage caused by exposure to light. Current recommendations for museum lighting include avoidance of non-visible radiant power (UV and IR), limitation of light level, and restriction of exposure duration. However, these recommendations do not distinguish between the potential of incident radiant power in the visible spectrum to stimulate the sense of brightness (illuminance) and its potential to cause damage (irradiance).

Generally, current practice for museum display lighting utilizes incandescent filament light sources, such as MR lamps. The spectral power distribution for this type of illumination is characterized by a continuous, smooth curve throughout the visible spectrum, increasing towards the long wavelength end. This project investigates the notion that the visual satisfaction provided by incandescent sources could be matched with significantly less irradiance by illumination composed of three spectral bands corresponding to red, green and blue light. The theoretical basis for this 3-band source is described in the introduction to the report.

Pairs of identical artworks were displayed in two adjacent simulated art galleries, and 16 subjects adjusted the illumination in the test gallery to match the appearance of the similar display in the comparison gallery. The artworks included chromatic and achromatic samples, and the light source in the comparison gallery was an MR display spotlight of either low (2850 K) or intermediate (4200 K) color temperature. The light source in the test gallery was either an MR spotlight identical to the lamp in the comparison gallery, or it was an experimental 3-band source for which the color temperature had been matched to that in the comparison gallery. For the same illuminance, the irradiance due to the 3-band source was less by 41% than that for the MR lamp at 2850K, and was less by 31% at 4200K.

It was found that subjects set for equal illuminance in the two galleries in all cases. They were questioned on any differences of appearance that they noticed, and generally they reported only slight differences. These differences of appearance are discussed, and it is concluded that a practical light source for museums could be developed that would equal the visual satisfaction provided by incandescent lamps at equal illuminances, while exposing exhibits to significantly less irradiance. This would have the effect of reducing the rate of degradation of museum objects on display.

1. Introduction

1.1 Lighting and Conservation

There are two processes by which exposure to light causes damage to museum exhibits: photochemical action and radiant heating effect (Cuttle, 1996). Photochemical action occurs when the activation energy for a chemical change is derived from the absorption of a photon, and as photon energy is inversely proportional to wavelength, photochemical action is associated with short-wavelength radiation, which includes non-visible ultraviolet (UV) radiation and short-wavelength visible (blue) radiation The most common symptoms are loss of color (fading), and loss of mechanical strength as evidenced by the fraying of textiles and paper becoming brittle. The absorption of radiant energy also causes a heating effect, and the daily switching of display lighting results in cyclic expansions and contractions of the exposed portions of exhibits, coupled with moisture migrations, which can result in cracking of wood, surface crazing of finished materials, and separation of varnish layers. This is particularly associated with incandescent display lighting, where the irradiance due to non-visible long-wavelength infrared (IR) radiation may exceed the irradiance for wavelengths within the visible spectrum.

Current recommendations for museum lighting practice are broadly in agreement that UV should be severely restricted or eliminated, and that exposure to light should be. limited both in intensity and duration (Rea, 1993, CIBSE, 1994) For exhibits that are categorized as highly susceptible to exposure damage, the recommended maximum illuminance is 50 lux, which is recognized as the lowest practical level for exhibits for which color discrimination is an important factor (Thomson, 1986). Even when these recommendations are strictly applied, display lighting still causes permanent damage to exhibits (Feller, 1968; Michalski, 1987). While there are no specific standards for IR control, dichroic reflector spotlights are generally recommended. The mirror that forms the beam for this type of spotlight has a wavelength-selective reflecting surface that directs light into the beam, but not IR.

It used to be supposed that incandescent light sources are safe because they are weak sources of short-wavelength radiation, but recent studies of exposure of artist's pigments have confirmed that it is the spectral absorption characteristic that determines the wavelength susceptibility of the pigment (Saunders and Kirby, 1994). An artist's palette that covers a full color range inevitably includes pigments that are selective absorbers for every waveband in the visible spectrum. For this reason, the damage potentials of the visible radiation provided by alternative light sources may be compared in terms of irradiances at equal illuminances (Michalski, 1987).

Irradiance is the measure of incident radiant power density in watts per square meter (W/m2), and illuminance is the measure of the density of incident light in lux, where one lux is one lumen per square meter. The basis for comparison used in this report is to evaluate sources in terms *of radiant luminous efficacy* measured in lumens per radiant watt (lm/Wr). This term should not be confused with the luminous efficacy values quoted in lamp catalogs, which are measures of lumens emitted per watt of electrical power input.

1.2 Lighting and the color appearances of exhibits

Although radiant luminous efficacy provides a useful basis for comparing alternative light sources, it is far from being the whole story. A critical concern in museum lighting is how the illumination affects the appearances of colored materials, and for this reason the emphasis of this study is upon relating the spectral power distribution of lighting to the responses of subjects viewing art works in simulated art gallery settings.

The color rendering properties of light sources are specified by reference to a black body, which is a theoretical substance for which its temperature defines the spectral distribution of radiant power emission. The *correlated color temperature (CCT)* of a light source is the temperature in degrees Kelvin (K) of a black body that most closely matches the color appearance of the source. At a low CCT (<3000 K) the appearance is a warm, yellowish light reminiscent of sunlight or a candle flame; at an intermediate color temperature (~4000 K) the color appearance is a more neutral or a more white light; and at a high color temperature (>5000 K) the appearance is a cool, bluish-white light reminiscent of sky light.

The *color rendering index* of a lamp is defined by a procedure that compares color metrics for a set of reference color samples illuminated by the lamp, with the color metrics for the same samples illuminated by a black body source having the same CCT as the lamp. (A different type of comparison source is used where CCT>5000 K.) If all of the samples match perfectly under both sources, the lamp is accorded a CRI of 100. Any departures from a perfect match reduce the CRI. This procedure assumes that, for low and intermediate color temperatures, a black body is the ideal color rendering source.

The black body source is luminous because it is incandescent, and its relative spectral power distribution almost exactly matches that of an electric incandescent lamp at the same CCT. Incandescent lamps are quoted to have CRI values of 99 or 100, and are widely perceived to be perfect color rendering lamps, but this perception needs to be qualified. They are perfect only in that the color appearances of illuminated surfaces match the appearances that they would have if illuminated by a black body of the same, low color temperature.

It is well understood by lamp manufacturers that it is not necessary to match the spectral power distribution of a black body to achieve a high CRI value. Tri-phosphor fluorescent lamps concentrate their radiant power emission into three spectral bands, and they achieve high CRI values. Thornton’s research (1992) has identified three optimal wavelengths for matching the lamplight from incandescent sources and achieving this with high radiant luminous efficacy. The band center wavelengths are approximately 450nm, 530nm and 610nm, and the light of these wavelengths have the characteristic colors of blue, green and red respectively.

These findings are highly relevant to this study, as they indicate that that there is scope to significantly reduce the irradiance of exhibits without reducing illuminance or sacrificing color rendering. If the irradiance is reduced, the rate of damage will be correspondingly reduced.

1.3 Research Objectives

The aim of the experiment was to evaluate paired comparison subjective assessments of a range of artworks illuminated alternately by a tungsten halogen MR spotlight and by an experimental 3-band source, both having the same correlated color temperature.

It was predictable that the CCT and the color appearance of an MR lamp could be matched by a 3-band source that would have significantly higher radiant luminous efficacy than the MR lamp. It was expected that if subjects were presented with an achromatic scene alternately lit to the same illuminance by these two types of light source, they would not differentiate between them. What could not be predicted was how they would respond to a scene that involved colored materials.

The basis for the comparison was an illuminance of 50 lux on the art work provided by an MR spotlight, as this the type of lighting and light level are widely adopted for display of susceptible exhibits. However, the CCT of the MR lamp is low: 3000 K at full voltage, and in practice often lower due to being dimmed to provide 50 lux. It was decided that the experiment should also include an intermediate color temperature source, and this was achieved by repeating the procedure using a new type of MR lamp that has a CCT of 4700 K at full voltage.

2. Methods and materials

2.1 Overview of the experiment

The experiment provided a situation in which identical reproductions of artworks were presented in two adjacent simulated art gallery settings, one being the test situation and the other the comparison situation. Subjects adjusted the illuminance in the test situation, which was illuminated alternately by an MR lamp and an experimental 3-band light source, to match the appearance of the comparison situation. The comparison situation was always illuminated to 50 lux by an MR lamp. The settings were recorded and compared to see whether there were differences in the illuminances that subjects selected to achieve similar appearances. Differences of irradiance were calculated from the recorded illuminances. Also, subjects were questioned on any differences of appearance they noticed after making each setting.

2.2 The 3-Band Light Source

Figure 1 shows the spectral power distribution for a MR16 20/12 BAB/FL/40 lamp operating on slightly reduced voltage to provide 50 lux in the experimental situation with a CCT of 2857 K. Note the characteristic smooth, continuous curve, climbing towards the long wavelength end of the spectrum. The decline above 700nm is due to the dichroic reflector, which is transparent to TX and extreme long wavelength visible radiation.

While a practical 3-band light source for museum use will comprise a single lamp, with or without a filter, for the experimental situation the three bands were provided by separate lamps, each with a band-pass filter. The band center wavelengths identified by Thornton are at 80nm intervals, and three types of 50mm diameter, 40nm band pass filters were obtained. The 450nm filter was available as a stock item, but the 530nm and 610nm filters were custom items. The filters were mounted in compact industrial luminaire housings fitted with 50-watt MR lamps. Because of the low radiant power from these lamps at short visible wavelengths, it was found necessary to use two 450nm sources.

Figure 2 shows the spectral power distribution for these lamp and filter combinations with their outputs balanced to match the CCT of the source shown in Figure 1. The difference in the SPD curves is strikingly obvious: not only are the end parts of the visible spectrum missing, but also there are two deep notches in the curve. Data for the MR and the 3-band sources are given in Table 1, from which it can be seen that the radiant luminous efficacy for the 3-band source is 70% higher that that for the MR lamp. This means that at equal illuminances (lux) the 3-band source will produce 41% less irradiance (W/m^2).

The process of adjusting the balance of the three wavebands of the experimental source was tedious and time-consuming. However, the experimental procedure required the 3-band source to be dimmable, and this created a problem: how to vary the output of the source while maintaining the balance of the wavebands? The problem was solved by feedback device that was developed specially for this experiment. Each lamp housing was fitted with a light sensor directed towards the lamp. The sensors were connected to the feedback device, which continually monitored the outputs of the lamps and maintained them in constant ratios. The control operated by the subject changed the output of the mid-waveband lamp, and the feedback device made instantaneous proportional changes to the lamp outputs for the other two wavebands. By turning a switch outside the test room, the experimenter selected whether the subject’s control operated the 3-band source or the MR lamp, so that the subject was given no obvious indication of the type of light source that was in use.

The first phase of the experiment was completed using low CCT (approximately 2850 K) sources. For the second phase, the regular MR lamps were replaced with 12-V 50-W “SoLux” MR lamps, which were dimmed to provide 50 lux at approximately 4200 K. Figure 3 shows the spectral power distribution, and the loss of long wavelength power to achieve the higher CCT is apparent. The 3-band source was adjusted to match this CCT, and the spectral power distribution is shown in Figure 4. Data for these sources are shown in Table 1, and for this higher color temperature the radiant luminous efficacy for the 3-band source is 46% higher than for the MR lamp. The main reason for this difference being less than for the low color temperature case is that the radiant luminous efficacy of the MR lamp is higher. However, this is not because this is a more efficient lamp, but is due to the lower radiant power emitted at the long wavelength end of the visible spectrum.

2.3 *Experimental Design*

The experimental design called for a pair of identical "art gallery" settings to be viewed sequentially; i.e., not simultaneously. Two adjacent partitioned offices measuring 8 feet 6 inches by 6 feet 9 inches by 7 feet high were lined with white "Foamcore", and three pairs of identical prints of artworks were presented in these simulated "art gallery" settings. Figure 5 shows one of the galleries. The artworks selected were:

> ESCHER: "Day and Night", by M.C. Escher (Figure 6). This woodcut is achromatic, comprising black on white contrasts and providing a transition from mainly white to mainly black.
>
> MONDRIAN: "Composition", by Piet Mondrian (Figure 7). This painting presents contrasting unique hues.
>
> RENOIR: "Portrait of Mme. Durand-Ruel", by Pierre Auguste Renoir (Figure This painting presents a broad range of hues (red hat, green foliage, blue dress) as well as delicate flesh tones.

The comparison condition was lit by an MR lamp that was preset by the experimenter to an illuminance of 50 lux. The test condition was lit alternately by a MR lamp identical to the one in the comparison condition, or by the 3-band source adjusted to have CCT and chromaticity matched to the comparison source. The arrangement of the light sources in the test room, including the sensors connected to the feedback device, is shown in Figure 9.

Each subject was taken to the comparison situation, where one of the artworks was on display at the preset illuminance. They were instructed to suppose that this was an art gallery, and that they had come to see this picture. Then they were taken to the test situation where the identical artwork was on display, and they were told to adjust the control "to match the appearance of this situation as closely as possible to the appearance of the previous situation". Subjects could return to the comparison situation as often as they wished, but could not view the two situations simultaneously. When a setting had been made, the experimenter recorded the control reading and asked the subject whether they could see any differences between the two situations, using five categories of difference:

> Brightness
> Clarity
> Acceptability of overall color appearance
> Brightness or colorfulness of individual colors
> Naturalness of individual colors

A seven-point scale of difference was used to describe the magnitude of the difference of appearance of the test situation relative to the comparison situation: +3 Much more; +2 More; +1 Slightly more; 0 No difference; -1 Slightly less; -2 Less; -3 much less.

For each phase of the experiment, subjects made six settings, one for each of the two light sources illuminating each of the three artworks. The order of presentations was randomized. The light source CCT was approximately 2850K for the first phase, and subjects returned to repeat the procedure for the second phase, for which the CCT was approximately 4200K. Light source data are given in Table 1.

3 Results and discussion

3.1 Subjects

Sixteen subjects completed both phases of the experiment. They were staff and students at the Lighting Research Center, but did not include faculty or others who had foreknowledge of the experiment. They comprised 6 males and 10 females.

3.2 Illuminance settings

Table 2 shows means and standard deviations for the illuminance settings made by the subjects in test room, and these data are illustrated in Figures 10 and 11 In every case the illuminance in the comparison room was preset to 50 lux, and it is apparent that subjects set the illuminance in the test room to match the illuminance in the comparison room.

3.3 Assessments of appearance

Tables 3-8 show the distributions of the subjects' assessments of the test room appearance relative to the comparison room, and Figures 12-17 illustrate the mean data. It can be seen that there are few instances of subjects reporting anything more than a slight difference between the appearances of the two rooms. In fact, all of the mean values correspond to fractional parts of a slight difference, and in many cases the reported difference of appearance between the 3-band source and the comparison MR source was less than the reported difference between the identical MR sources.

The brightness and clarity criteria attracted very few comments from the subjects. The color appearance of the Escher print illuminated by the 3-band source attracted several comments. Some subjects who rated the difference favorably described the test situation as appearing "more white", while others who rated it unfavorably criticized the non-uniformity of color appearance. The blending of the colored light sources in the test situation was imperfect, and this shortcoming was more evident when viewing the achromatic print than when viewing the chromatic artworks.

The color appearance of the Mondrian illuminated by the 3-band source also attracted comments. The colors were described as "less vivid" or "faded", particularly the red pigment. However, at the lower CCT there was some favorable comment that the blue pigment appeared brighter, and also unfavorable comment that there was an overall cooler appearance. These comments are understandable. Incandescent filament lighting enhances the apparent saturation of red colored surfaces, particularly at the lower CCT, and reduces the apparent saturation of blue surface colors.

The appearance of the Renoir painting under the 3-band source attracted a variety of both favorable and unfavorable comments. At the lower CCT, favorable assessments ("colors seem to look better") were matched by unfavorable assessments (colors "more washed out"). At the higher CCT, flesh tones were criticized.

3.4 Discussion of results

Subjects matched the illuminance in the test room to the illuminance in the comparison room, indicating that illuminance effectively evaluates the overall sense of equality of illumination as it affects the appearances of the art gallery settings, despite the very different spectral compositions of the two types of lighting. The fact that the 3-band source provides a given illuminance with substantially lower irradiance on the illuminated object offers a significant benefit for conservation.

For the light sources used in the experiment, the irradiances in watts per square meter (W/m^2) to provide 50 lux on the artworks were:

	MR lamp	3-band source
Low CCT (2850 K)	0.22	0.13
Intermediate CCT (4200 K)	0.20	0.14

It is conventional to assess the exposure of illuminated museum exhibits in terms of lux-hours per year (lx h/y so that an object lit to 50 lux and exhibited for 3,000 hours per year is exposed to 150,000 lx h/y (Rea, 1993). This measure does not distinguish between the different irradiances of light sources at the same illuminance. If the light source in this example is a regular MR lamp, then changing to a 3-band source would reduce the effective exposure to 89,000 lx h/y Looked at another way, it would take 1.7 years of exposure to the low CCT 3-band source to subject the object to the same effective exposure as would occur in one year with a regular MR lamp at the same illuminance. For the intermediate CCT sources, it would take 1.4 years.

The reported differences of appearance between the 3-band source and either of the MR sources were slight. Even so, if the requirement is to produce a low radiant power light source that is indistinguishable from a MR lamp, some increase of long wavelength visible radiation will be needed. This would have the effect of increasing the vividness of strong red surface colors and making flesh tones appear warmer.

There are two approaches to developing practical light sources that can gain the conservation advantage of the 3-band source. A new type of filter could be developed that would convert the continuous spectrum of a regular MR lamp into a 3-band spectrum. While this would achieve high radiant luminous efficacy (lm/Wr), the luminous efficacy of the lighting system in terms of lumens per watt of electrical power input would be poor. Whenever a filter is added to a lamp, it is necessary to increase the lamp wattage to maintain the illuminance. A more efficient approach would be to develop a new lamp type specifically for museum applications in which a 3-band spectrum is generated by efficient conversion of electrical power. While this latter approach offers the prospect of a superior solution, the development costs are likely to be much higher. Even so, some lamp manufacturers might be willing to enter into collaborative research.

It should not be presumed that the museum community will respond with enthusiasm to this initiative. There is a long history of museum directors, particularly art museum directors, insisting that natural light is the only true light for the museum experience. The distinctly unnatural spectral power distribution of the 3-band source favored by this study is likely to be regarded with strong suspicion, even if there is no visible difference in the lighting. A further study in a real art gallery directed towards gaining critical evaluations of museum professionals is recommended.

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Figure 1 Spectral Power Distribution for MR lamp, 2850K

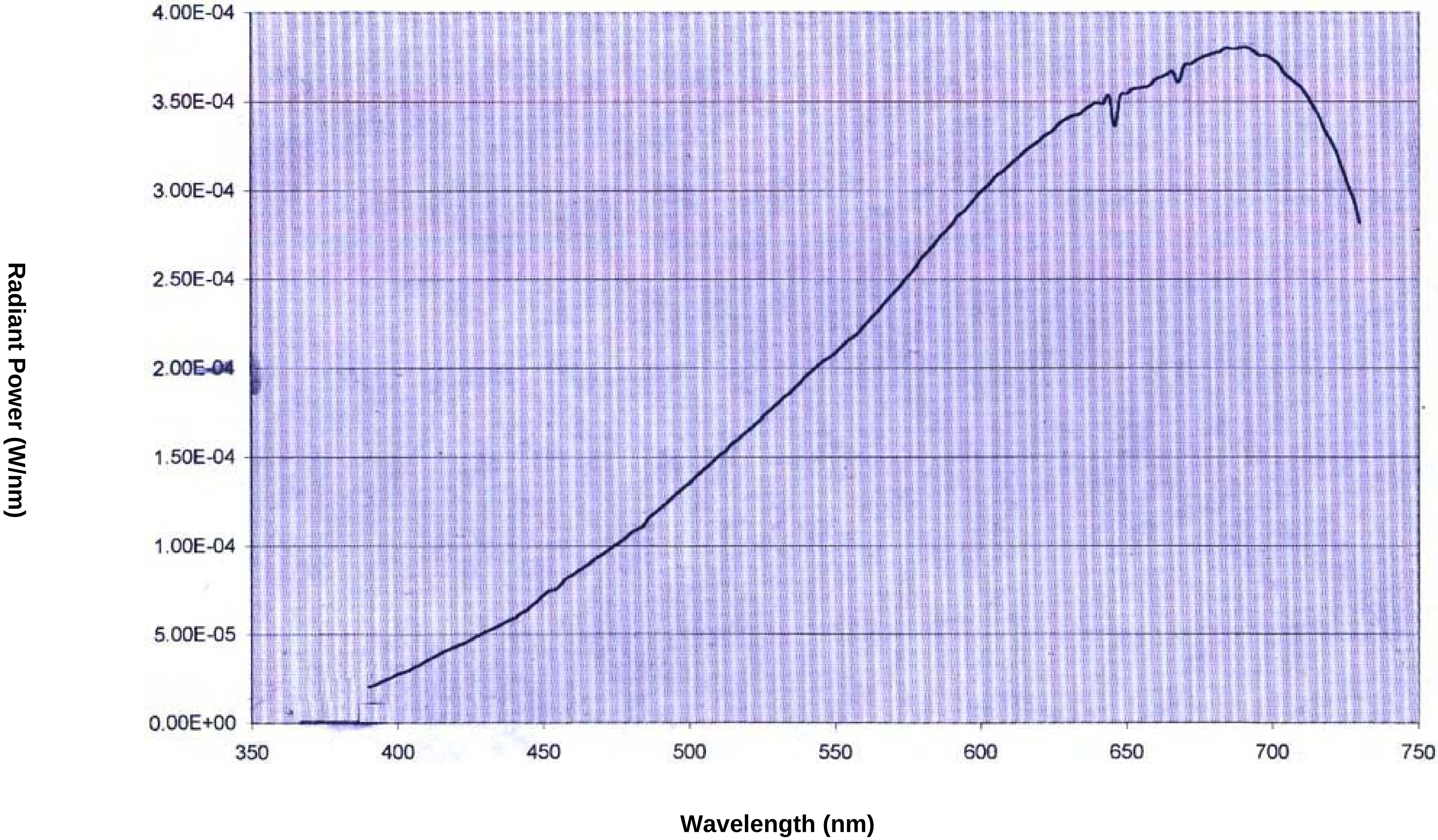


Figure 2 Spectral Power Distribution for 3-band source, 2850K

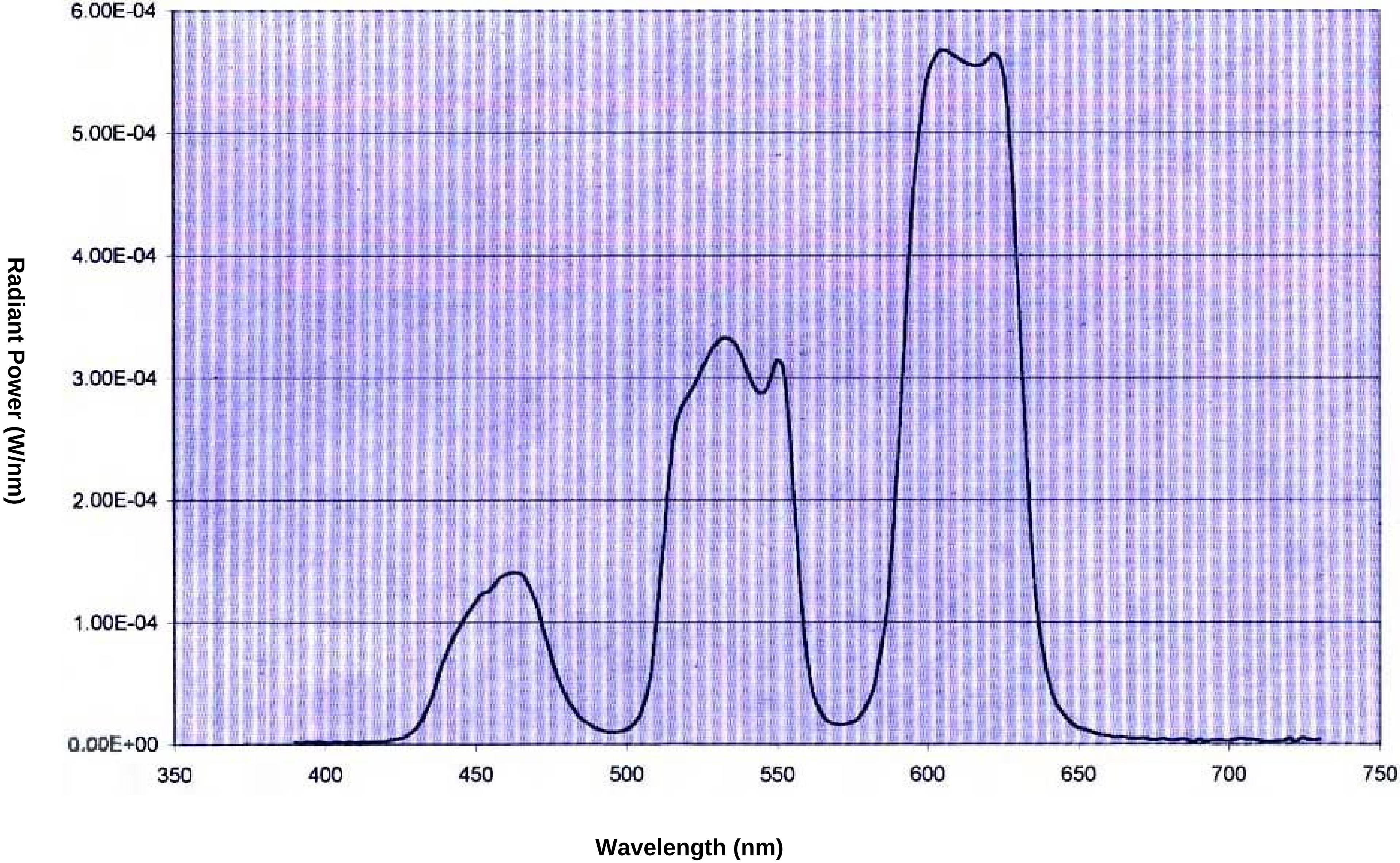


Figure 3 Spectral Power Distribution for MR lamp, 4200K

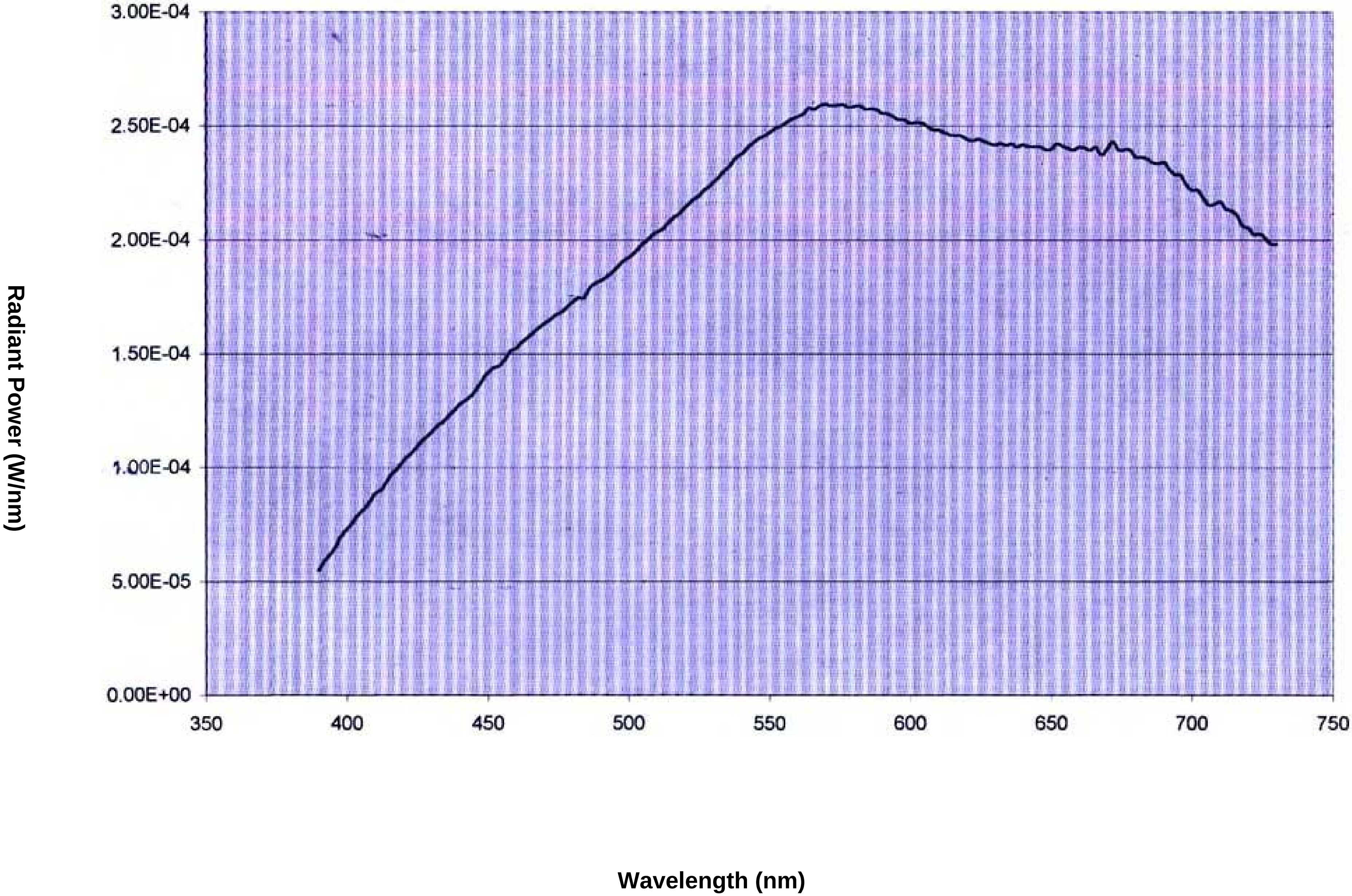


Figure 4 Spectral Power Distribution for 3-band source, 4200K

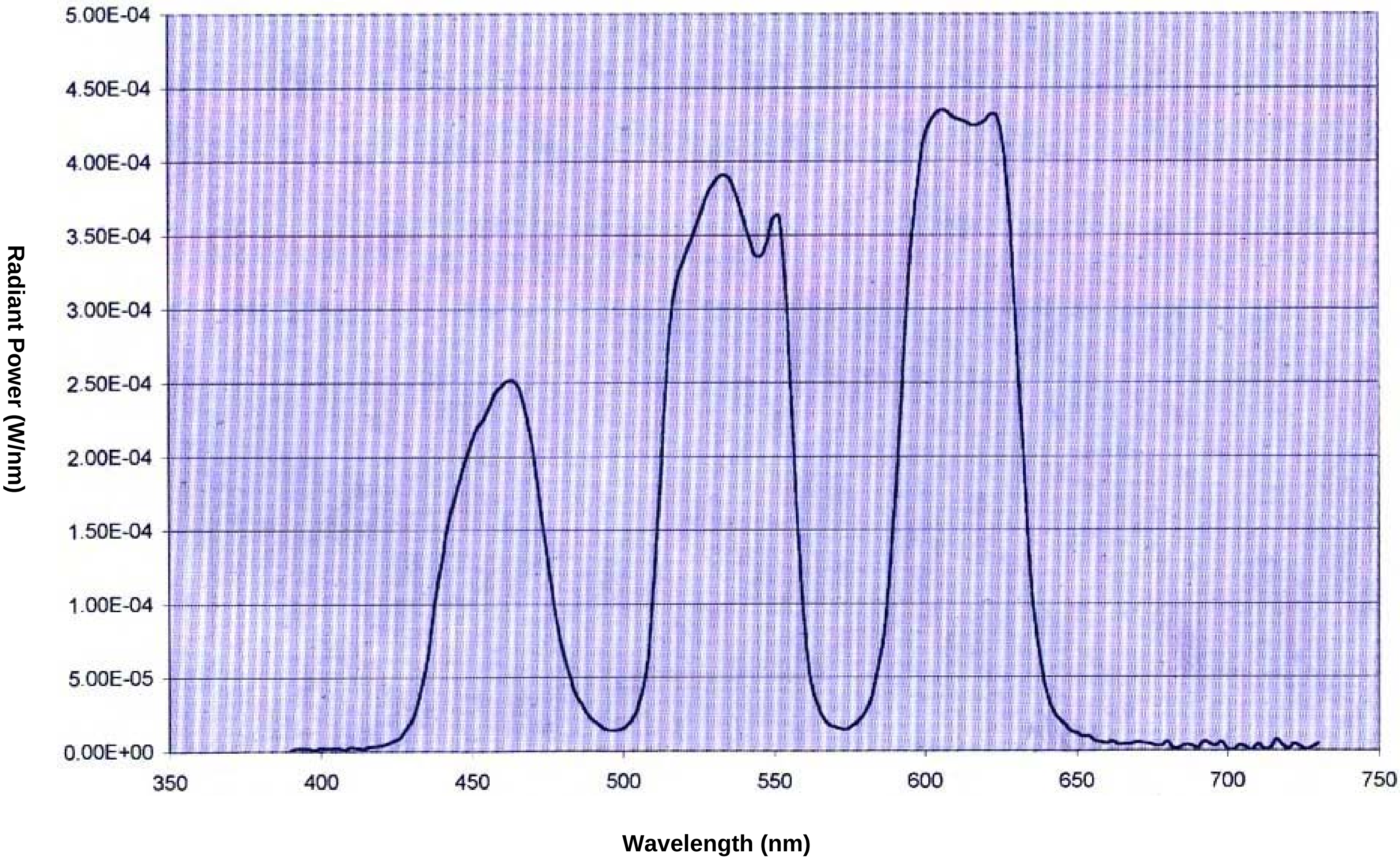


Figure 5 An experimental art gallery setting

Figure 6 ESCHER

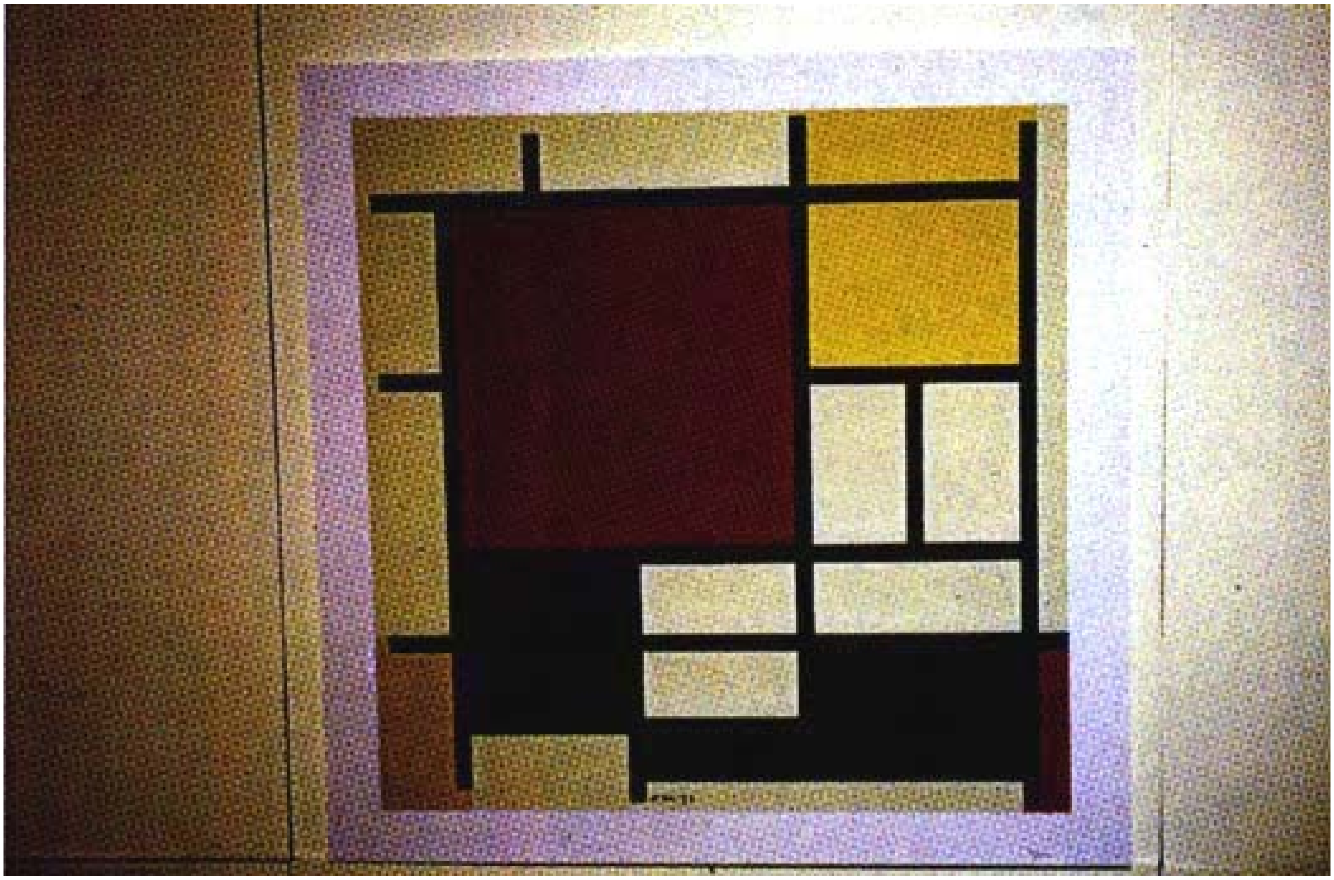


Figure 7 MONDRIAN

Figure 8 RENOIR

Figure 9 Light sources in the test room

Figure 10 Illuminance settings for low CCT

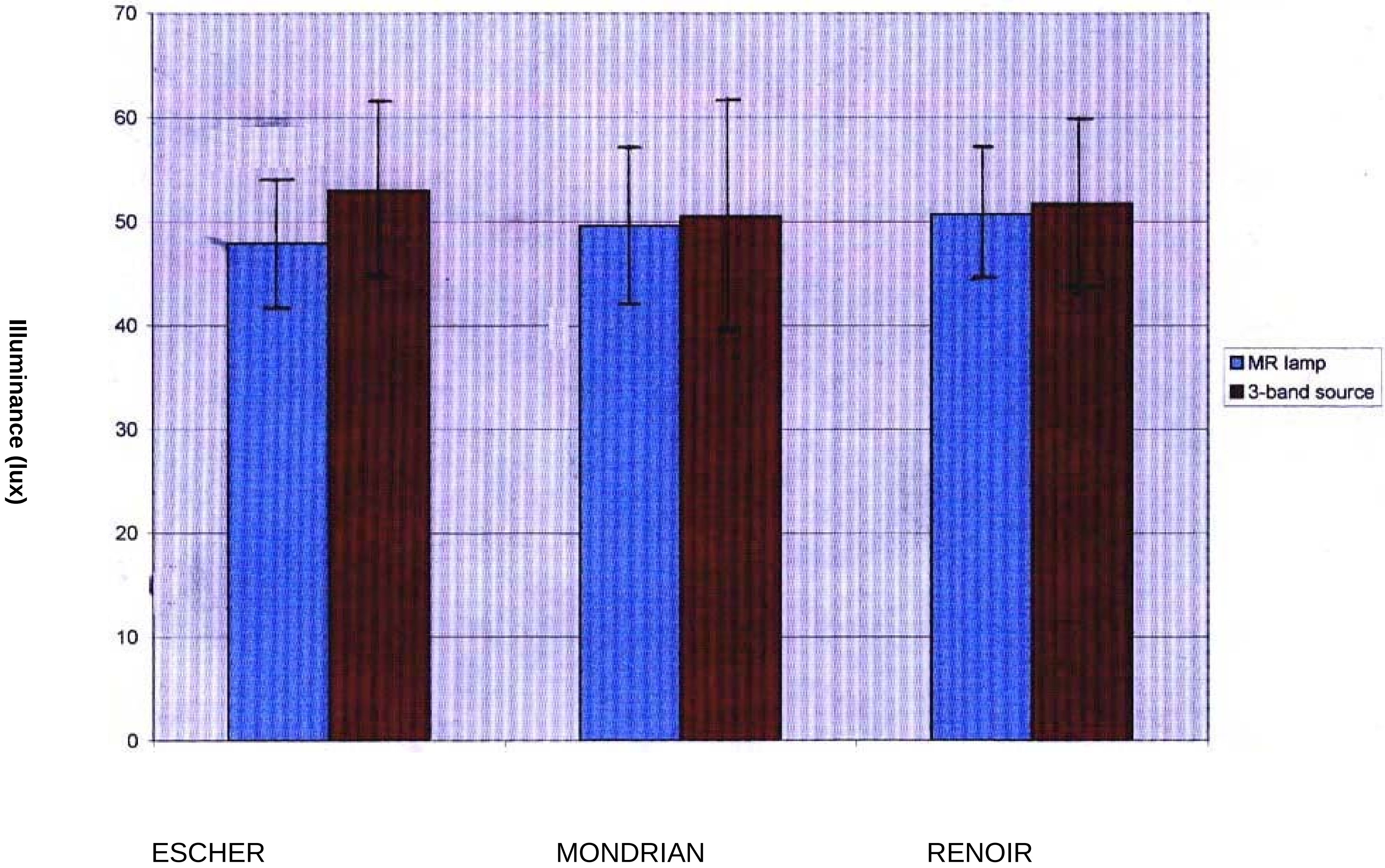


Figure 11 Illuminance settings for intermediate CCT

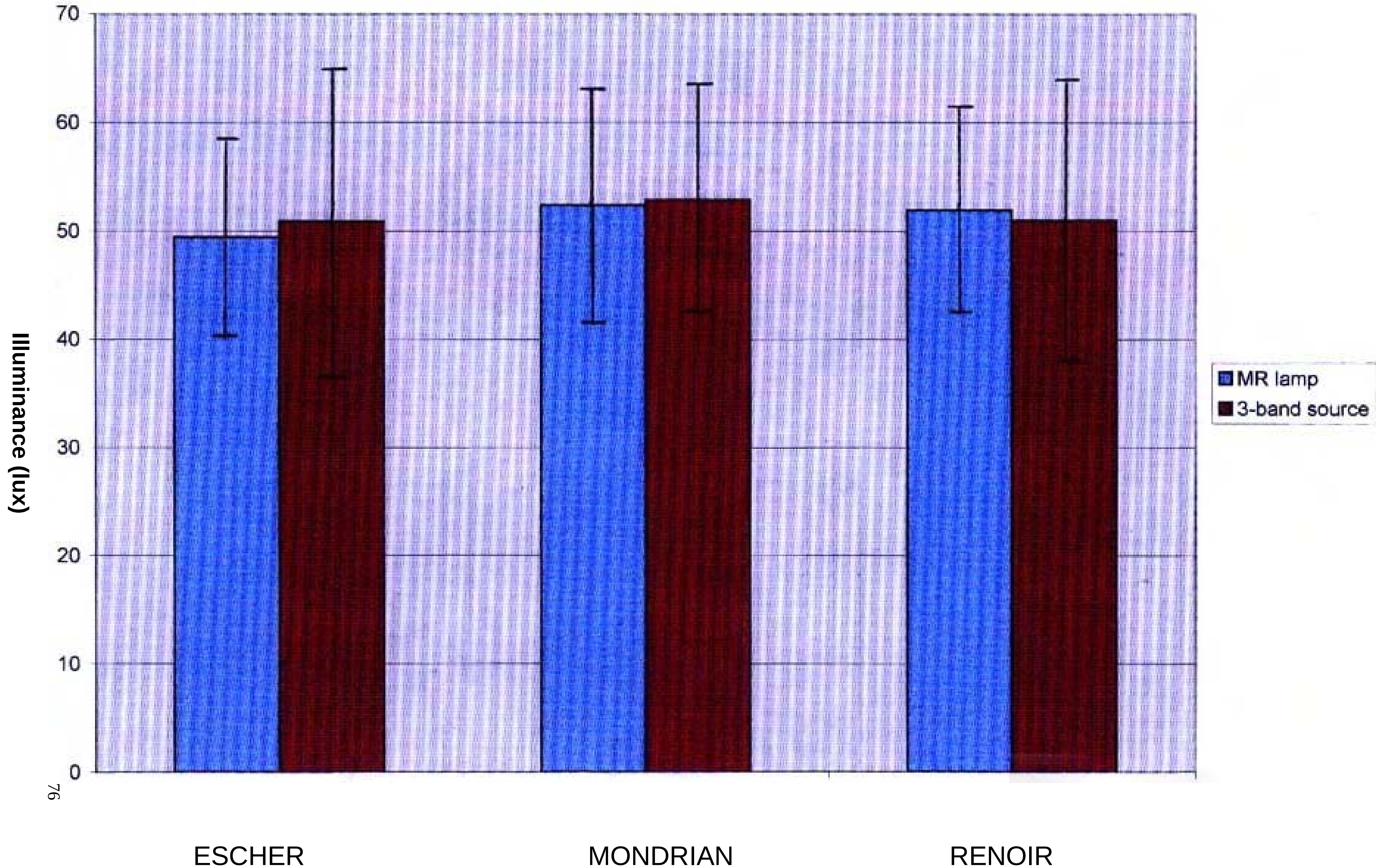
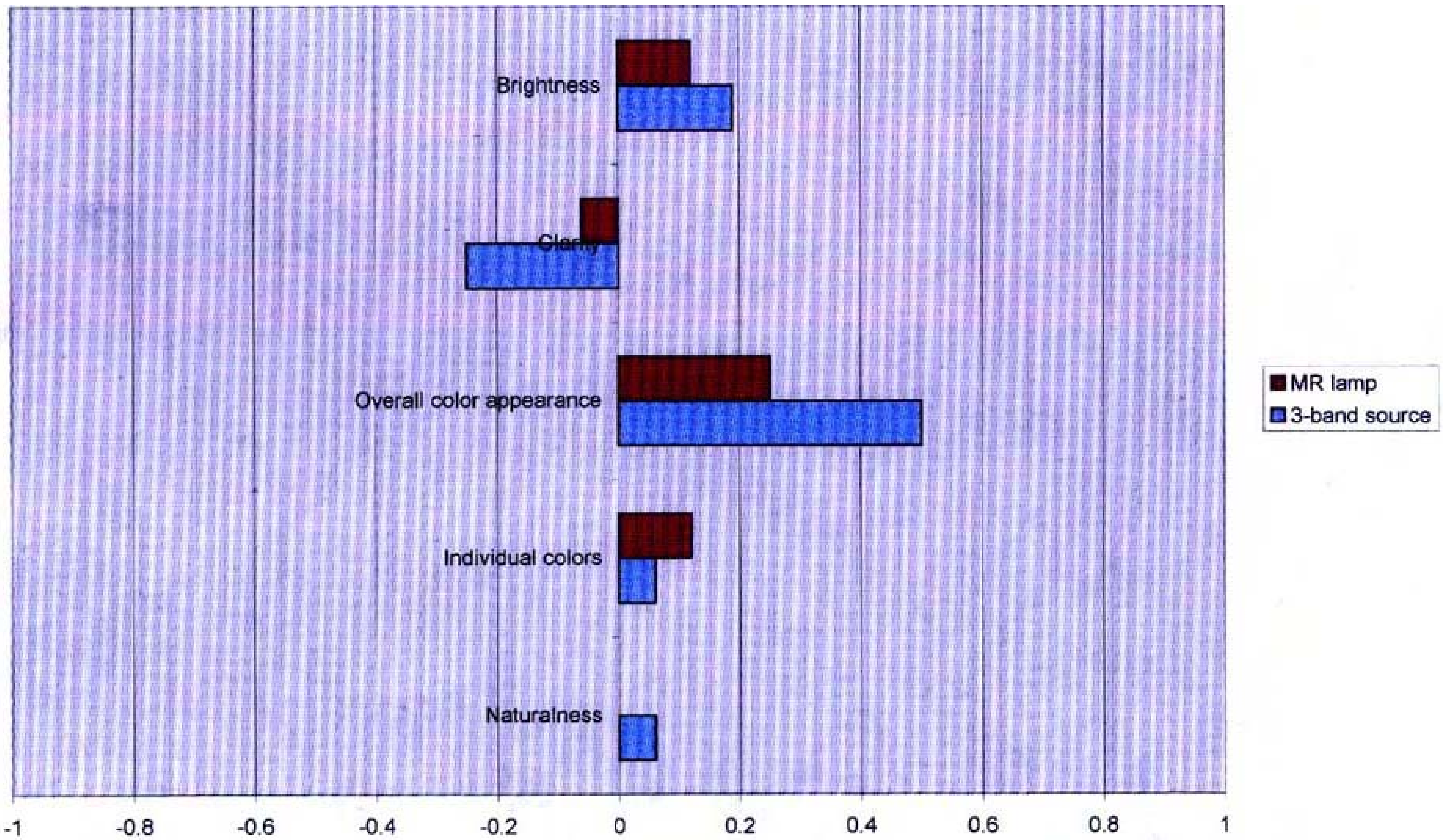


Figure 12 Subjective assessment ratings for ESCHER at low CCT



Subjective assessment ratings

Figure 13 Subjective assessment ratings for mONDRIAN at low CCT

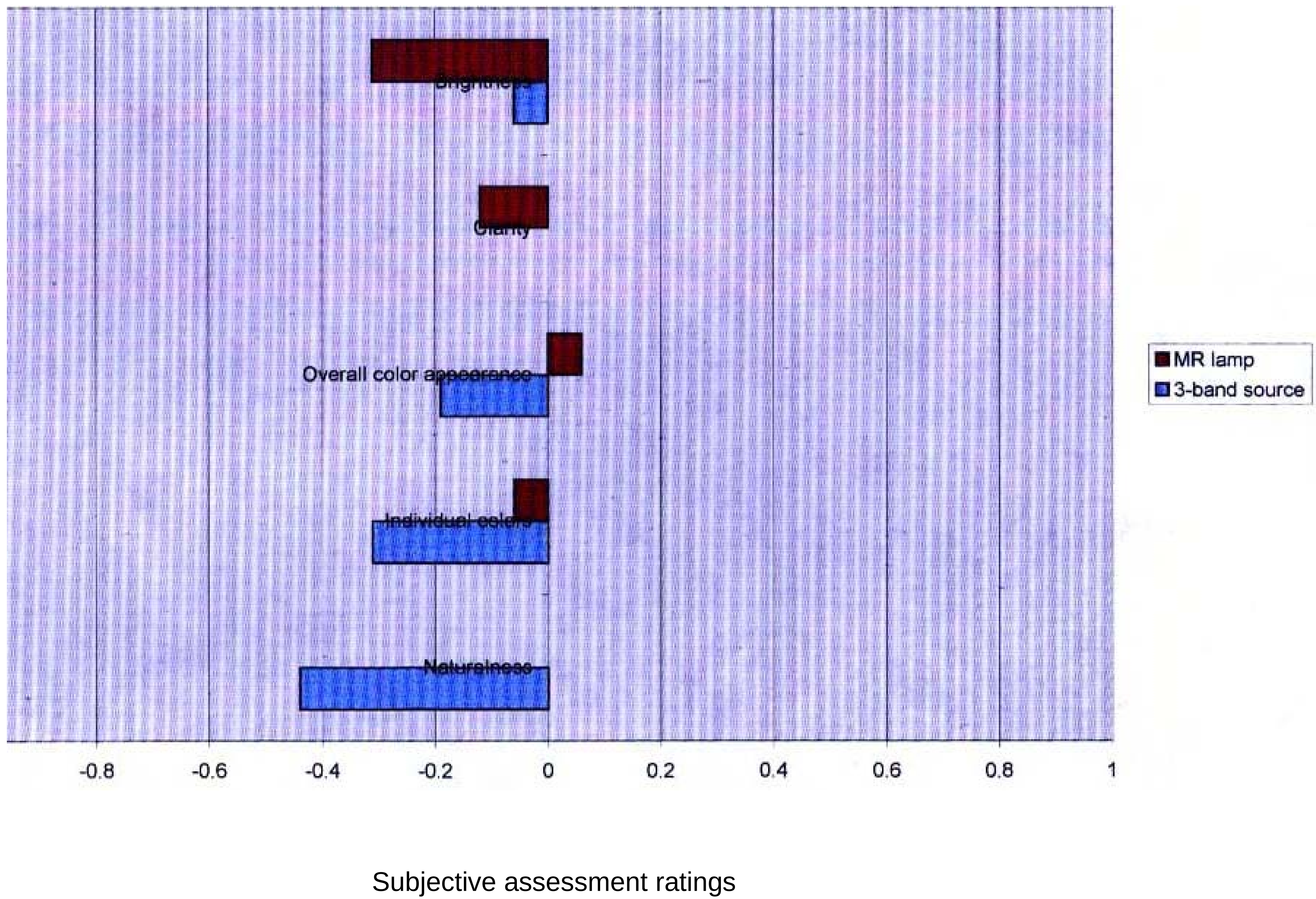
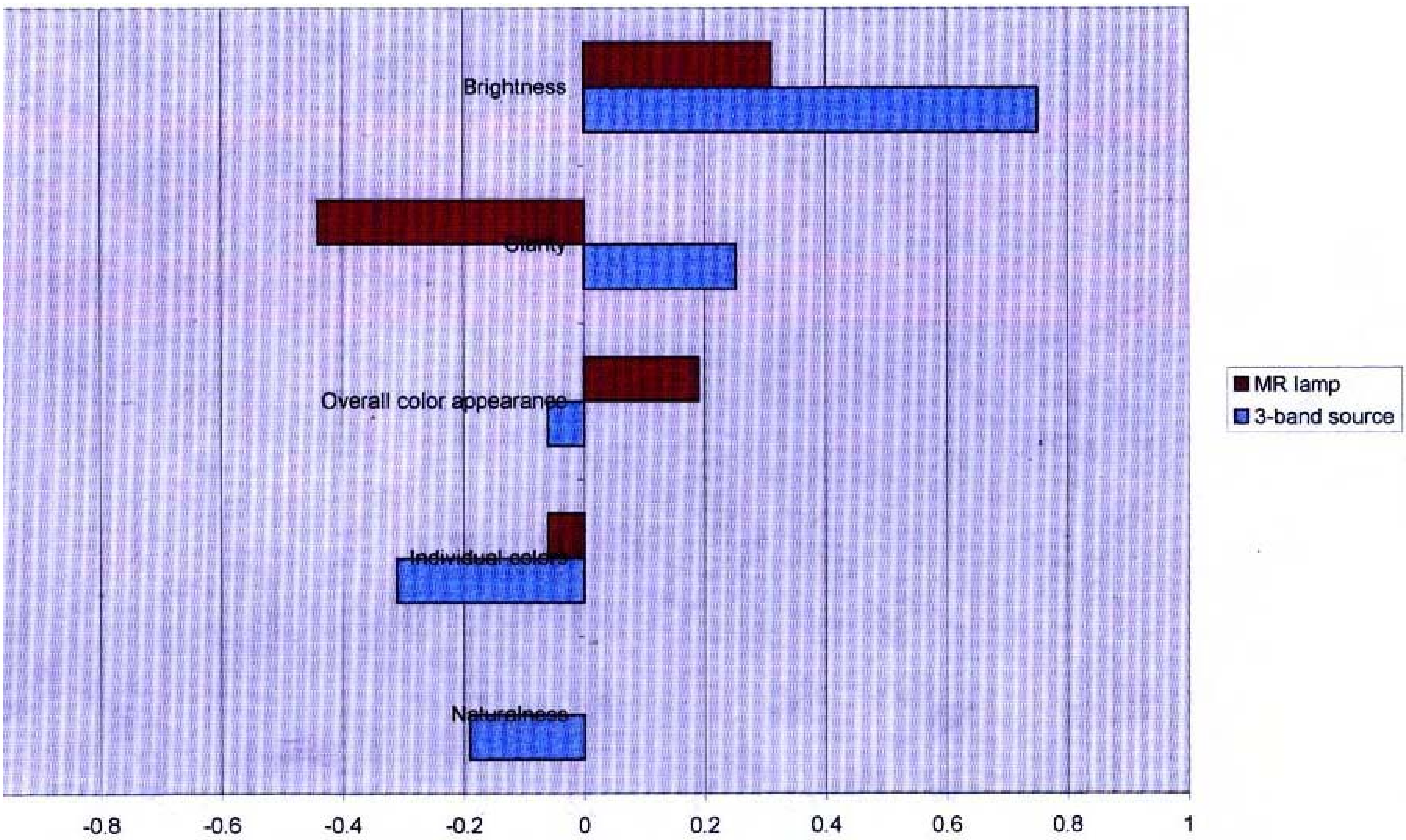
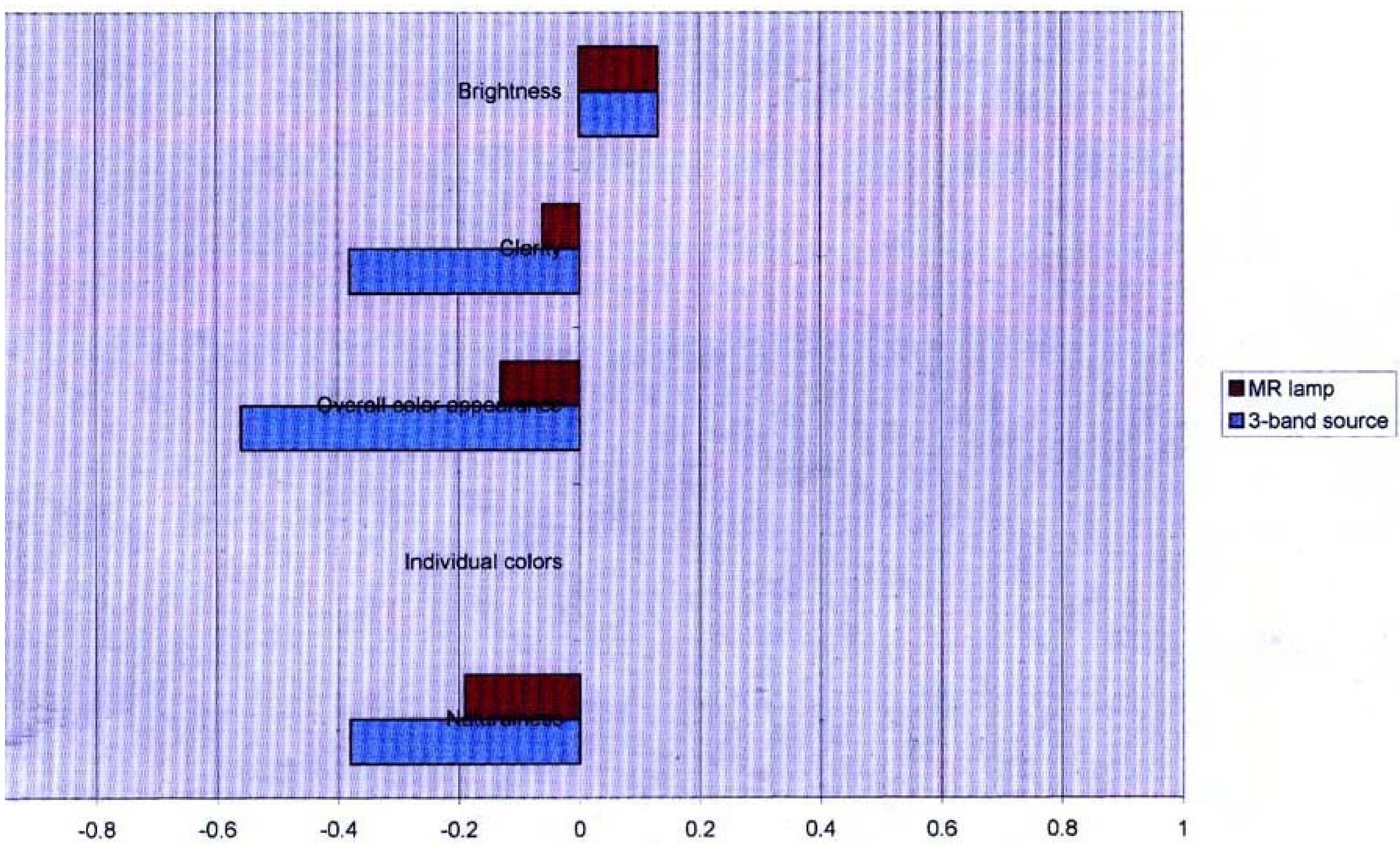


Figure 14 Subjective assessment ratings for RENOIR at low CCT



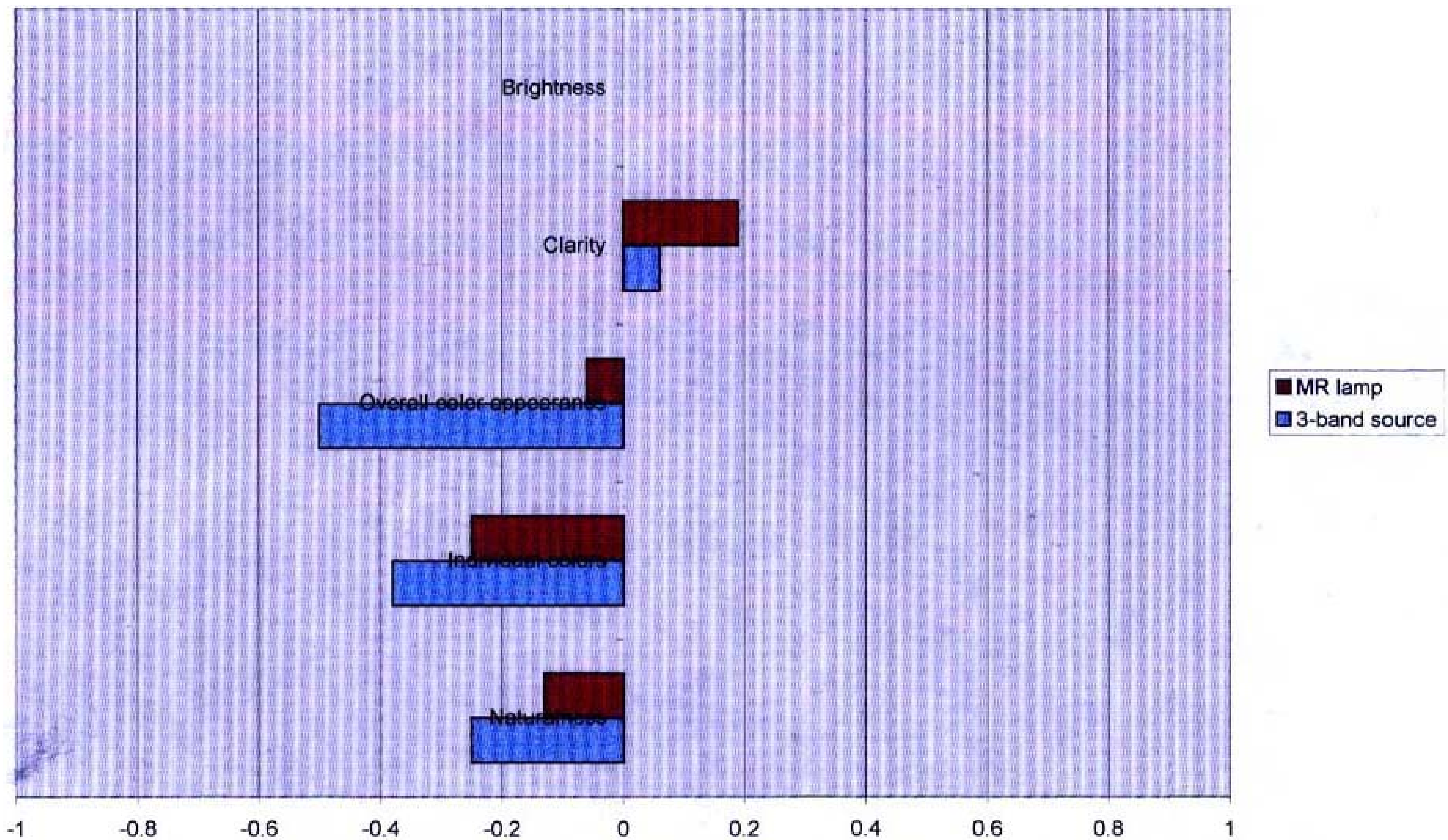
Subjective assessment ratings

Figure 15 Subjective assessment ratings for ESCHER at intermediate CCT



Subjective assessment ratings

Figure 16 Subjective assessment ratings for MONDRIAN at intermediate CCT



Subjective assessment ratings

Figure 17 Subjective assessment ratings for RENOIR at intermediate CCT

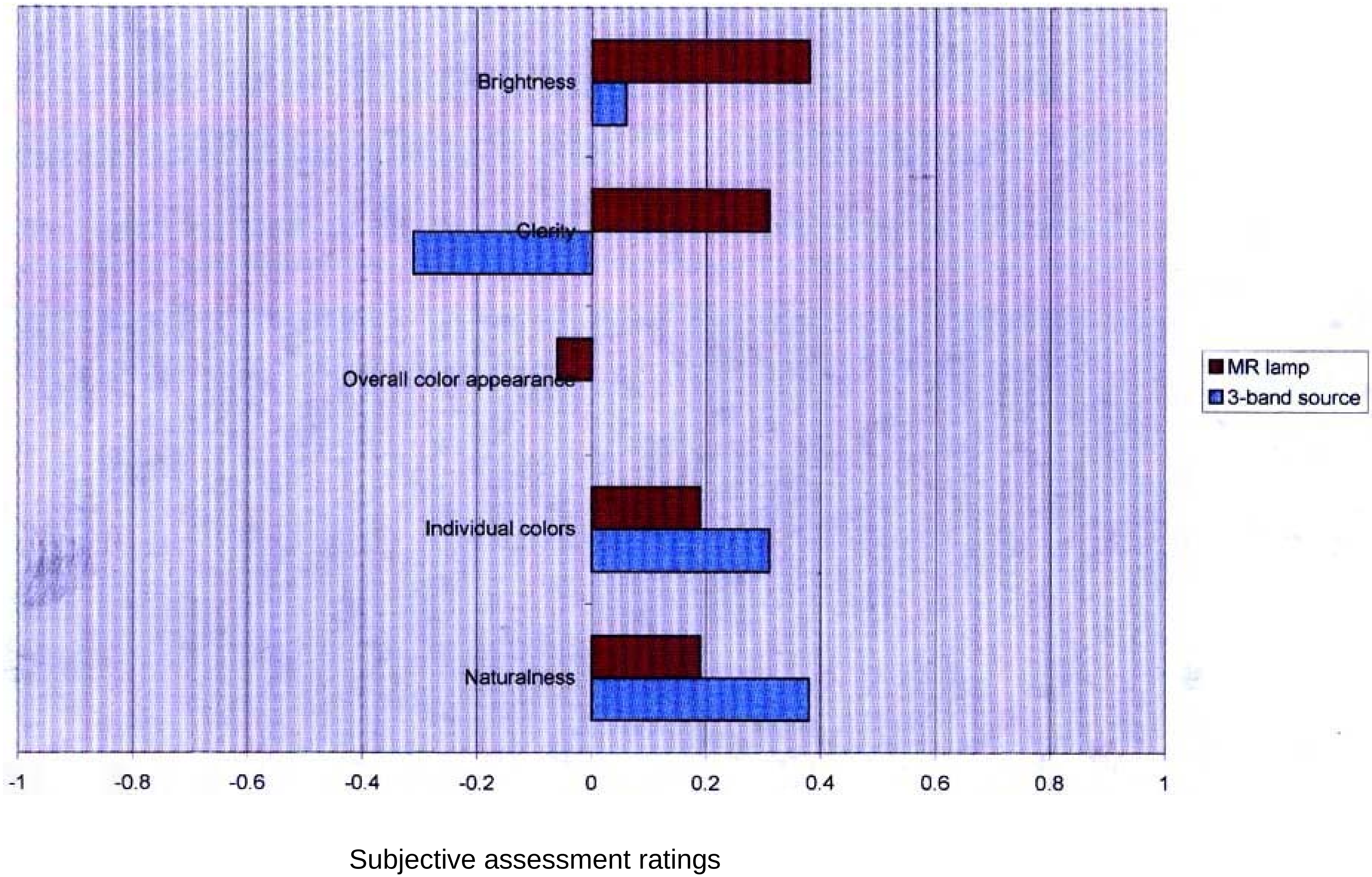


Table 1. Data for the two light source types at low and intermediate correlated color temperatures in the test situation.

	Low CCT		Intermediate CCT	
	MR	3-band	MR	3-band
Correlated color temperature (K)	2857	2856	4185	4197
Chromaticities: x y	 0.4492 0.4107	 0.4487 0.4098	 0.3766 03885	 0.3761 0.3884
Radiant Luminous Efficacy (lm/Wr)	224	380	252	367

Table 2. Mean illuminance in lux and standard deviation (in Parenthesis) for settings by the 16 subjects to match the appearance of the comparison situation preset to 50 lux.

	Low CCT		Intermediate CCT	
Artwork	MR	3-band	MR	3-band
Escher	47.9 (6.1)	53.0 (8.5)	49.4 (9.1)	50.9 (14.1)
Mondrian	49.6 (75)	50.5 (11.1)	52.4 (10.8)	52.9 (10.5)
Renoir	50.7 (6.3)	51.7 (8.2)	51.9 (9.5)	51.0 (12.9)

Table 3. Subjective assesment ratings for:

Artwork - Escher
CCT - 2850K

Criterior	Light Source	Rating							Average Rating
		-3	-2	-1	0	+1	+2	+3	
Brightness	MR			1	12	3			+0.12
	3-B			2	10	3	1		+0.19
Clarity	MR		1	2	10	3			-0.06
	3-B		2	4	6	4			-.025
Overall color appearance	MR			1	10	5			+0.25
	3-B			1	8	5	2		+0.5
Indvidual colors	MR				14	2			+0.12
	3-B			1	13	2			+0.06
Natuarlness	MR			2	12	1			0
	3-B		1	2	9	3	1		+0.06

Table 4. Subjective assesment ratings for:

Artwork - Mondrian
CCT - 2850K

Criterior	Light Source	Rating							Average Rating
		-3	-2	-1	0	+1	+2	+3	
Brightness	MR		1	4	10	1			-0.31
	3-B		1	3	8	4			-0.06
Clarity	MR			2	14				-0.12
	3-B		2	1	9	3	1		0
Overall color appearance	MR			1	14		1		+0.06
	3-B		2	4	6	3	1		-0.19
Indvidual colors	MR			3	11	2			-0.06
	3-B	1	3	2	5	4	1		-0.31
Natuarlness	MR			1	14	1			0
	3-B		2	4	9	1			-0.44

Table 5: Subjective assesment ratings for:

Artwork - Renoir
CCT - 2850K

Criterior	Light Source	Rating							Average Rating
		-3	-2	-1	0	+1	+2	+3	
Brightness	MR			1	11	3		1	+0.31
	3-B				6	8	2		+0.75
Clarity	MR		2	3	11				-0.44
	3-B	1		1	7	6	1		+0.25
Overall color appearance	MR			2	10	3	1		+0.19
	3-B		1	4	6	5			-0.06
Indvidual colors	MR			5	8	2	1		-0.06
	3-B	1	2	1	9	3			-0.31
Natuarlness	MR			3	11	1	1		0
	3-B		2	3	7	4			-0.19

Table 6. Subjective assesment ratings for:

Artwork - Escher
CCT - 4200K

Criterior	Light Source	Rating							Average Rating
		-3	-2	-1	0	+1	+2	+3	
Brightness	MR			2	11	2	1		+0.13
	3-B			2	10	4			+0.13
Clarity	MR			3	11	2			-0.06
	3-B		1	6	7	2			-0.38
Overall color appearance	MR			2	14				-0.13
	3-B		2	6	7	1			-0.56
Indvidual colors	MR			1	14	1			0
	3-B		1	1	11	3			0
Natuarlness	MR		1	1	14				-0.19
	3-B		1	4	11				-0.38

Table 7. Subjective assesment rateings for:

Artwork - Mondrain
CCT - 4200K

Criterior	Light Source	Rating							Average Rating
		-3	-2	-1	0	+1	+2	+3	
Brightness				4	10	2	1		0
				2	12	2			0
Clarity					13	3			+0.19
				1	13	2			+0.06
Overall color appearance			1	2	11	1	1		-0.06
			3	5	5	3			-0.50
Indvidual colors			1	4	8	2			-0.25
			3	3	7	3			-0.38
Natuarlness				2	14				-0.13
			1	4	9	2			-0.25

Table 8. Subjective assement ratings for:

Artwork - Renoir
CCT - 4200K

Criterior	Light Source	Rating							Average Rating
		-3	-2	-1	0	+1	+2	+3	
Brightness					10	6			+0.38
			1	2	8	5			+0.06
Clarity				2	9	3	2		+0.31
			1	4	8	2	1		-0.13
Overall color appearance				3	11	2			-0.06
			3		8	2	2		0
Indvidual colors				2	10	3	1		+0.19
			2	1	6	4	3		+0.31
Natuarlness					13	3			+0.19
			1	1	8	3	3		+0.38