Measuring Colour Dissimilarities Under Neutral Light Sources Differing In Intensity

Rumi Tokunaga and Alexander D. Logvinenko; Department of Vision Sciences, Glasgow Caledonian University; Glasgow, United Kingdom

Abstract

Logvinenko & Maloney (2006) previously demonstrated that surface albedo and lighting intensity both contribute to rated dissimilarity in lightness when surfaces are viewed under different illuminants. We extend these results to dissimilarity of coloured surfaces under neutral illuminants that differ in intensity. Observers saw three spatial arrays each containing seven Munsell papers. Each array was illuminated independently with intensity 6, 110, or 2100 lux. Subjects judged the dissimilarity of all possible pairs of surfaces. Two methods - quadruple comparisons, and ranking – were used. The resulting MDS solutions showed separable effects of hue and light intensity. The effect of change in illumination was to scale down the output configuration: decreased intensity corresponded to decreased dissimilarities.

Introduction

Using multidimensional scaling (MDS) it was recently found that the lightness continuum shrinks when the light intensity decreases [1]. However, a similar experiment on the yellow-blue continuum showed no shrinking effect [2]. One possible explanation of such a difference between the results of these two studies might have been the categorization effect found in [2]. Specifically, the dissimilarity between the two chromatic clusters (yellow, and blue) of chips and the neutral was found to be larger then between the chips within each cluster. We argue that the categorization effect might have disguised the shrinking effect, if any. To test this hypothesis we conducted a similar experiment using Munsell papers of different hue and maximal chroma, without achromatic papers, to prevent the categorization effect.

Experiment

The experimental setup is shown in Figure 1. A stimulus display consisted of three identical arrays of seven Munsell papers (5R4/14, 5YR7/12, 5Y8/12, 5G6/10, 10BG5/8, 5PB5/12 and 10P5/12). Each array subtended 8.4 angular degrees. The arrays were illuminated independently by three neutral lights of intensities 6, 110, and 2100 lux. Five observers with normal trichromatic colour vision took part in experiment.

The experiment was divided into two parts. In the first part, dissimilarities between the seven Munsell papers of most intense illumination (2100 lux) were evaluated by using a method of quadruple comparisons. In one trial, two pairs of Munsell papers were pointed out randomly by the experimenter. Observers were asked to judge which pair were more dissimilar in colour. All 210 possible pairs of pairs of 7 papers were evaluated in one experimental session. Ten sessions had been carried out with each of five observers.

The results were recorded as a response matrix, $r(i,j;k,l)$ $(i,j,k,l=1,...,7)$, where $r(i,j;k,l)=n$ $(0 \le n \le 10)$ stands for that pair (c_i,c_j) was judged as not less dissimilar than (c_k,c_l) n times. We took as a measure of dissimilarity between papers c_i and c_j the following number

$$d(i,j)=\sum_{k,l=1,...,7} r(i,j;k,l) \qquad (1)$$

This measure is simply the number of times the pair (c_i,c_j) was preferred to all other pairs as not less dissimilar.

In the second part, the dissimilarities between Munsell papers illuminated by the dimmer lights (110 and 6 lux) were evaluated as compared to the dissimilarities of the corresponding pairs illuminated by the light of 2100 lux. More specifically, a pair, say (c_i,c_j), in the bright array (2100 lux) and the same pair (c_i,c_j) in a dimmer array (110 or 6 lux) were singled out by the experimenter. Observers first judged which pair of the papers was more dissimilar, then they evaluated the dissimilarity between the papers in the dimmer array as compared to that between the papers in the bright array with a number (rank), taking the dissimilarity between the papers in the bright array as 100. Five experimental sessions had been accomplished for each of the two dimmer arrays. Therefore, each of 21 pairs under each of two illuminants (110 and 6 lux) had been evaluated five times.

A dissimilarity matrix for the dim array, $d_D(i,j)$, was then derived from that for the bright array, $d_B(i,j)$, by multiplying the latter by $s(i,j)$: $d_D(i,j)=s(i,j)d_B(i,j)$.

Figure 1. *Experimental setup. SP - slide projectors; D – stimulus display.*

Results and Discussion

Fig.2 presents the two-dimensional output configurations produced by the non-metric MDS algorithm [3] for the dissimilarities obtained in the first part. As one can see, in spite of unavoidable individual differences all the output configurations correspond. While they are not quite circular (as those obtained in the previous studies [4, 5, 6]), the circular order of the colours is the same as in the Munsell book.

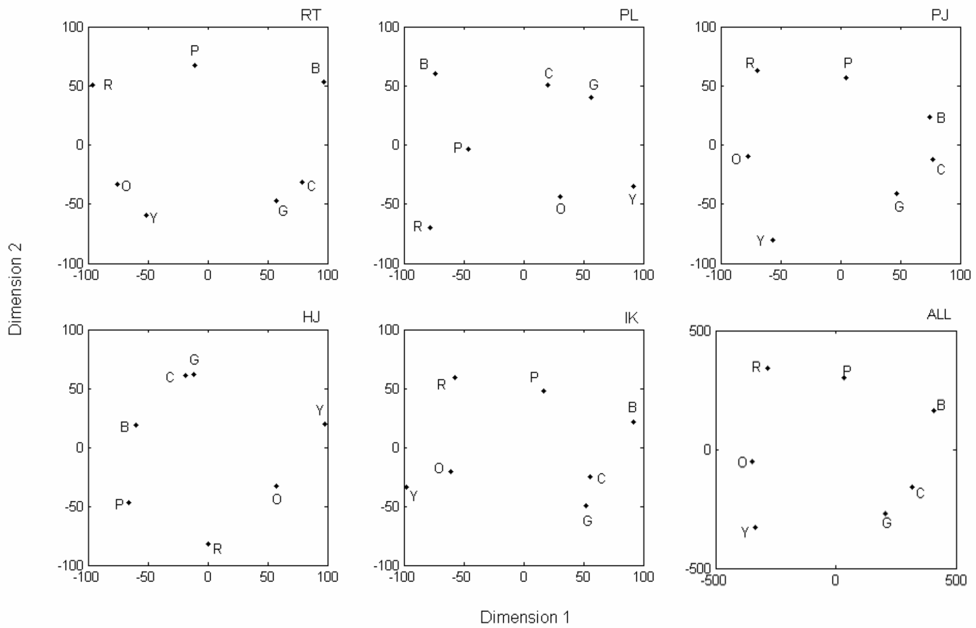

Figure 2. *Output MDS configurations for each observer and for the whole group (ALL) obtained under the brightest light (2100 lux). Acronym R stands for the Munsell paper 5R4/14, O for 5YR7/12, Y for 5Y8/12, G for 5G6/10, C for 10BG5/8, B for 5PB5/12, P for 10P5/12.*

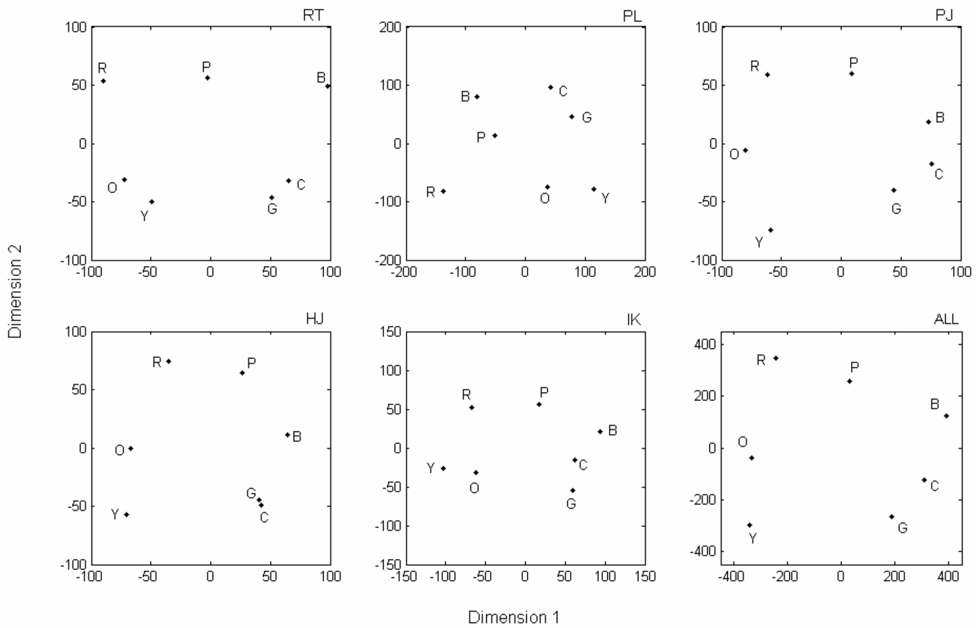

Figure 3. *Output MDS configurations for the light of 110 lux. Acronyms are the same as in Figure 2.*

The results for the second part are shown in Figs 3 and 4. In Fig.3 the shapes of individual output configurations remain similar to those in Fig.2. The circular order of the colours is the same as in the Munsell book except for observer IK. This observer exhibits a permutation between O and Y in Fig.3 as compared to Fig.2. In Fig.4, the circular order of the colours is preserved, but the shapes of individual output configurations somewhat change as compared to figures 2 and 3. In particular, for observer HJ, colors are clustered into three groups P and R; O and Y; and G, C, and B. Observers IK and PL also show a similar trend.

We perform Procrustes analysis [3] to ascertain how the shapes of the output configurations obtained under three different illuminations for the same observers are related to each other. Specifically, we derived the admissible transformations of the output configurations for the dimmer lights so as to best match the output configuration for the brightest light for each observer. The transformed configurations along with the output configuration for 2100 lux are shown in Fig.5. The Procrustes statistic (a measure of the match) has been evaluated (Table 1). The smaller the statistics value the better match [3].

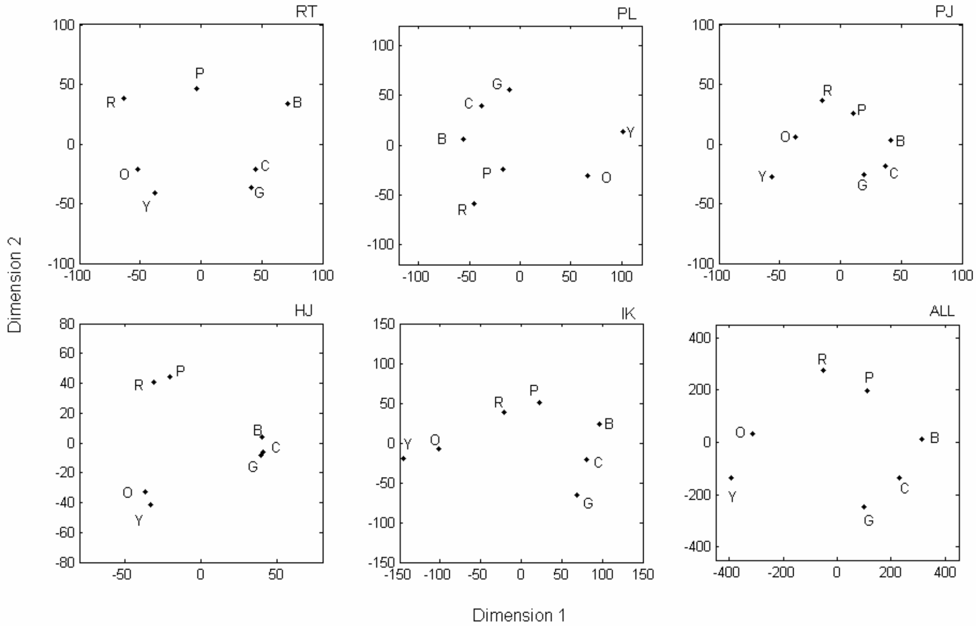

Figure 4. *Output MDS configurations for the light of 6 lux. Acronyms are the same as in Figure 2.*

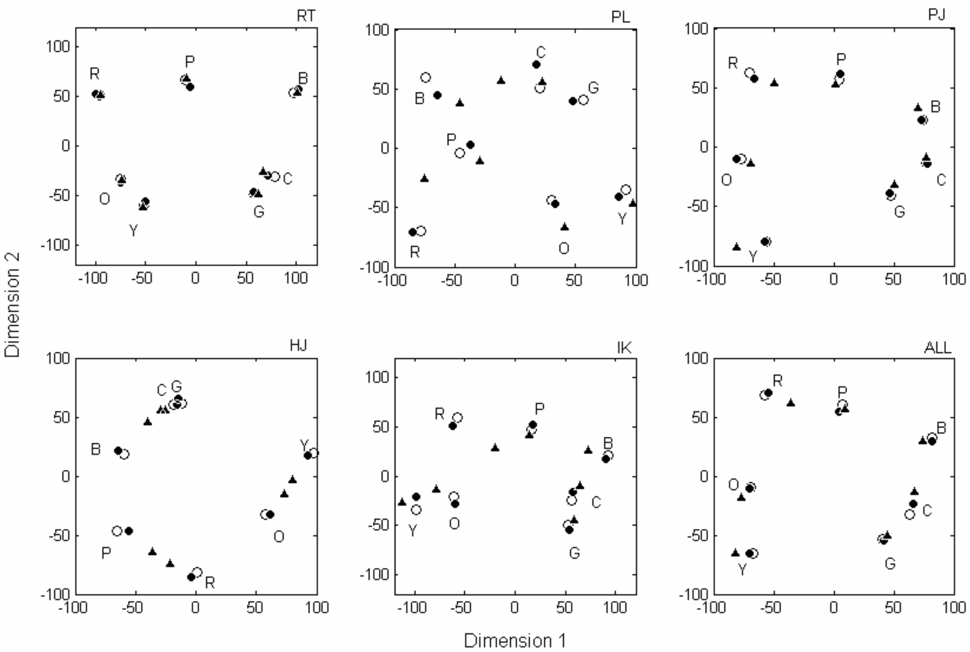

Figure 5*. Procrustes analysis. Open circles stand for the brightest light (2100 lux), filled circles for 210 lux, and filled triangles for 6 lux. Acronyms are the same as in figure 2.*

As one would expect, the match between the configurations for 110 lux is better than for 6 lux. Practically, a change of illumination from 2100 to 110 lux does not affect the pattern of results. As to the dimmest light, while there is a good match between all the three configurations for the combined (ALL) and some individual (RT and PJ) data, there are some differences for observers PL, HJ, and IK. Still, we believe that it is safe to assume that, in general, a change in illumination preserves the shape of the output configuration.

As each plate of each graph in figures 2-5 has independent axes (in arbitrary units) one cannot judge how the output configurations obtained for different lights are scaled to each other. We have evaluated the median ranks (across papers and repeats) for each observer and the whole group (Table 2). The medians significantly differing from 100 ($p < 0.05$) are marked with asterisk. As one can see, both the median ranks for the whole group (ALL) significantly less than 100. It means that on average the dissimilarities between the Munsell papers under dimmer lights were less than under the brightest light. In other words we observe shrinking of the colour "circle" similar to that obtained for the achromatic colours [1]. Note that reducing light from 2100 to 110 lux results in only 2.5% shrinking

Table1: Procrustes statistics

Illumination	RT	PL	PJ	HJ	IK	ALL
6 lux	0.0037	0.1606	0.032	0.1158	0.0888	0.032
110 lux	0.0043	0.0249	0.0021	0.0059	0.0103	0.0037

Table2: Median ranks

Illumination	RT	PL	PJ	HJ	IK	ALL
6 lux	73*	52*	48*	40*	98	69*
110 lux	97.2	98	95.2*	85*	101.6	97.5*

whereas decreasing light from 110 to 6 lux causes 28.5% shrinking. This is in line with the previous study of the yellow-blue continuum [2].

There are important individual differences. Observer IK showed no significant effect of illumination on colour dissimilarity judgments. Observers PJ and HJ showed significant shrinking for both illuminations, and two (RT and PL) only for the dimmest illumination. It should be mentioned though, that there is no information concerning inter-individual differences in the previous studies of the effect of illumination on colour dissimilarity [1, 2] so we cannot put our finding in the broader context.

We conclude that in an agreement with [1] we found that the dissimilarities between Munsell papers became smaller on average when the light intensity decreased. Moreover, we found that the shape of the output configuration had a tendency to change when the illumination decreased. There were some individual differences which were to be further investigated.

References

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Authors' Biographies

Rumi Tokunaga received her PhD in Engineering from the Ritsumeikan University in Japan (2004). She had worked at the department of Human and Computer Intelligence, the Ritsumeikan University for two years. Since 2006 she has worked at the Glasgow Caledonian University. Her research is devoted to lightness and colour perception in the real environment.

Alexander Logvinenko received his BS in psychology (1972) and in applied mathematics (1979), and his PhD in psychology (1974) from the Moscow State University, Russia. He had worked in the Psychology Department of the Moscow State University (1975-1992), and the Queen's University of Belfast (1993-2004). Now he is a professor of vision sciences at Glasgow Caledonian University. His research interests are in colour vision and psychophysics.