SPEC User Manual

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Contents

1 Introduction

This package enables colour parameters to be calculated directly from files produced by the two major spectrophotometric software packages (SpectraWin and Ocean Optics). The focus is on psychophysical measures of colour, although I have included some previously used physical measures. I believe this will be much faster than current methods, as several thousand files can be processed per hour.

2 SpectraWin and Ocean Optics Software

The package is designed to deal with data files produced by SpectraWin and Ocean Optics software. I have assumed that data files produced by SpectraWin 5.0 and OOIBase32 are representative of files produced by all versions of the two respective spectrophotometric software packages. If this is not the case, e-mail me, and I can amend the programs so that they can deal with different file types.

2.1 SpectraWin Files

In the case of SpectraWin files, the file name should have three components: the experiment name, a four-digit number that corresponds to the n^{th} measurement within that experiment, and the suffix .ttt (e.g. P3224020012.ttt). The data columns should start on the 8^{th} line of the file, the % transmittance should be in the 5^{th} column, and the corresponding wavelength in the 1^{st}. The data should be separated by semi colons.

2.2 Ocean Optics Files

The filename should be comprised of an experiment name followed by a dot and a 5 digit number which corresponds to the $(n+1)^{th}$ measurement within that experiment. The file name ends with the suffix .Master.transmission (e.g. P322402.00011.Master.transmission). The data columns for these files should start on the 15^{th} line, the wavelength being in the 1^{st} column, and % transmission in the 2^{nd}. The data should be tab delimited.

2.3 Spreadsheets

In those cases where the raw files are unavailable, the data can be processed from a comma-separated spreadsheet. It has to be in the following format, with wavelengths in the first column, the experiment name in the first row, and the file number in the second row:

Exp.Name	K983388	K983388	K983388	..	P322402
File No	1	2	3	..	15
300.24	10.56	10.94	11.12	..	6.19
300.60	11.42	12.14	11.35	..	5.84
:	:	:	:		:
758.38	7.58	9.71	2.00	..	6.12

All spreadsheets should be placed in the spreadsheets folder within the data folder.

3 R

All programs are written in **R**, a free S-Plus emulator, which can be downloaded from http://www.r-project.org/. The help.pdf and refman.pdf that come with the package will answer most basic questions concerning the language, and the R-help mailing list is a good way of dealing with more difficult problems. Other than the basic "source file" command, knowledge of **R** is not needed to run these programs. Current versions of R seem to be incompatible with these programs for Macintosh users (problems with defunct functions and end of line recognition) meaning that unless R version 1.6.1 is used there may be some incompatibility with different operating systems. Fortunately, all R versions can be downloaded from the archive folder.

4 The SPEC package

4.1 Data Folder

All databases to be processed must be moved to the Data Folder.

A demonstration database, "ASCII files", is provided as an example. It contains three experiments, corresponding to three blue tits (*P*arus caeruleus) ringed as K983388, N863616, and P322402. 15 measurements are made for each bird (experiment), the first 3 files being cap measurements, 4-6:backs, 7-9:wings, 10-12:chests, 13-15:tails. I have duplicated file P3224020010.ttt and renamed it P3224020009.ttt so that both these files now contain a chest measurement instead of one wing and one chest. This is to illustrate how the program "Calculating discriminability" can find such problem files. All output files are written to the Data Folder.

4.2 Cone Sensitivities

A library of spectral data is provided. These include cone sensitivities, irradiance spectra (Daylight, Blue Sky and Forest Shade. See Graph 1) and ocular

media transmittances all scaled to one at their maximimum. Currently the library contains data taken from the blue tit [5], the chicken [4, 7, 2] and humans [8]. It is possible to use your own spectral data in place of those in the library as long as the first column in the file corresponds to wavelength and remaining columns are normalised spectral data. It is important that the range of wavelengths of all spectra are as broad as the sensitivity of the cones used, and that the files are saved as comma delimited. If data from other species are submitted to me, I can include them in the library.

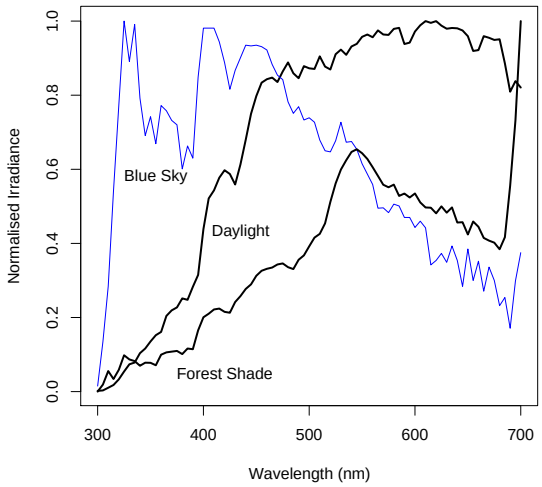

Figure 1: Graph showing the three irradiance spectra included in the library. They can be broadly categorised into Endler's Daylight, Blue Sky, and Forest Shade [3]

4.3 Source Code

The easiest way to learn how the package works is to open R and then go to "Source R code" ("Source file" for Mac users) and source each of the eight programs in turn. For each program follow the prompts that process the demonstration data base "ASCIIfiles".

4.3.1 Physical measures

This program calculates UV chroma and Intensity. UV chroma is calculated by summing the intensity of reflected light for each wavelength between 320nm

and 400nm, and dividing this value by the intensity of reflected light summed for all wavelengths between 400 and 700nm [1].

$$UVChroma = \frac{\int_{\lambda=320}^{400} S(\lambda)d(\lambda)}{\int_{\lambda=400}^{700} S(\lambda)d(\lambda)} \quad (1)$$

where λ = wavelength in nanometers and $S(\lambda)$ = the percent of light reflected from a patch comapred to a white standard.

Intensity is calculated as the intensity of reflected light summed for all wavelengths divided by the number of wavelengths measured.

$$Intensity = \int_{\lambda=320}^{700} S(\lambda)d(\lambda)/(700-320) \quad (2)$$

This gives the intensity as a proportion [1] of the white standard. All relevant files (i.e. ttt or master.transmission) in the selected folder will be processed. This program is only an example of how previously used measures of colours can be calculated quickly, and provides a template for those wishing to write a program that calculates other physical parameters such as λ max and R50.

4.3.2 Quantum cone catches

This program multiplies cone sensitivities by the reflectance spectrum, and if specified, the irradiance spectrum and the transmission spectrum of the ocular media. This is done for every wavelength to which the cones are sensitive, and these values are then summed for each cone type i, to give quantum cone catches [10]. Since irradiance spectra and ocular media transmission spectra are normalised, this integral is divided by the integral of the spectral sensitivity to give the quantum cone catch, Q_i, as a proportion of the maximum quantum cone catch (i.e. when the reflectance spectrum is equal to the white standard, the irradiance spectrum is achromatic, and the ocular media is perfectly transparent).

$$Q_i = \frac{\int_\lambda R_i(\lambda)S(\lambda)I(\lambda)O(\lambda)d(\lambda)}{\int_\lambda R_i(\lambda)} \quad (3)$$

Where $R_i(\lambda)$ = the sensitivity of cone type i, $I(\lambda)$ = the irradiance spectrum, and $O(\lambda)$ = the transmittance spectrum of the ocular media.

From this, it can be seen that cone catches will change with varying illumination, $I(\lambda)$, yet many animals are able to discount variation in illumination

[1] **It should be noted here, that although both SpectraWin and Ocean Optics display the intensity of reflection as a percentage of the white standard, I divide through by 100 to give proportions.**

through colour constancy [6]. To account for this, colour constancy can be modelled using a von Kries algorithm, whereby Q_i is normalised by the quantum cone catch for the irradiance spectrum:

$$q_i = k_i Q_i \tag{4}$$

Where the scaling factor, k_i, is defined as:

$$k_i = 1/\frac{\int_\lambda R_i(\lambda) I(\lambda) O(\lambda) d(\lambda)}{\int_\lambda R_i(\lambda)} \tag{5}$$

Giving the von Kries transformed quantum cone catch, q_i, as:

$$q_i = \frac{\int_\lambda R_i(\lambda) S(\lambda) I(\lambda) O(\lambda) d(\lambda)}{\int_\lambda R_i(\lambda) I(\lambda) O(\lambda) d(\lambda)}$$

(6)

The von Kries quantum cone catch is once again expressed as a proportion of the maximum quantum cone catch. However, this proportion should be consistently higher than Q_i, because the scaling factor, k_i, controls for the fact that the irradiance spectrum is not achromatic, and the ocular media not perfectly transparent. The efficacy of k_i to control for varying illumination is dependent both on the visual system, the reflectance spectrum, and illumination, but in most cases k_i is quite effective. This can be seen by comparing von Kries transformed cone catches with cone catches for which the ocular media and the irradiance spectrum are ignored (See Figure 2).

4.3.3 Normalising cone catches

This removes any achromatic signal from the cone catches and will be unnecessary if you want to use parameters based on the ratio of cone catches (for example UV/SW+MW+LW), or want to use the cone catches for calculating discriminability. It simply divides all cone catches for a particular measurement by the maximum cone catch for that measurement.

4.3.4 Calculating discriminability

I implement a receptor-noise-limited colour opponent model, proposed by Vorobyev and Osorio [10, 11], to calculate the discriminability of two stimuli. The following equations (Equations 7:11) are taken directly from these papers:

The logarithm of q_i is taken to give the signal of receptor i in accordance with Fechner's law:

$$f_i = log(q_i) \tag{7}$$

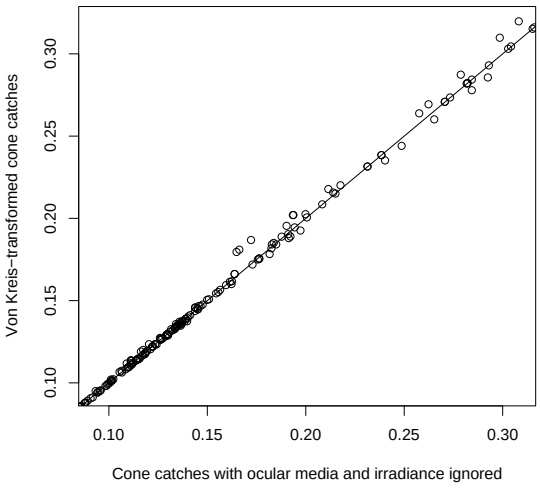

Figure 2: Von Kries transformed cone catches versus cone catches for which the ocular media and illumination is ignored. These data are taken from the "ASCII files" database. The line corresponds to a 1:1 relationship, and it can be seen that there is little dispersion around this line.

And the difference in receptor signals (Δf_i) for two stimuli, a and b, is defined as:

$$\Delta f_i = f_{i,a} - f_{i,b} \tag{8}$$

The following equation models the discriminability (ΔS) of the two stimuli for a dichromat,

$$(\Delta S)^2 = \frac{(\Delta f_1 - \Delta f_2)^2}{e_1^2 + e_2^2} \tag{9}$$

a trichromat,

$$(\Delta S)^2 = \frac{e_1^2(\Delta f_3 - \Delta f_2)^2 + e_2^2(\Delta f_3 - \Delta f_1)^2 + e_3^2(\Delta f_1 - \Delta f_2)^2}{(e_1 e_2)^2 + (e_1 e_3)^2 + (e_2 e_3)^2} \tag{10}$$

and a tetrachromat.

$$\begin{aligned}(\Delta S)^2 = ((e_1 e_2)^2(\Delta f_4 - \Delta f_3)^2 + (e_1 e_3)^2(\Delta f_4 - \Delta f_2)^2 \\ +(e_1 e_4)^2(\Delta f_3 - \Delta f_2)^2 + (e_2 e_4)^2(\Delta f_3 - \Delta f_1)^2 \\ +(e_3 e_4)^2(\Delta f_2 - \Delta f_1)^2 + (e_3 e_2)^2(\Delta f_1 - \Delta f_4)^2))/ \\ ((e_1 e_2 e_3)^2 + (e_1 e_2 e_4)^2 + (e_1 e_3 e_4)^2 + (e_2 e_3 e_4)^2)\end{aligned} \tag{11}$$

Noise in receptor type i, (e_i), can be modelled in various ways and a flexible function is provided to do so. Three sources of noise are recognised, and user defined or default values can be used to parameterise the model:

$$e_i = \sqrt{\frac{(1/(log(T\frac{(Q_{i,a}+Q_{i,b})}{2}))^2 + w_i^2)}{n_i}} \tag{12}$$

Where T is a scaling factor which relates Q_i (which is expressed as a proportion of the maximal cone catch) to an absolute quantum catch value [9], w_i = the Weber fraction for cone type i, and n_i = the relative abundance of cone type i in the retina.

$1/(log(T\frac{(Q_{i,a}+Q_{i,b})}{2}))^2$ models quantum flux dependent noise whereby noise increases as the average absolute quantum catch for the two stimuli decreases. This may be because the colours are dark (i.e. Q_i is small), or the colours are viewed under poor illumination (i.e. T is small). We give two default settings for T (500, and 10,000) that roughly correspond to dim and bright illumination.

The Weber fraction, w_i, describes the inherent noise to signal ratio in receptor cells of type i, independent of the quantum catch. We give a default value of 0.05 for all cone types.

Since the sampling variance associated with cone type i will decrease as the number of cells of type i increases, we divide through by n_i. We use the relative abundance of blue tit cones as the default (VS=0.37, S=0.7, M=0.99, L=1)[5].

Ideally, ΔS, will be in units of "Just Noticeable Differences" (JND's), where a value of less than 1 indicates two colours that cannot be discriminated. However, difficultly with parameterising the receptor noise model means that these units will be an approximation. The default parameters will give values that are a good approximation but care should be taken when making concrete inferences.

Data that has not undergone a von Kries transformation can also be processed, since this has no effect on discriminability. However there may be a slight discrepancy due to rounding errors. This is because Q_i, not q_i, is important for determining quantum flux, and so for von Kries transformed data, q_i is multiplied by the von Kries denominators recorded in the file header.

Currently the model can be implemented in two ways:

All

ΔS is calculated for all pairwise combinations of measurments within a "Cone quantum catches" output file, giving rise to a matrix with dimensions equal to the number of measurements. This is fairly straightforward, but it should

be remembered that as the number of measurements increase, the number of comparisons increase by a power of two. Large numbers of measurements may take a long time to process, and for those people who want to read the output file in Excel, you will have to limit the number of measurements to 254.

Specific

This implementation of the model restricts the calculation of ΔS to specific combinations of measurements. This is done by comparing all measurments, stimului a, to a number of reference measurements, stimului b, and then getting the average ΔS for each measurement. The primary motive for the "Specific" mode is to find miss-measured files in large databases. This is achieved by specifying which experiment names contain no miss-measured files, and then using these as reference measurements. For example, by specifying K983388 as a reference experiment, and stating that 5 patches were measured 3 times, the programwill calculate the average ΔS for the 1^st measurement (a cap) of each experiment, by using K9833880001, K9833880002, and K9833880003 as reference stimuli (all caps). It is therefore important that all files within an experiment correspond to the same patch, and that all patches have the same number of measurements.

It should be noted that the method is not foolproof; some miss-measured colours may have relatively low contrasts and some real measurements high contrasts. This will be the case for highly variable patches, and for databases where only a few standard birds are selected. I used about 15 standard birds from my database of a 1000, and the break between the discriminability of miss-measured colours and genuine patch colours was quite neat. For those that have run the demonstration notice that the discriminability value for P3224020009.ttt is high. This is because the 9th measurement of P322402 is a miss-measured chest and contrasts strongly with the wing measurements of the reference birds.

If you wish to calculate the discriminabilty of the patches against a set background I suggest two methods:

a) Take the same number of measurements of a background as there are measurements from a bird and use the experiment name of this background as a patch standard,

or,

b) paste background cone outputs into a "Quantum cone catch" or "Averaging data for patches" output file, making sure that the background has the same number of rows as other experiment names. Again, use the experiment name of this background as a patch standard.

4.3.5 Viewing contrasts

This allows you to look at successive plots, starting with those files that are most discriminable from the "patch standard". It is therefore only applicable to "calculating discriminability" output files for which specific reference stimuli were used. Using this method, only a small subset of the database should need to be checked for dud files.

4.3.6 Averaging data for patches

This program calculates the average patch value for each bird. It will only work if all birds have their patches measured in an identical sequence and have the same number of measurements for all patches. This program can be applied to data outputted from any of the first four programs, and in turn, programs which process non-averaged data files can be applied to their averaged counterparts.

4.3.7 Creating averaged files

Single measurements are often missing or miss-measured. So that the programs 4 (Specific), 5 and 6 can be implemented correctly, missing files can be created that are an average of other files that pertain to that patch on that bird. For example, the 9^{th} measurement of bird P322402 is actually a chest and needs to be destroyed. It is advantageous to create a file in it's place that is the average of files P3224020008.ttt and P3224020007.ttt. This allows the bird to have a full complement of files with out affecting the mean value for that patch. These files are not written to the database itself but to the database's parent directory. This allows you to look at the file before replacing the original.

4.3.8 Plotting files

This program simply allows you to view any file in graphic form by opening the relevant ttt or Master.transmission file.

5 Acknowledgements

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