Lightness constancy: ratio invariance and luminance profile

SORANZO, Alessandro <http://orcid.org/0000-0002-4445-1968>, GALMONDE, Alessandro and AGOSTINI, Tiziano

Lightness constancy; ratio invariance and luminance profile

Alessandro Soranzo#, Alessandra Galmonte§ & Tiziano Agostini¶

#School of Social Science and Law – University of Teesside

§Department of Psychology and Cultural Anthropology – University of Verona

¶Department of Psychology – University of Trieste

Abstract

The term simultaneous lightness constancy describes the capacity of the visual system to perceive equal reflecting surfaces as having the same lightness despite lying in different illumination fields. In some cases, however, a simultaneous lightness failure occurs, that is equal reflecting surfaces appear different in lightness when differently illuminated. An open question is if the luminance profile of the illumination edges affects simultaneous lightness constancy even when the ratio invariance property of the illumination edges is preserved. To explore this issue, we run two experiments by using bipartite illumination displays. Both the luminance profile of an illumination edge and the luminance ratio amplitude between the illumination fields were manipulated. Results revealed that the simultaneous lightness constancy increases when the luminance profile of the illumination edge is gradual (rather than sharp) and homogenous (rather than inhomogeneous), whilst it decreases when the luminance ratio between the illumination fields is enlarged. Results are interpreted according to the layer decomposition schema, stating that the visual system splits the luminance in the perceived lightness and in the apparent illumination components. We suggest that illumination edges having gradual and homogeneous luminance profiles facilitate the luminance decomposition process, while wide luminance ratios impede it.

Introduction

Simultaneous lightness constancy is the phenomenon whereby equal reflecting surfaces are perceived as having the same lightness despite lying in different illumination fields. This phenomenon constitutes a problem for vision science since visual objects are perceived by means of the light rays reflected from the surfaces to the retina. The amount of light reflected by the surfaces reaching the retina (i.e. luminance) is the product between the incident light and the reflectance of the surfaces. Therefore, equal reflecting surfaces placed in different illumination fields project different amounts of light to the retina. Nevertheless, under many conditions, surfaces sharing the same reflectance are perceived as having the same lightness although differently illuminated. How can the visual system recognize the reflectance equality among surfaces despite they are projecting different amount of light to the retina?

To recognize this equality, it is necessary for the visual system to distinguish the different illumination intensities in the visual image. In this regard, it has been proposed that to achieve the simultaneous lightness constancy, the visual system has to detect which, among the luminance edges in the image, are the illumination edges (Gilchrist, 1988). According to this view, one way to investigate the simultaneous lightness constancy is to find out which are the cues helping the visual system to individuate the illumination changes. Two of these cues are investigated in the present research: The ratio invariance property and the gradual luminance transition.

The ratio invariance property refers to a physical property of the illumination edges. According to Gilchrist (1988), the nature of the intersection where an illumination edge crosses a reflectance edge can determine if the first will be actually perceived as a change in illumination. This intersection, indeed, owns the ratio invariance property; that is the luminance ratio between regions under different illumination intensities remains the same when an illumination edge crosses them. Therefore, in order for the simultaneous lightness constancy to occur, an illumination edge has to cross at least one reflectance edge, so to create the ratio invariance cue. If, on the other hand, an illumination edge does not cross any reflectance edge, the simultaneous lightness constancy should not occur, and physically equal surfaces should be perceived as having different lightness. Experimental evidence showed that this is what actually happens. Specifically, Gilchrist (1988) has shown that when the intersection between an illumination and a reflectance edge is hidden from the view, surfaces sharing the same reflectance are perceived to be different in lightness leading, therefore, to a simultaneous lightness constancy failure.

Concerning the second illumination cue, the gradual luminance transition, Hering (1920) observed that a shadow covering a homogeneous surface appears as a dark stain if the gradual luminance transition at its edge is masked by means of a black ink. In other words, when the gradual luminance transition at the shadow edges is masked, the underling surfaces differ in the perceived lightness, leading - again - to a simultaneous lightness constancy failure. The observation that gradual luminance transitions help the visual system to individuate the illumination changes is confirmed by other studies (Kardos, 1934; MacLeod, 1947; Agostini & Galmonte, 1997, 2002). Outcomes of these researches induced the authors to conclude that gradual luminance transitions favor the percept of a change in the illumination intensity. In these studies, however, the gradual luminance transitions were the only illumination cue in the visual scene, as the ratio invariant property was never maintained. Because of that, the gradual luminance transitions in conjunction with the ratio invariance property have never been considered together as a cue favoring the occurrence of the simultaneous lightness constancy. Hence, an unresolved question is: Do gradual luminance transitions help the visual system to achieve the simultaneous lightness constancy even when the ratio invariant property is maintained?

To answer to this question we compared the effects on simultaneous lightness constancy of gradual and sharp luminance transitions by using display where the ratio invariant property was always preserved. Therefore, since the gradual luminance transitions were not the only illumination cue in the image, we crate critical conditions for testing their effect on simultaneous lightness constancy.

I EXPERIMENT

In this experiment, the effects on simultaneous lightness constancy of illumination edges having a gradual luminance profile were compared with the effects of illumination edges having a sharp luminance profile. The congruency of the illumination edge profile was also manipulated. It could be either congruent (i.e. homogeneously gradual or homogeneously sharp) or incongruent (i.e. partially gradual and partially sharp). Finally, we manipulated the luminance ratio amplitude between regions separated by the illumination edge.

Method

Observers

Twenty-six volunteer observers participated in this experiment. All had normal or corrected-to-normal vision and were naïve with regard to the experimental design.

Apparatus and stimuli

The stimuli were generated by a Macintosh Quadra 840/AV computer and were presented on a calibrated CRT Trinitron monitor (1280 x 1024 pixels)[1]. The screen of the monitor was vertically divided in two halves by a luminance edge. Then two additional rectangles were positioned on the centre of these two halves. The luminance ratio between the two areas on the left and the corresponding areas on the right was the same. Under these conditions, being the ratio invariance property preserved, the four areas are perceived as two surfaces (referred as Contextual and Mediating background) under two illumination intensities: The illuminated and the shadowed field. The portion of the luminance edge dividing vertically the screen crossing the Contextual background was the Contextual edge, while the portion of the same edge crossing the Mediating background was the Mediating edge. On the shadowed field, there was another surface, the Standard, having a fixed luminance, while on the illuminated field there was the Target, which luminance was adjustable from the computer console. We manipulated three experimental variables: 1) Congruency of the illumination edge, 2) Mediating edge profile and 3) Luminance ratio amplitude.

The Congruency variable had two levels: i) Congruent (the Mediating and the Contextual edge shared the same profile) and ii) Incongruent (the Mediating and the Contextual edge had different profile). The Mediating edge profile variable was also dichotomous: i) Gradual (the luminance profile at the Mediating edge was gradual) and

[1] For a discussion on the use of the CRT method in the lightness studies, see Bruno, 1994, and Soranzo and Agostini, 2006b.

ii) Sharp (the luminance profile at the Mediating edge was sharp). For the Luminance ratio amplitude variable, the luminance ratio between the illuminated and the shadowed fields was manipulated; it could be 2:1, 10:1 and 30:1. Altogether, there were twelve stimuli (2 x 2 x 3).

Figure 1a depicts the displays[2]; 1.b indicates the luminance – in cd/m^2 (the question mark indicates that the luminance of the Target was randomly assigned by the software at the beginning of each trial); and 1.c reports both the size of each area of the displays in deg (the width of the gradual transition, not indicated in the figure, was 1 deg) and the names of the two portions of the illumination edge.

Figure 1 about here

Procedure

Observers viewed the stimuli, presented in random order, in a darkened room from a distance of 57 cm from the monitor.

They were instructed to match the lightness of the Target patch on the illuminated field to the corresponding Standard patch on the shadowed field, by using the plus and minus keys of the keyboard. Pressing the spacebar key signaled that a satisfactory match was achieved. At that point, the Target luminance was recorded and the next trial began. The luminance of the Target was set to a random value at the beginning of each trial. In order to obtain a lightness match, observers were asked to make the Target patch "look

[2] On behalf of brevity, figure 1a represents the 10:1 level of the Luminance ratio amplitude variable only.

as if it were cut from the same piece of paper as the Standard”. The observers performed two matches for each of the 12 stimuli, so they provided 24 matches. Each display was left on the screen as long as needed to produce the match. The whole session lasted about 20 minutes.

Results and discussion

Mean ratings are made comparable by an index that can be defined the “Thouless luminance ratio” (TLR). The TLR is the same as the Thouless (1931) ratio, but uses luminance values directly instead of transforming them into reflectance. This is, therefore, very useful to measure lightness constancy degree in researches using CRT screens or on natural scenes where the reflectance values are laborious to derive.

According to Fechner’s law (1889), luminance values are firstly transformed into log units. Then, by following Thouless’ proposal, the following formula is obtained:

$$TLR = \frac{\log(PSE) - \log(L)}{\log(R) - \log(L)}$$

Where:

PSE=Point of Subjective Equality.

L = Luminance of the Standard.

R = Theoretical luminance value corresponding to perfect constancy.

Finally, by means of simple mathematical transformations, the following manageable index is obtained:

$$TLR = \frac{\log(PSE/L)}{\log(Ratio)}$$

Where *Ratio* is the luminance ratio between the illumination fields.

Mean index-linked values and the Standard errors are shown in figure 2.

Figure 2 about here

A three way repeated-measure ANOVA, performed on the index-linked values, revealed a significant effect of the three experimental variables ($p < 0.001$), while the interactions among them were not significant.

As can be observed in figure 2, for all the levels of the Luminance ratio amplitude variable, the constancy index is closer to one (i.e. the constancy degree is higher) when the luminance profile at the Mediating edge is gradual rather than sharp. Furthermore, the degree of constancy improves when the illumination edge profile is congruent, i.e. when the Mediating and Contextual edges share the same profile.

The last square means analysis, revealed a significant difference among all the conditions of both the Mediating edge profile and the Congruency variables ($p<0.001$). Specifically, it emerged that the constancy degree was higher in the Congruent-gradual rather than in the Congruent-sharp condition [$t_{(25)} = 5.2$; $p < 0.01$].

These results indicate that gradual luminance transitions improve the constancy degree even when the ratio invariance property is preserved. Furthermore, this effect seems to be independent from the luminance ratio amplitude between the illumination fields.

Figure 2 shows also that for all the levels of the Congruency and the Mediating edge profile variables, the constancy degree was lower in the 30:1 condition rather than in the other conditions. The last square mean analysis indicated a significant difference between the conditions 30:1 vs. 10:1 and between the conditions 30:1 vs. 2:1 [$t_{(25)} = 4.58$; $p < 0.01$ and $t_{(25)} = 5.75$; $p < 0.01$, respectively], whilst the difference between the conditions 2:1 vs. 10:1 was not significant. This suggests that there is no correspondence between the constancy degree and the luminance ratio amplitude: When the luminance ratio between an illuminated and a shadowed field is 30:1, the constancy degree decreases compared to conditions having a smaller ratio. From this experiment, however, it is not possible to understand if the constancy failure occurring in the 30:1 condition is due to the wide ratio or to the low luminance intensities in shadow. These two variables, indeed, changed at the same time. Therefore, a second experiment was performed where both the luminance ratio amplitude and the luminance intensities were controlled.

II EXPERIMENT

The experimental displays of the first experiment differed for both the luminance intensities in shadow and for the luminance ratio amplitude between the illumination fields. In order to identify which one of these two factors was more effective in determine the constancy failure registered in the 30:1 condition, in the second experiment we controlled for both factors.

Method

Observers

Ten volunteer observers participated to this experiment. All had normal or corrected-to-normal vision and were naïve with regard to the experimental design. None of them had participated in the first experiment.

Apparatus and stimuli

The apparatus was the same as in the first experiment. As in the first experiment, the stimuli were simulations of a scene under two different illumination intensities. Hence, there were a Mediating and a Contextual backgrounds vertically crossed by a luminance edge. There were also a Standard, in shadow, and a Target in light. The sizes of the displays areas were the same as in the first experiment (see figure 1c). There were two independent variables; the first was the Absolute luminance values with three levels:

1. High-luminance, which was identical to the 10:1 display of the first experiment;
2. Low-luminance, all the luminance values were reduced by 1/3 compared to the High-luminance condition. In this way, the luminance ratio amplitude between the two illumination fields was equal to 10:1 as in the High-luminance condition, but all the luminance values were lowered;
3. Large-ratio, the luminance values in the illuminated field were the same as in the High-luminance condition, while those in the shadowed field were the same as in the Low-luminance condition. The luminance ratio amplitude between the two fields was 30:1 (this display was, therefore, identical to the 30:1 display of the first experiment).

The second independent variable was the Illumination edge profile with two levels: 1) Gradual (the luminance profile of the illumination edge was gradual) and ii) Sharp (luminance profile of the illumination edge was sharp).

Figure 3a shows the experimental conditions of the Illumination edge profile, while figure 3b shows the luminance - in cd/m^2 - of the displays.

Figure 3 about here

In total, there were six stimuli (3x2).

Procedure

The procedure was the same as in the first experiment.

Results and discussion

Mean ratings have been transformed with the same TLR-index used in the first experiment (see the results section of the first experiment). A two way repeated-measure ANOVA, performed on the index-linked values, revealed a significant effect of both the Absolute luminance values and the Illumination edge profile variables [$F_{(2,9)} = 4.82$; $p < 0.05$; $F_{(1,9)} = 17.19$; $p < 0.01$, respectively]. The interaction between them was not significant. Figure 4 depicts the mean index-linked values and the Standard errors of the second experiment.

Figure 4 about here

The last squares means comparison performed on the Absolute luminance values variable revealed a significant difference between the High-luminance vs. Large-ratio conditions, and Low-luminance vs. Large-ratio conditions [$t_{(9)}$=2.60; $p< 0.05$; and $t_{(9)}$=2.77; $p<0.05$, respectively]. There was no significant difference between the High- and Low-luminance conditions. Then, there was a significant difference between conditions differing for the luminance ratio amplitude, but no difference between the conditions differing for the luminance intensities. It seems therefore that when the luminance ratio amplitude between the illumination fields is 10:1, the simultaneous lightness constancy improves in comparison to the condition where this ratio is 30:1; and this effect seems to be independent from the absolute luminance intensities.

In addition, in this second experiment, the effect of the luminance profile on the simultaneous lightness constancy was replicated. When the profile of the illumination edge was gradual, the simultaneous lightness constancy degree was higher compared to the conditions in which it was sharp.

GENERAL DISCUSSION

From our work, it emerges that in a bipartite illumination field displays lightness constancy is affected by the following factors:

1) The illumination edge luminance profile;
2) The congruency of the illumination edge;
3) The luminance ratio amplitude between the illumination fields.

These factors are discussed separately.

1) The illumination edge luminance profile

The present research was first aimed at answering at the following question: Do gradual luminance transitions help the visual system to achieve the simultaneous lightness constancy when the ratio invariant property is maintained? Outcomes show that, when the luminance ratio invariant property is preserved, simultaneous lightness constancy improves when the luminance profile of an illumination edge is gradual rather than sharp. It seems therefore that the ratio invariance property and the gradual luminance transition do cooperate to achieve a better constancy degree. In addition, this effect was found to be independent from the luminance ratio amplitude between the fields.

To interpret this outcome, two theories on lightness perception both taking into account high-level visual processes are considered. Most lightness theorists have accepted the high-level viewpoint, suggested firstly by Koffka (1935), that the retinal image is decomposed into separate components. However, there are two types of decomposition schemas: the "layer" type and the "framework" type.

The layer decomposition schema states that the visual system decomposes the pattern of light intensities reaching the eyes into separate contributions: Reflectance, illumination and so on (Musatti, 1953; Kozaki, 1965; Oyama, 1968; Beck, 1972; Bergström, 1977; Barrow & Tenenbaum, 1978; Gilchrist, 1977; 1979; Adelson & Pentland, 1990; Schirillo, 1999a; 1999b).

Although this schema accounts for the simultaneous lightness constancy phenomena, it has been argued that its attempt to explain the losses of constancy has not proven to be very effective (Gilchrist at al. 1999; Gilchrist, 2005; 2006). If the visual system would be able to split the luminance into components, errors should not occur in lightness perception. However, this is not the case; in some conditions, the visual system attributes different lightness values to equal reflecting surfaces. To solve this problem, it has been recently proposed that, in those conditions, the visual system may commit an error in the layer decomposition process (Gilchrist, 1988; Anderson & Winawer, 2005; Soranzo and Agostini (2004; 2006a; 2006b). This error can be named the "luminance misattribution" meaning that part of the luminance that should be attributed to one component, is attributed to another instead. The amount of luminance misattribution should be inversely proportional to the number and strength of illumination cues in the visual scene.

In the displays of this research, the luminance misattribution should imply that: (a) Part of the Standard luminance that should have been attributed to its reflectance is attributed to the illumination; and/or (b) part of the Target luminance that should have been attributed to the illumination is attributed to its reflectance.

As the constancy degree was higher when the profile of the illumination edge was gradual rather than sharp, it seems that the luminance ratio invariance and the gradual luminance transitions are both cues facilitating the correct layer decomposition process and having additive effects.

The framework approach, however, argues against the illumination interpretation of the luminance gradients (Gilchrist et. all. 1999; Bressan, 2006). This approach claims that the visual system divides an image into contiguous regions of illumination or shadow, like states on a map. The perceived lightness of any given surface depends mainly on its photometric relationship with the highest luminance (anchor) in the same framework.

In comparison to the layer approach, errors in lightness perception are much better operationalized: they depend on the amount of framework segregation. The more one framework is segregated by the others; the more the perceptual lightness is correctly computed.

According to this view, the role of the luminance gradients should be to increase the framework segregation, leading to an increase of lightness constancy. In the displays of the present research, both the ratio invariance and the gradual luminance transition cooperate to produce higher lightness constancy degrees. Therefore, according to the framework approach, these factors should contribute conjunctively and cumulatively to segregate the image into frameworks.

To sum up, the increase of lightness constancy degree produced by the gradual luminance transitions in the presence of the ratio invariance property can be interpreted by both the decomposition schemas. According to the layer approach, these factors should facilitate the luminance attribution to the different components; according to the framework approach, they should facilitate the image segregation into frameworks.

In the next section, however, it is shown that the effect on simultaneous lightness constancy of the Congruency of the illumination edge cannot be explained by both the decomposition schemas.

2) Congruency of the illumination edge luminance profile

The second major outcome of the present research is that the simultaneous lightness constancy improves when the congruency of the illumination edge profile is maintained rather then altered. Specifically, results show a better lightness constancy degree when a Mediating and a Contextual edge share the same luminance profile rather then a different one. This effect is so robust that the constancy degree was higher in the

Congruent-sharp display rather than in the Incongruent-gradual. This point need to be stressed because in the Incongruent-gradual condition, the surfaces to be compared in lightness (Standard and Target) were separated by a gradual luminance transition, whilst in the Congruent-sharp condition they were separated by a sharp transition. Therefore, it seems that in order to achieve a better constancy degree, the congruency of the illumination edges is more effective than the type of their luminance profile.

This outcome has very important theoretical consequences because, as anticipated, it seems to challenge one of the decomposition schemas.

As stressed, results show better constancy in the Congruent-sharp rather then in the Incongruent-gradual condition. According to the layer decomposition schema, the degree of constancy should depend on the number and strength of illumination cues in the visual scene. Congruency of the illumination edge should be considered one of the most important illumination cues, favoring the correct luminance attribution to the different components. As in the Incongruent-gradual condition, this factor is absent whilst it is present in the Congruent-gradual condition, the layer approach correctly accounts for the better lightness constancy degree measured when the Congruency of the illumination edge was preserved.

According to the framework approach, however, in the Incongruent-gradual condition the ratio invariance property and the gradual luminance transition are both active factors to segregate cumulatively the frameworks, whilst in the Congruent-sharp condition the ratio invariance property is the sole active factor to operate the segregation. Therefore, better lightness constancy degree should occur in the Incongruent-gradual, rather then in the Congruent-sharp condition, but this is not what actually happens.

By comparing the results of the two incongruent conditions, another consideration can be made. Outcomes reveal that the gradual luminance profile at the Mediating edge increases the simultaneous lightness constancy degree compared to the sharp profile at this edge. This difference can be explained taking into account the number of cues signaling that the Target and the Standard were in different illumination fields. Whilst in the Incongruent-sharp condition this information is carried out from the ratio invariance property only, in the Incongruent-gradual condition, this information is strengthened by the presence of the gradual luminance transition at the Mediating edge (only in the Incongruent-gradual case the Standard and the Target were separated by a gradual luminance transition; see figure 1).

Hence, the layer decomposition approach explains this result too. In the next section, however, it is shown the limits of this approach.

3) Luminance ratio amplitude between the illumination fields

In the first experiment of this research, it emerged that, when the luminance ratio amplitude between the illumination fields was equal to 30:1, the constancy degree decreased with respect to the 10:1 or 2:1 cases.

Therefore, in bipartite displays, when the luminance values in shadow are reduced, a constancy failure occurs. A similar result emerged in the studies of Katz (1911, 1935) and Helson (1948). Both authors attributed this effect to the low luminance intensities in the shadowed field of their displays. However, in the second experiment of the present research, the effects of the luminance values in shadow on the simultaneous lightness constancy were compared to those of the luminance ratio amplitude between the illumination fields. As a difference from Katz and Helson's suggestions, we found that when the intensities in shadow are kept constant, wide luminance ratios between the illumination fields induce a lightness constancy failure.

This result is tricky to be interpreted within both the theoretical decomposition schemas. The framework schema does not include, at present, the luminance ratio amplitude among frameworks as a factor affecting lightness perception. To explain this result within the framework paradigm it should be assumed that the higher the luminance ratio between two frameworks, the lower their segregation from each other. This explanation seems, at most, counterintuitive.

On the other side, to explain this result within the layer decomposition paradigm it has to be assumed that the relation linking the luminance ratio amplitude with lightness constancy is not a linear relation. At this regard, Beck' (1972) suggested that the relation linking lightness to the apparent illumination is inversely proportional, but it varies when the absolute luminance in the visual scene is changed, leading, therefore, to a non-linear relation. Following Beck's idea, it could be argued that the visual system splits correctly (or almost correctly) the luminance in the stimuli only within a small luminance range; beyond that range, a greater luminance misattribution should occur. This means that the visual system does not consider wide luminance ranges among illumination fields as illumination cues. This is unexpected considering that from photometric measurements of natural scenes, it emerges that the widest luminance ratios are produced by illumination changes rather than reflectance ones (Leibowitz, 1965; Brown e Deffenbacher, 1979; Dember e Warm, 1979; Goldstein, 1980). Therefore, one would expect that the visual system consider wide luminance ratios as an illumination cue. Nevertheless, it seems to be not what actually happens.

This put in evidence one of the major shortcomings of the layer approach: It is difficult to postulate *a priori* what the visual system will consider an illumination cue.

The other important shortcoming of this schema is that no predictions on what an observer actually perceives are given. In particular, the layer approach does not include any anchor to derive the perceived lightness values. On the contrary, the anchor is one of the advantages of the framework approach. Therefore, accordingly with Gilchrist (2005), we believe that integration between the layer and the framework decomposition schemas might give rise to a more comprehensive lightness theory. One possibility is that the visual system first attributes the luminance to the different components, basing this attribution to the number and strength of the illumination cues in the image; then, on the "provisory" lightness values resulting from this attribution, principles proposed by the framework decomposition schemas are applied. This hypothesis needs to be tested with further experiments.

Figure captions

Figure 1.a. Stimuli of the first experiment (10:1 luminance ratio amplitude only). They are displayed according to their level in the Mediating edge profile variable (columns) and Congruence variable (rows).
b. Luminance values (in cd/m2) for the three levels of the luminance ratio amplitude variable.
c. Stimuli size in degrees of visual angle. The width of the gradual transition (not showed in the figure) was equal to 1 deg.

Figure 2. Mean index-linked values (TLR) of the first experiment. Bars represent Standard errors.

Figure 3.a. Levels of the Illumination edge profile variable.
b. Luminance (in cd/m2) of the Absolute luminance values variable.

Figure 4. Mean index-linked values of the second experiment (TLR). Bars represent Standard errors.
.

References

ADELSON, E. H. & PENTLAND, A. P. (1990). The perception of shading and reflectance. *Vision and Modeling Technical Report*. **140**: MIT Media Laboratory.

AGOSTINI, T. & GALMONTE, A. (1997). Luminance gradients, perceived illumination, and lightness perception. *Review of Psychology*. **4.** 3-6.

AGOSTINI, T. & GALMONTE, A. (2002). A new effect of luminance gradient on achromatic simultaneous contrast. *Psychonomic Bulletin & Review*. **9**(3). 264-269.

ANDERSON, B. & WINAWER, J. (2005). Image segmentation and lightness perception. *Nature* **434**. 79–83.

BARROW, H. G. & TENENBAUM, J. (1978). Recovering intrinsic scene characteristics from images. in *Computer Vision Systems* Eds A R Hanson & E. M. Riseman (Orlando: Academic Press). 3-26.

BECK, J. (1972). *Surface color perception*. Ithaca. NY: Cornell University Press.

BERGSTROM, S. S, (1977). Common and relative components of reflected light as information about the illumination, colour, and three-dimensional form of objects. *Scandinavian Journal of Psychology*. **18**(3). 180-186.

BRESSAN, P. (2006). The place of white in a world of grays: a double-anchoring theory of lightness perception. *Psychological Review,* **113**, 526-553

BROWN, E. L. e DEFFENBACHER, K. (1979). *Perception and the senses*. New York: Oxford University Press.

BRUNO, N. (1994). *Failures of lightness constancy, edge integration, and local edge enhancement*. Vision Research **34** (17) 2205-2214.

DEMBER, W. N., & WARM. J. S. (1979). *Psychology of perception*. New York: Holt. Reinhart & Winston.

FECHNER, G. T. (1889). *Elemente der Psychophysik* (2nd ed.), Leipzig: Breitkopf & Härtel.

GILCHRIST, A. L. (1977). Perceived lightness depends on perceived spatial arrangement. *Science*. January 14. **195**. 185-187.

GILCHRIST, A. L. (1979). The perception of surface blacks and whites. *Scientific American*. **240**. 112-123.

GILCHRIST, A. L. (1988). Lightness contrast and failures of constancy: a common explanation. *Perception & Psychophysics*. **43**. 415-424.

GILCHRIST, A. L., KOSSYFIDIS, C., BONATO, F., AGOSTINI, T., CATALIOTTI, J., LI, X., SPEHAR, B. E SZURA, J. (1999). A new theory of lightness perception. *Psicologichal Review*. **106**(4). 795-834.

GILCHRIST A L, 2005 "Lightness Perception: Seeing One Color through Another" *Current Biology* **15**(9) R330-R332

GILCHRIST A L, 2006 *Seeing Black and White* (Oxford University Press)

GOLDSTEIN, E. B. (1980). Sensation and perception. Belmont. CA: Wadsworth.

HELSON, H. (1943) Some factors and implications of color constancy. *Journal of the Optical Society of America A.* **33.** 555-567.

HERING, E. (1920) *Grundzuge der Lehre vom Lichtsinn*. Springer. Berlin.

KARDOS, L. (1934). Ding und Schatten. Barth (Ed.). Leipzig.

KATZ, D. (1911). Die Erscheingsweisen der Farben und ihre Beeinflussung durch die individuelle Erfahrung. *Zeitschrift für Psychologie*, **7**.

KATZ, D. (1935). *The World of Colour*. London: Kegan Paul, Trench, Trubner & Co.

KOFFKA, K. (1935). *Principles of Gestalt psychology*. New York: Harcourt. Brace and World.

KOZAKI, A. (1965). The effect of co-existent stimuli other than the test stimulus on brightness constancy. *Japanese Psychological Research*. **7**. 138-147.

MACLEOD, R. B. (1947). The effect of "artificial penumbrae" on the brightness of included areas. *Miscellanea psychologica Albert Michotte*. 138-154. Louvain: Institut Superieur de Philosophie.

MUSATTI, C. L. (1953). Ricerche sperimentali sopra la percezione cromatica. *Archivio di Psicologia, Neurologia e Psichiatria*. **14**. 541-577.

OYAMA, T. (1968). Stimulus determinants of brightness constancy and the perception of illumination. *Japanese Psychological Research*. **10**. 146-155.

SCHIRILLO, J. A. (1999a). Surround articulation. I. Brightness judgments *Journal of the Optical Society of America A.* **16.** 793-803.

SCHIRILLO, J.A. (1999b). Surround articulation. II. Lightness judgments. *Journal of the Optical Society of America A.* **16**. 804-811.

SORANZO, A. & AGOSTINI, T. (2004). Impossible shadows and lightness constancy. *Perception*. **33** (11). 1359-1368.

SORANZO, A. & AGOSTINI, T. (2006a). Does perceptual belongingness affect lightness constancy? *Perception*, **35**. 185 – 192.

SORANZO, A. & AGOSTINI, T. (2006b). Photometric, geometric and perceptual factors in Illumination-independent lightness constancy. *Perception & Psychophysics*, **68** (1). 102-113.

THOULESS, R. H. (1931). Phenomenal regression to the "real" object. *British Journal of Psychology*, **22**, 1-30.