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**Gloss as an Aspect of the
Measurement of Appearance**

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ABSTRACT

The perception and measurement of gloss is part of the concept of ‘appearance’ measurement. This paper describes the comparison between data derived by 20 observers who each scaled the perceived gloss of a set of 84 neutral and coloured test samples, and measurements of those samples made using three different instruments. By using two gloss meters, the relationship between the visual scaled data and the measured gloss values could be described by a three-part linear fit or, with a higher correlation, a cubic function. The third instrument was a sphere-based spectrophotometer. The difference in luminance factor, ΔY , was found to give a better linear correlation with the observer-scaled data. The reflection haze of the samples was also measured and compared with the visual gloss data.

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Gloss as an Aspect of the Measurement of Appearance

1. Introduction

Appearance can be described in terms of the ability of an observer to recognise an object and this recognition is possible because of the interaction between light and the material of the object. The four major things that can happen to light when it encounters an object are:

- Specular reflection at the first surface of the object – associated with gloss
- Absorption within the object – largely responsible for colour
- Scattering within the object – associated with diffuse reflection and transmission: translucency, haze
- Transmission through the object – associated with transparency, opacity and clarity.

It has been suggested that the characterisation of these optical properties of materials can be divided into at least four groups, colour, gloss, translucency and surface texture¹. These groups are perhaps not definitive but they represent useful categories for measurement, especially in view of the fact that measurement techniques already exist for some of them.

1.1 Gloss

Gloss is the attribute of a surface that causes it to have a shiny or lustrous, metallic appearance and is generally associated with the specular reflection of light from the surface of the object². The amount of this specular reflection can vary from one surface to another depending on several physical parameters:

- The fraction of light reflected in the specular direction.
- The nature and extent of the light that is spread to either side of the specular direction.
- The change in specular reflection as the specular angle changes.

Hunter was one of the first to be aware of these variations in specular reflection and he designed, in 1934, a gloss meter to compare the capabilities of materials to reflect light at 45° to the surface normal². He studied many different materials and concluded that there were six different visual criteria that could be used to rank, and potentially to measure, their gloss:

- *specular gloss* – the ratio of the light reflected from a surface at a specified angle to that incident on the surface at the same angle on the opposite side of the surface normal;
- *sheen* – the gloss at grazing angles of incidence and viewing;
- *contrast gloss* or *lustre* – the ratio of the specularly reflected light to that diffusely reflected normal to the surface;
- *absence-of-bloom* – a measure of the absence of haze or the ‘milky’ appearance adjacent to the specularly reflected light;
- *distinctness-of-image* – the sharpness of the specularly reflected light;
- *surface uniformity* – a measure of the freedom from surface non-uniformities such as texture.

Thus, a surface can appear very shiny if it has a well-defined specular reflectance at the specular angle. The perception of an image reflected in the surface can be degraded by appearing unsharp, or by appearing to be of low contrast. The former is characterised by the distinctness-of-image and the latter by the haze or contrast gloss (haze is the inverse of absence-of-bloom). An added complexity is due to surface non-uniformity leading to an effect known as orange peel. This effect can be caused, for example, by uneven coating of the acrylic overcoat on an automobile finish leading to a relatively low frequency ‘ripple’.

1.2 Gloss Measurement Standards

Many developments of gloss measurement have been carried out as part of the technical work of the American Society for Testing and Materials (ASTM) commencing in 1925 with the instrument constructed by Pfund³. This used parallel light to illuminate the sample at 20° with a detector placed at 20° on the opposite side of the normal. Hunter and Judd later incorporated this design into an ASTM Standard Method⁴ which designated three angles (20°, 60° and 85°) for measurement, depending on the relative gloss of the surface and measurements are made relative to a highly polished black glass standard.

In order to differentiate the gloss of different samples, it is necessary to select the appropriate measuring geometry. The sample is first measured with 60° geometry. If the gloss value is higher than 70 (high gloss) then it is re-measured at 20°, and if less than 10 (low gloss) re-measured at 85°. These values were loosely defined following some experimental work described by Byk-Gardner⁵ in which 13 black glass tiles were visually ranked from matt to high-gloss and the results compared with measurements at the three angles, Fig. 1. It was found that the largest difference could be detected by using 85° for low gloss samples, 60° for semi-gloss samples and 20° for high gloss samples. This appears to be the background to the recommendation that high gloss, medium gloss and low gloss samples should be measured at 20°, 60° and 85° respectively.

Standardisation in gloss measurement was led by Hunter and ASTM who first produced ASTM D523 *Standard test method for specular gloss* in 1939. This standard incorporated a method for measuring gloss at a specular angle of 60°. Later editions of the Standard (from 1951) included methods for measuring at 20° (high gloss) and 85° (matt, or low, gloss). ASTM has a number of other gloss-related standards designed for application in specific industries⁶⁻¹².

In the paint industry, measurements of the specular gloss are made according to International Standard ISO 2813¹³. This standard is nominally the same as ASTM D523 although differently drafted. BS 3900, Part 5¹⁴ (UK); EN ISO 2813¹⁵ (Europe); DIN 67530¹⁶ (Germany); NFT 30-064¹⁷ (France); AS 1580¹⁸ (Australia); JIS Z8741¹⁹ (Japan) are also equivalent.

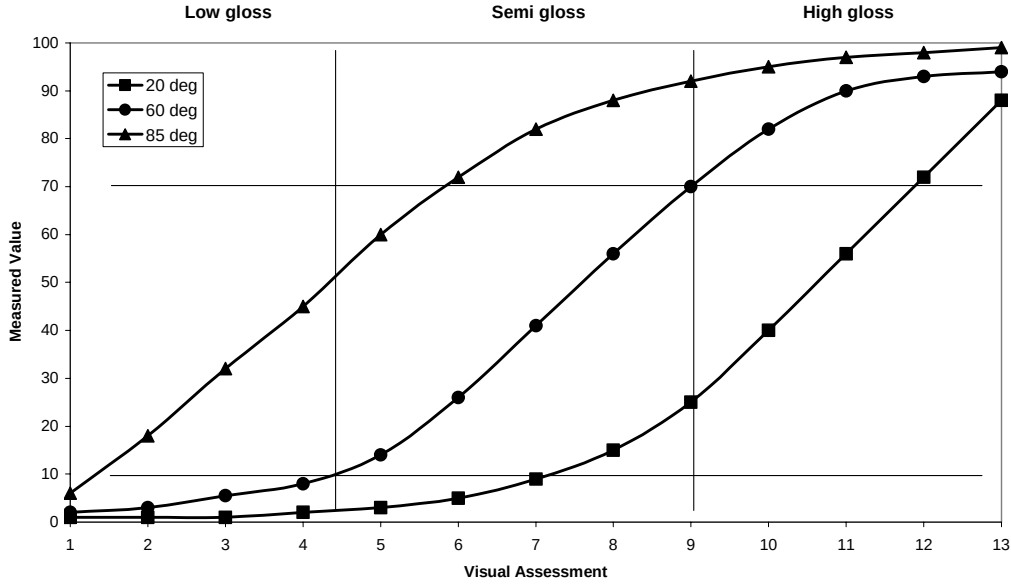


Figure 1. Measurements of a series of samples, at three angles of illumination, as a function of the rank order of a visual assessment of their gloss.

1.3 The Gloss Unit

As described above, the measurement of gloss is based around a physical concept and the gloss unit is defined such that a glass material of refractive index, n , equal to 1.567 is given a value of 100 Gloss Units for any angle of incident light. Using Fresnel's Equations, the reflectance, R , can be calculated as follows:

$$R_s = \left(\frac{\cos \theta - (n^2 - \sin^2 \theta)^{1/2}}{\cos \theta + (n^2 - \sin^2 \theta)^{1/2}} \right)^2 \quad (1)$$

$$R_p = \left(\frac{n^2 \cos \theta - (n^2 - \sin^2 \theta)^{1/2}}{n^2 \cos \theta + (n^2 - \sin^2 \theta)^{1/2}} \right)^2 \quad (2)$$

$$R = \frac{(R_s + R_p)}{2} \quad (3)$$

where R_s is the amplitude of the s-polarised reflected light, polarised perpendicular to the plane of incidence, R_p is the amplitude of the p-polarised reflected light, polarised parallel to the plane of incidence and θ is the angle between the incident light and the normal to the surface of the sample. Figure 2 shows the relative intensity of the reflected light, as a function of the angle of incidence, θ for a sample with a value of refractive index equal to 1.567. When the angle of incidence is zero degrees, the amount of reflected light is 4.8%, equivalent to the minimum reflectance from the surface. Note also that the value of R_p is zero at approximately 57° which is known as the Brewster Angle, the angle at which the reflected ray and the ray refracted into the medium is a right angle.

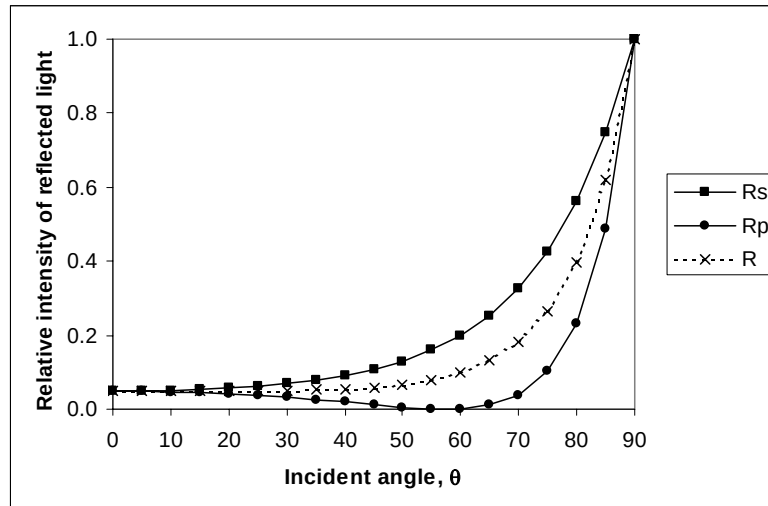


Figure 2. The relative intensity of reflected light as a function of incident angle, for light polarised parallel to and perpendicular to the incident plane.

By substituting n equal to 1.567 the values of the reflectance, R , given in Table I can be obtained. Thus, the values obtained by measuring the reflectance using a gloss meter must be multiplied by the factor shown in Table I to obtain a value of the measurement in Gloss Units.

Table I. The value of reflectance giving 100 Gloss Units and the associated normalising factor.

Angle	Reflectance giving 100 Gloss Units	Normalising factor
20°	4.908	20.376
60°	10.006	9.9944
85°	61.915	1.6151

ASTM D523 states that the reference material shall be a highly polished, plane, black glass with a refractive index of 1.567 for the sodium D line (589 nm)⁴. A typical gloss meter consists of an incandescent light source giving a parallel beam of light incident on the surface to be measured, a means of locating the surface of the sample, and a receptor located to receive the rays reflected by the sample, Fig. 3. The ASTM method states that the illumination should be defined such that the source-detector combination is spectrally corrected to give the CIE luminous efficiency, $V(\lambda)$, with CIE Illuminant C²⁰.

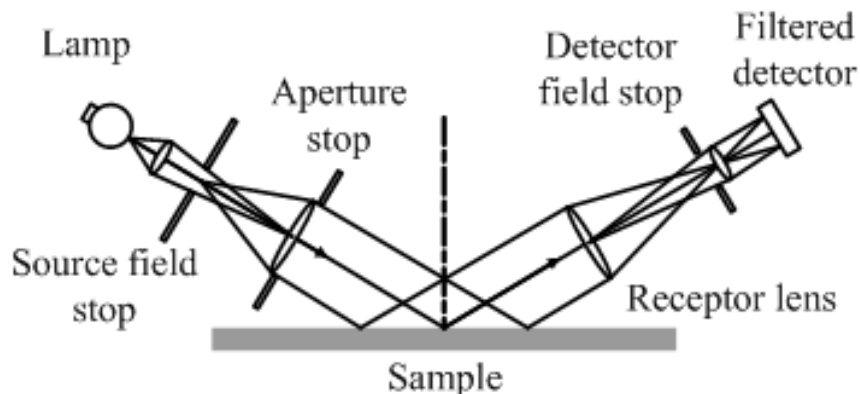


Figure 3. A parallel-beam specular reflection instrument.

A number of instruments are commercially available that conform to the above standards in terms of their measurement geometry and the standards set tolerances for the various angles involved.

2. Experimental Work

2.1 Previous Experiments

The above sections of this paper discuss the establishment of the measurements of gloss and the physical principles on which these measurements are based. Harrison²¹, after extensive studies in which the ability of individual observers to rank a range of surfaces according to their gloss was compared with instrumental measurements, has concluded that the gloss of surfaces is not a simple physical property but a psychological *Gestalt*, that is an appraisal of the physical situation taken as a whole. It was found that observers tend to fall in to one of two categories. In the first, observers judge gloss with reference to the total amount of light reflected from a surface, whilst the others judge gloss according to the sharpness of images seen via the reflecting surface.

A major comprehensive study of visual gloss scaling was that made by Billmeyer and O'Donnell²². Painted panels were prepared with a wide range of gloss and three achromatic colours (white, grey and black) by varying the composition and heat treatment of an automobile acrylic lacquer system. Magnitude scaling was used to estimate the visual dissimilarities between members of all possible pairs of specimens in series of 15-20 samples. The data were analysed using multidimensional scaling techniques. Measurements were also made using a conventional three-angle gloss meter (described below). It was considered conceivable that observers would be able to distinguish at least three types of gloss simultaneously: distinctness-of-image gloss, specular gloss and reflection haze. The results of the multidimensional scaling analysis however, showed that observers could not reliably distinguish more than one dimension. This perhaps suggests that there is an inherent property of a surface, related to its gloss, which was scaled by the observers and which is independent of illumination and viewing angle. Put another way, the concepts of distinctness-of-image gloss, specular gloss and reflection haze are essentially all aspects of the same phenomenon²³. It was also noted that the visual data obtained in this experiment did not always correlate well with associated measurements made using the conventional gloss meter.

Another experiment that should be mentioned is that which describes a model of surface reflectance for use in computer modelling and computer design software in order that the shading of objects on the CRT display matches that of the real world objects which they are trying to mimic. This aspect of a computer-displayed image is important because the perceived shape of an object is heavily influenced by the variation (and uniformity) of the light reflected from its surface. Ferwerda et al.²⁴ generated a number of computer images of white, grey and black spheres using a model of surface reflection²⁵. The model allowed the diffuse reflectance, the energy in the specular component and the spread of the specular component to be varied, thus making it possible to produce a systematic array of spheres. The observers were shown pairs of spheres (378 pairs in total) and asked to judge their difference in terms of apparent gloss. Multidimensional scaling analysis was then applied and two dimensions found to adequately describe the data and these could be related to the apparent contrast of the reflected image (contrast gloss) and the distinctness of the reflected image (distinctness-of-image). A second experiment was conducted to place metrics on these two axes. Observers were asked to use magnitude estimation to scale the perceptual gloss

dimensions, using a sub-set of the spheres from the first experiment. Analysing these data showed that the perceived gloss values enabled the derivation of a model that relates the perceived contrast gloss and distinctness-of-image gloss to parameters of a model used to display correctly shaded images on a computer display²⁶.

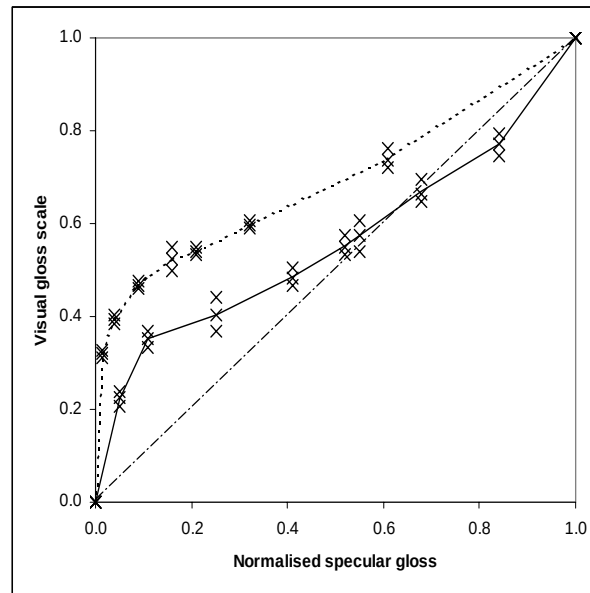


Figure 4. Visual scales measured by one observer as a function of normalised measured using 60° (full line) and 20° (dashed line) geometry.
From Obein, et al.²⁹.

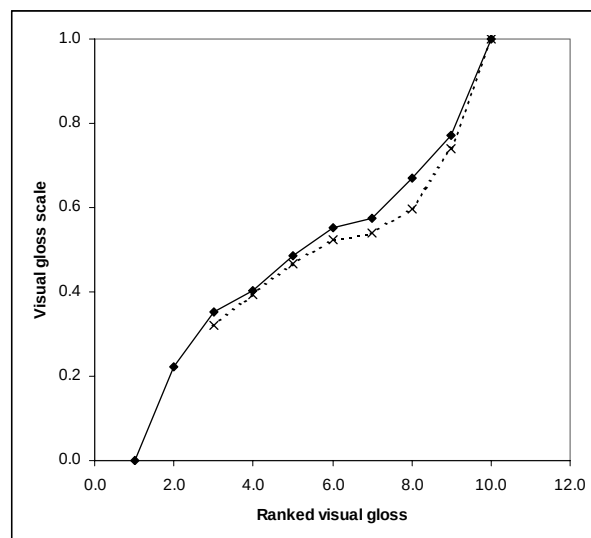


Figure 5. Visual scales measured by one observer as a function of ranked sample number of the series. From Obein, et al.²⁹.

Obein et al.²⁷⁻²⁹ argue that gloss is very much a ‘second-order’ visual attribute in that it results from an interpretation by the brain of first-order signals. This implies that an observer must look at an object from two or three different angles to receive enough information to be able to attribute a value to the gloss of that surface. Their work showed that the scaled visual

gloss of a set of samples, obtained using a pair comparison technique, was not linearly related to the corresponding values obtained from a gloss meter, Fig. 4. For matt samples, the visual scale undergoes compression, and for very high gloss samples, the gain of the visual responses rises steeply. In the intermediate range, the two scales are almost linearly related. They show that this agrees with the work of Ferwada²⁴, and Harrison and Poulter³⁰. This concept also has some similarities with the findings of Billmeyer and O'Donnell²². Analysis of the Obein et al. data also shows that the observers exhibit a form of gloss constancy. When data obtained using two different observing angles (60° and 20°) are plotted versus a unique abscissa, for example the sample number in the series, the two plots superimpose, Fig. 5. This would indicate that, although the flux that is collected by the eye varies according to the angle of view, an observer is able to recover a visual gloss index that is inherent to the surface. Thus, just as an observer can assign a colour to a sample under lights of different spectral power distribution, he can also assign a gloss value to a surface despite the change in geometrical distribution of the light, a finding first discussed by Billmeyer and O'Donnell²².

2.2 New Visual Experiments

2.2.1 The Samples

An experiment was designed in which a number of observers would visually scale the apparent gloss of a series of samples in defined viewing conditions and for this work, a set of suitable samples was required. The Swedish Color Foundation, the producers of the Natural Color System (NCS) kindly donated three neutral gloss scales (white, grey and black) with six gloss levels in each, and eight NCS colours with two gloss levels in each. More NCS coloured samples with different gloss levels were added by hand-spraying duplicate examples of the coloured samples with a matting agent to obtain the different gloss levels. A black pile sample having a measured gloss value of less than one Gloss Unit was also included. In total, 84 samples were available for use; the sub-sets are outlined in Table II.

Table II. The subsets of the set of 84 test samples

Sample group	No. of colours	No. of gloss levels	No. of samples
Neutral	3	6	18
Black pile	1	1	1
Coloured	8(11)	2(1)	27
Hand-sprayed	19	2	38
Total	-	-	84

Note: The number in brackets is the number of samples having only one gloss level.

Some tests, described below, were made to ensure that the spray coating was uniform such that the gloss appearance of the sample was the same over a reasonable amount of the surface of the sample.

The distribution of the samples in a colour sense is shown in Fig. 6(a) in terms of CIELAB a^* , b^* and Fig. 6(b) in terms of CIELAB C^* , L^* . It can be seen that, while 18 of the samples fall close to the neutral point, there is a reasonable distribution of coloured samples, in terms of both chromatic content and lightness.

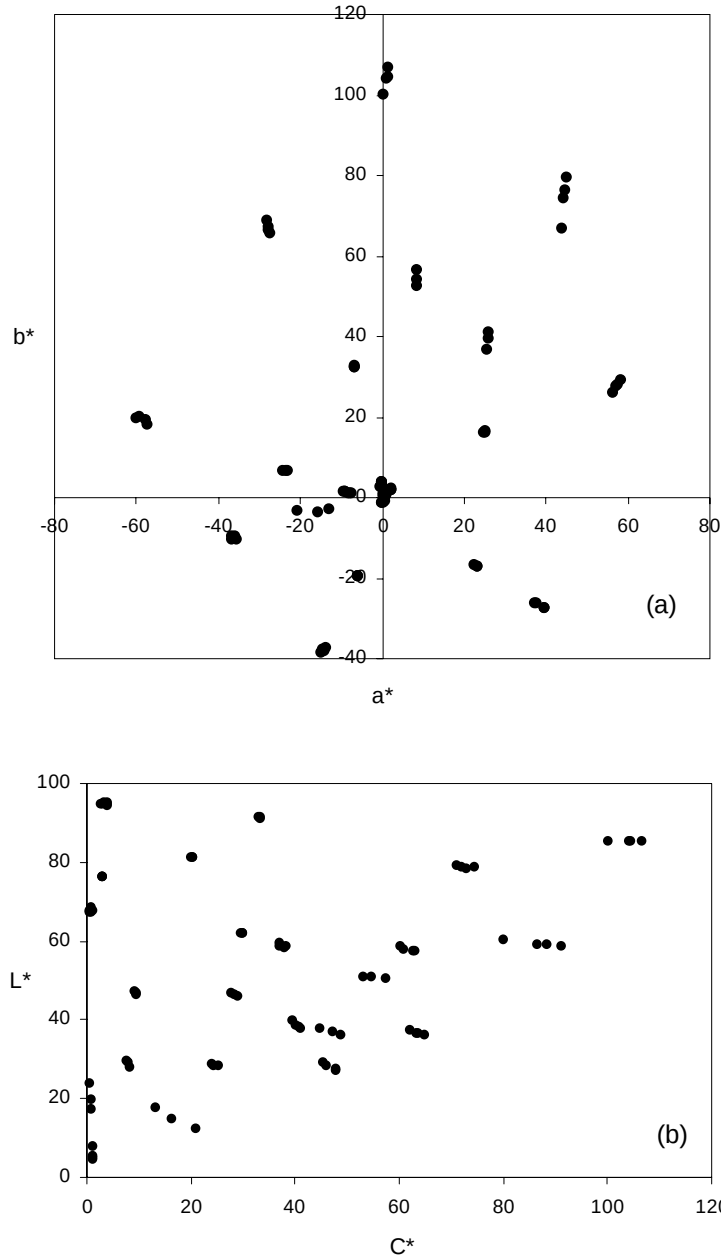


Figure 6. The distribution of the 84 samples in (a) a CIELAB a^*b^* and (b) a CIELAB L^*C^* plane.

2.2.2 The Psychophysical Experiment

The psychophysical experiment was conducted using a Macbeth SpectraLight II® viewing cabinet containing illumination that simulated CIE Standard Illuminant D65 and the samples were assessed against a grey background with a value of CIELAB lightness, L^* , of 70. Observers were given a neutral reference gloss sample that they were told to assign a value of 50 gloss units and asked to scale the gloss of each presented sample on a scale where zero represented no perceived gloss. Each sample was compared side-by-side with the reference sample having an L^* value of 68 and a gloss unit of 43 at the measurement angle of 60° . This scaling method is known as magnitude estimation.

Fourteen observers scaled 84 test samples and seven of these observers repeated their observations to give 20 sets of observer data. Observers were asked to tilt the test and the reference samples to find an angle of viewing that gave the maximum perceived gloss: this represents the viewing method typically used for assessing gloss in industry, Fig. 7. To preserve their integrity, the observers were asked to wear cotton gloves to prevent fingerprints being left on the samples.

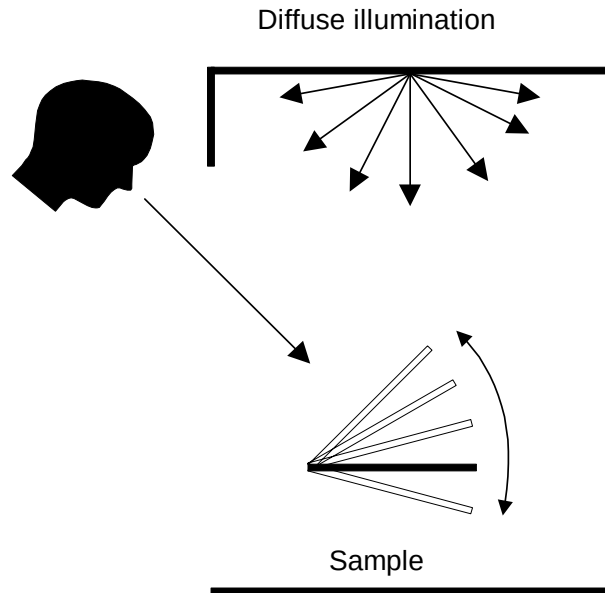


Figure 7. The geometric arrangements for the scaling experiment. The observer views the samples in viewing booth such that the samples can be rotated to alter the angle of view. Diffuse illumination is provided such that no light can directly enter the observer's eyes.

A training session was arranged, prior to the main experiment, in which the samples from a Munsell Gloss Scale³¹, which comprise black samples at five gloss levels, were scaled using the method to be used in the main experiment. These samples were not included in the main set of samples because they duplicated some of the NCS black samples, and the data generated as part of the training exercise were not used in the final analysis.

2.3 The Data Analysis

As mentioned earlier, the data was gathered using the magnitude estimation method. Hence, the data is presented on a ratio scale and the geometric mean was typically used as the measure of the central tendency.

Since the individual data are either logarithmic or power functions of the stimulation, they will each be related to the geometric mean function by a power transform³²⁻³⁵. This automatically establishes a basis for normalising the results of individual observers.

$$\log_{10} \bar{S}_i = a \log_{10} S_i + b \quad (4)$$

$$S'_i = 10^{\frac{\log_{10} \bar{S}_i - b}{a}} \quad (5)$$

where S_i and $\bar{S}_i$ are the individual observer's raw data and the geometric mean calculated from all observers respectively. The coefficients, a , a scale factor corresponding to the gradient of a straight line fitted to the data and b , the corresponding intercept, were obtained for each individual observer using the least-square fitting method between the base-ten logarithm of the S_i data and the base ten logarithm of the geometric mean values, $\bar{S}_i$, Eqn. 5. The values of the coefficients a and b are given in Table III. These results showed that although all the values of the scale factor, a , are close to unity, they still varied by 36%, i.e. from 0.83 to 1.13 in terms of the magnitude of the raw data. For the values of b , all results were close to zero. Thus, the individual observers' scales could be 'corrected' to the mean observer scale using Eqn. 5 above.

Table III. The coefficients scaling factor a and intercept b for each observer.

Observer	Scale Factor	Intercept	Observer	Scale Factor	Intercept
1	0.96	0.02	11	0.96	0.10
2	1.00	0.00	12	1.12	-0.21
3	0.87	0.16	13	0.91	0.15
4	0.96	0.04	14	0.90	0.19
5	0.95	0.05	15	0.98	0.01
6	0.81	0.41	16	1.09	-0.19
7	1.03	-0.02	17	0.88	0.17
8	0.91	0.23	18	0.83	0.29
9	0.84	0.27	19	0.82	0.30
10	0.98	0.00	20	0.85	0.22

Figure 8 shows the geometric mean data, $\bar{S}_i$, plotted against the individual observer scaled data, S'_i . It can be seen that there is a small scattering between the two sets of data. This implies a good agreement between observers.

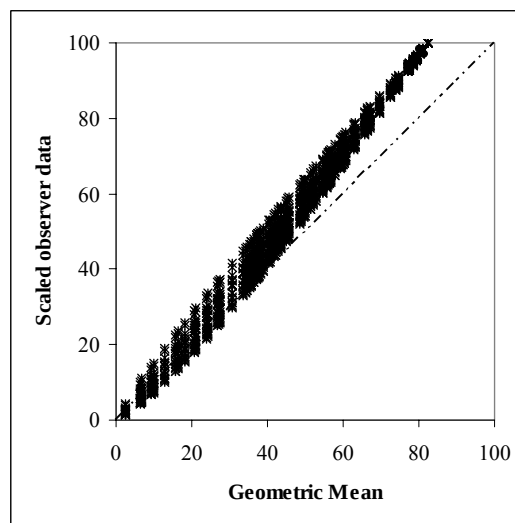


Figure 8. Twenty observers' scaled gloss data plotted against their overall geometric mean.

Two methods were used to aid the comparison between any two data sets. The scatter diagram was employed to visualise their difference and, because in many comparisons the data should be linearly related, the correlation coefficient, r , or, more correctly, the coefficient of determination, r^2 , was used as a measure of the concordance between the two data sets. The coefficient of variation, CV , was also used as a statistical measure to investigate the agreement between any two sets of data, for example, x and y . The coefficient of variation is a measure of the distance in the y direction of the points from the 45° line in the plot of y versus x : it expresses the root-mean-square deviation of the distances of the points from this line as a percentage of the mean value of the data set. This statistic has the advantage of giving results that are independent of the size of the data set. It can be thought of as the relative percentage error and is calculated using the following equation:

$$CV = \frac{100}{\bar{y}} \sqrt{\frac{(x_i - y_i)^2}{n}} \quad (6)$$

where n is the number of samples in the x and y data sets and $\bar{y}$ is the mean value of the y set. A value of CV equal to zero indicates perfect agreement between the two data sets being compared. The coefficient of variation only has a sensible meaning when it is calculated using similar scales for the x and y data.

3. The Results

Seven of the observers repeated the scaling of the 84 samples. The values of the coefficients of determination and the variation associated with the seven sets are given in Table IV.

Table IV. Values of the coefficients of determination, r^2 , and variation, CV , for the seven observers who repeated the scaling of the 84 samples. Data are presented for all 84 samples and for the 18 neutral samples.

All samples (84)								
Observer	1	2	3	4	5	6	7	Mean
r^2	0.9984	0.9974	0.9977	1.0000	0.9990	0.9997	0.9999	0.9989
$CV\%$	4.2	5.4	5.0	0.1	3.3	2.0	1.3	3.1

Neutral samples (18)								
Observer	1	2	3	4	5	6	7	Mean
r^2	0.9989	0.9980	0.9984	1.0000	0.9993	0.9998	0.9999	0.9992
$CV\%$	5.1	6.4	6.2	0.2	4.1	2.3	1.5	3.7

The values of r^2 range from 0.9974 to 1.0000 with a mean value of 0.9989. The average value of CV is 3.7 indicating that, on average, the variation between the first and second set of data is 3.7%. This result reflects the typical observer repeatability on scaling gloss perception. In an experiment to scale the colourfulness of a series of test colours using magnitude estimation method, for example, corresponding values of 19% was obtained³⁵. In this experiment, the geometric mean was also used for colourfulness to represent the panel results because it was an open end scale, i.e. only the zero (neutral) and a reference colourfulness sample assigned a number of 40 used, similar to the current study. The result in this study shows that scaling colourfulness is much less accurate than scaling gloss.

The lower part of Table IV shows a similar analysis made just using the 18 neutral samples from the NCS gloss scale. It can be seen that there is not much difference between scaling all samples and scaling only neutral samples.

Another way of understanding the implications of differences in the scaling data of different observers, obtained using the same samples, is to consider the following four cases involving two observers each scaling a series of 18 samples which progressively increase in gloss:

1. Observer 1 scales the samples using a scale with values from 5 to 90 in steps of 5. Observer 2 scales the same samples giving the same numbers except for one, which is scaled 5 units higher (or lower). The associated values of the coefficients of determination and variation are 1.00 (actually 0.9981) and 2.5% respectively.
2. Observer 1 scales the samples as before. Observer 2 scales the same samples giving numbers which are consistently 5 units higher. The associated values are 1.00 (the correlation is perfect) and 9.5% respectively.
3. Observer 1 scales the samples as before. Observer 2 scales the same samples giving numbers which are alternately 5 units higher and 5 units lower. The associated values of the coefficients are 0.96 and 10.5% respectively.
4. Observer 1 scales the samples as before. Observer 2 scales the same samples giving the numbers which are equally spaced by 4 units, thus $5 \equiv 5$, $17 \equiv 20$, $41 \equiv 50$, $73 \equiv 90$. The associated values of the coefficients are 1.00 (the correlation is perfect) and 25.5% and respectively.

Table V shows the values of the coefficients of determination and variation for each individual data set tested against the geometric mean value of the 20 data sets.

Table V. Values of the coefficients of determination, r^2 , and variation, CV, for the twenty data sets compared with the geometric mean data set, using all of the 84 samples.

Observer	1	2	3	4	5	6	7
r^2	0.9999	1.0000	0.9981	0.9958	0.9998	0.9957	0.9999
CV	1.1	0.3	4.6	6.9	1.4	7.0	1.1
Observer	8	9	10	11	12	13	14
r^2	0.9992	0.9971	1.0000	0.9999	0.9987	0.9992	0.9991
CV	3.1	5.7	0.3	1.2	3.9	3.1	3.2
Observer	15	16	17	18	19	20	Mean
r^2	1.0000	0.9991	0.9984	0.9967	0.996	0.9974	0.9894
CV	0.3	3.1	4.2	6.1	6.7	5.4	3.4

The values of r^2 range from 0.9957 to 1.0000 with a mean value of 0.9894 which is commendably high. The average value of CV is 3.4. The range of the values is from 0.3% to 7.0%. Again, these values are small.

Fig. 9 shows the geometric mean value of gloss for all 84 samples plotted in rank order of gloss values of all 84 gloss samples. The error bars represent $\pm$ the associated value of standard deviation. The values of the standard deviation are also plotted at the bottom of the graph as a function of scaled gloss value. The latter plot shows that, after an initial rise in value of standard deviation, the value remains approximately constant within a defined range until a certain amount of gloss value. The low values of standard deviation are associated with samples with very low gloss and very high gloss while the middle range of scaled gloss value is likely to be consistent.

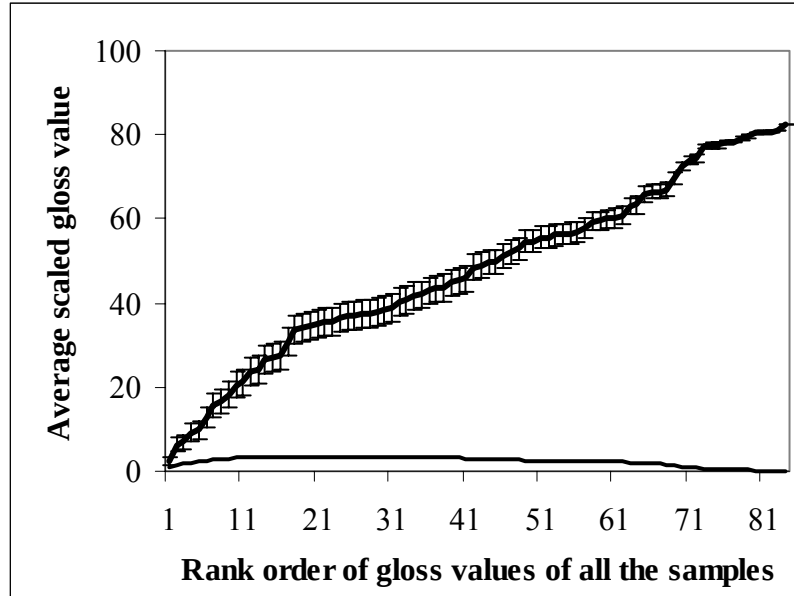


Figure 9. The average scaled gloss value, for all 84 samples, in rank order of gloss values of all the samples. The error bars represent $\pm$ the associated value of standard deviation for each sample. The values of the standard deviation are also plotted at the bottom of the graph as a function of the rank order of gloss value.

Thus, a series of 84 gloss samples have been scaled by 20 observers, a mean value obtained for each sample, with an associated value of standard deviation.

4. Measurements

Each of the 84 samples was measured using three different instruments: two gloss meters and a sphere-based spectrophotometer.

4.1 Gloss Meter

The Sheen Tri-Gloss 160/T gloss meter³⁶ provides three readings of a sample using illumination angles of 20°, 60° and 85°. Its configuration is similar to the generic instrument describe above and illustrated in Fig. 3.

4.2 Appearance Meter

The second instrument was a Panaspect Appearance Meter³⁷ which is a conventional 20°/60° gloss meter that has one unique feature. The usual single detector has been replaced by a 256 element, linear, photo-diode array (LDA) that is designed to measure the gloss value together with the distribution of the light on either side of the gloss peak. The spacing of the pixels of the LDA is such that it measures at the gloss angle $\pm 6^\circ$ in steps of 0.047° ($12^\circ/255$). Each measurement actually provides 255 values and these are available for analysis. The use of an odd number of measurements ensures that a pixel (nominally the 128th) is placed at the centre of the measurement area, i.e. at the true position of the specular reflection. The orientation of the source slit/aperture is set perpendicular to the plane of the incident and reflected beams to comply with ISO 2813, while the LDA is set in the plane of reflection. Thus, in Fig. 3, the single detector is replaced by the LDA. The sensitivity of the LDA is very high and this makes it possible to use a green LED as the source of radiation. A wavelength region of 550 – 570 nm is used to correspond most closely to the required spectral response, i.e. close to the peak of the photopic response function, $V(\lambda)$. Fig. 10 shows typical data from this instrument.

The graph shows the distribution of light reflected from the sample in the range $\pm 6^\circ$ measured from the specular angle. The samples measured are the NCS Gloss Scale samples with nominal gloss values of 90, 70, 40 and 20 respectively: the sample with the highest gloss gives the highest peak.

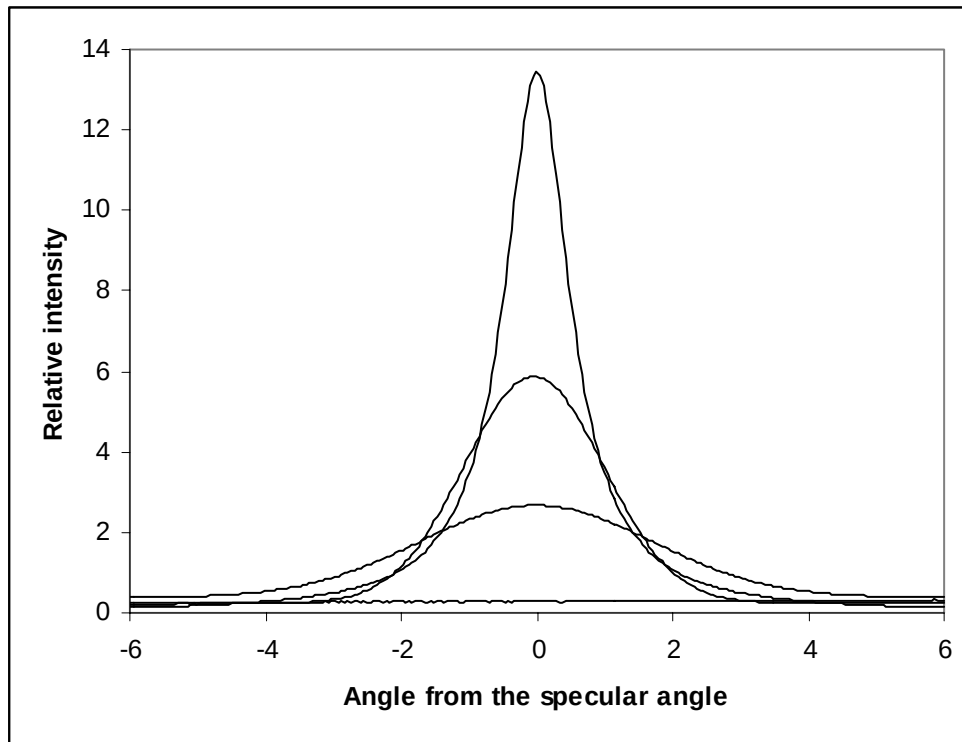


Figure 10. Four samples of the NCS Gloss Scale measured using the Panaspect Appearance Meter. The samples have nominal gloss values of 90 (highest peak), 70, 40 and 20 (lowest peak) respectively.

The standard methods for measuring gloss at 20° require an acceptance angle of $\pm 0.9^\circ$ which is approximately equivalent to summing the values of ± 18 pixels (37 pixels in total) on either side of the specular angle:

$$Gloss = \frac{\sum \text{Pixels between } 20^\circ \pm 0.9^\circ (\text{sample})}{\sum \text{Pixels between } 20^\circ \pm 0.9^\circ (\text{standard})} \quad (7)$$

or:

$$Gloss = \frac{\sum \text{Pixels 110 to 146 (sample)}}{\sum \text{Pixels 110 to 146 (standard)}} \quad (8)$$

For measuring gloss at 60° , the angle of acceptance must be widened to $60^\circ \pm 2.2^\circ$ to conform to the standard. This is equivalent to summing the values of ± 46 pixels (93 pixels in total) on either side of the specular angle:

$$Gloss = \frac{\sum \text{Pixels between } 60^\circ \pm 2.2^\circ (\text{sample})}{\sum \text{Pixels between } 60^\circ \pm 2.2^\circ (\text{standard})} \quad (9)$$

or:

$$Gloss = \frac{\sum \text{Pixels 82 to 174 (sample)}}{\sum \text{Pixels 82 to 174 (standard)}} \quad (10)$$

Various attempts have been made to use a gloss meter fitted with multiple stops to measure haze.³⁸ One configuration that has found acceptance is to focus the light source on to a central stop and collect the haze component of the reflected light by placing apertures set at 2° or 5° off the specular. This arrangement calls for perfect alignment but, with the use of an LDA, this is automatically achieved. The Panaspect instrument uses the procedure described in ASTM E430 and collects the light between 1° and 2° either side of the specular angle. Thus, for a 20° measurement, haze is given by:

$$Haze = 100 * \frac{\sum \text{Pixels from 18.0}^\circ \text{ to } 19.0^\circ (\text{sample}) + \sum \text{Pixels from 21.0}^\circ \text{ to } 22.0^\circ (\text{sample})}{\text{Specular Gloss (Standard)}} \quad (11)$$

or:
$$Haze = 100 * \frac{\sum \text{Pixels 86 to 106 (sample)} + \sum \text{Pixels 150 to 170 (sample)}}{\text{Specular Gloss (Standard)}} \quad (12)$$

For a 60° measurement, the selected pixels correspond to 58° to 59° and 61° to 62° respectively.

4.3 Spectrophotometer

The third instrument that was used to measure the samples was a GretagMacbeth CE7000A sphere-based spectrophotometer. This instrument uses diffuse illumination into the integrating sphere and detects the light reflected by the sample at 8° to a normal to its surface: designated d/8° geometry. An attachment to the sphere has the facility either to include the light reflected by the sample at the specular angle by fitting a plate to the sphere which is coated with a material similar to that used to coat the inside of the sphere, or to exclude this light using a so-called gloss-trap. Two sets of measurements were made, the first without using the gloss trap, specular included (SPIN) configuration and the second with the gloss trap fitted, specular excluded (SPEX) configuration. CIE X, Y, Z tristimulus values were calculated from the spectral reflectance data and the difference, ΔY , calculated between the value of the luminance factor calculated from the data that included the specular component, Y_{in} , and that calculated from the data that excluded the specular component, Y_{ex} . This should provide a measure of the light that is reflected at the specular angle. It is unlikely however, that the geometry of this aperture complies with the specification prescribed for measuring gloss.⁴ Thus, three sets of measurements of the 84 samples were available.

4.4 Sample Uniformity

Some investigatory measurements were made on the uniformity of the samples and their spatial variation in gloss value is summarised in Table VI.

Table VI. Sample uniformity for the 84 samples expressed in terms of

the coefficient of variation.

Sample group	No. of samples	Coefficient of variation %	
		Mean	Maximum
Original samples	45	2.8	8.3
Sprayed samples	38	8.4	15.3
Black-pile sample	1	2.0	~
All samples	84	6.0	15.3

Each sample was measured in five positions using the Sheen Tri-microgloss 160/T gloss meter: top-right, top-left, bottom-right, bottom-left, and centre. The coefficients of variation were calculated between the five measurements and their mean and over the samples in each of the four groups described in Table V. As might be expected, the value of the coefficient of variation is larger for the sprayed samples than for the original (unsprayed) samples because the spraying process, which was carried out by hand, contributed to the non-uniformity. All samples were considered acceptable by visual inspection however, because the variation in uniformity was not visible at the optimum viewing angle for gloss detection. Indeed the larger non-uniformity in appearance terms was that due to the gloss itself rather than the surface variability.

4.5 Sample Stability

Measurements were also made to monitor the sample stability during the running of the experiment. Each of the 84 samples was measured twice prior to any observer making any observations, Set 1-2, and a third time after an interval of one month during which time the observations were made, Set 1-3. Table VII shows the values of the correlation coefficient, and the coefficient of variation, between these three sets of data.

Table VII. Sample stability in terms of the correlation coefficient, r , and the coefficient of variation, CV%, as measured using the Sheen gloss meter.

		20°	60°	85°
Set 1-2	r	1.00	1.00	1.00
	CV%	2.3	0.6	0.3
Set 1-3	r	1.00	1.00	1.00
	CV%	4.8	3.5	5.1

Thus, there was a small amount of variation in the measurements over a short period of time, 0.6% at 60°, with larger variation over the longer time interval during which the experiment was carried out, 3.5% at 60°. It should be noted that the sample stability over time is better than the sample uniformity.

5. Data Analysis

5.1 Comparison between Two Gloss Meters

Measurements of the gloss of 84 samples were made using two gloss meters: the Sheen Trigloss 160/T and the Panaspect Appearance Meter. Fig. 11 shows the values obtained using the 60° geometry, together with a least squares fit line. Similarly, Fig. 12 shows data for the 20° measurement geometry. Values of the coefficient of determination, r^2 , the slope, m , the intercept, c , and the coefficient of determination, CV%, are given in Table VIII below. The statistics are tabulated for three groups: the 18 neutral samples, the 66 coloured samples and the total 84 sample set. It should be noted that, for the measurements made using the 60°

geometry, the slope is not significantly different from unity and the intercept different from zero, both at the 95% confidence level: this is not true of the slope and intercept for the measurements made using 20° geometry indicating wider variation between the data sets together with an offset.

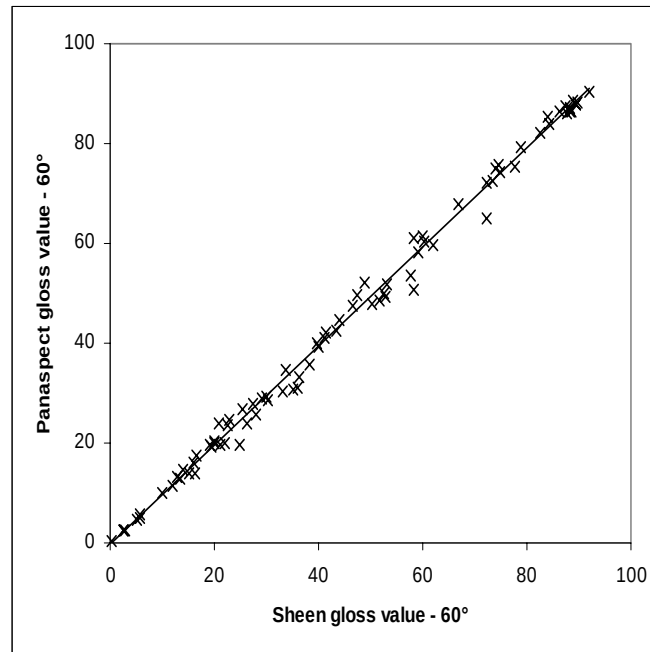


Figure.11. Gloss values for 84 test samples measured with 60° geometry using two gloss meters, together with a least-squares fit line.

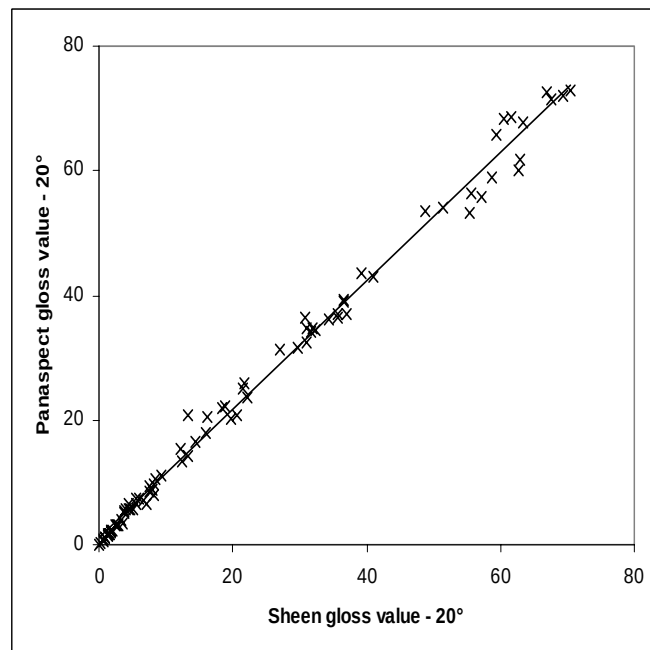


Figure 12. Gloss values for 84 test samples measured with 20° geometry using two gloss meters, together with a least-squares fit line.

Thus, it appears that there is little difference between the values of the measurements obtained using the two different instruments. This suggests that the different light source and different detector used in the Panaspect instrument in no way degrades the measurements

made using that instrument. Indeed, an independent assessment of the instrument showed that it gave measurements directly correlated with those obtained using a reference instrument at the National Physical Laboratory.³⁹ These results also suggest that there is little difference between the measured values of gloss for the coloured samples and the neutral samples.

Table VIII. The statistics of a least-squares line relating the measurements made using two gloss meters, considering all 84 samples, and just the 18 neutral samples.

	r^2	m	c	CV%
18 Neutral samples				
60° geometry	0.9976	0.9789	-0.2656	5.5
20° geometry	0.9978	1.0770	0.2923	13.5
66 Coloured samples				
60° geometry	0.9940	0.9953	-0.4825	4.6
20° geometry	0.9922	1.0201	1.2535	10.3
All samples				
60° geometry	0.9951	0.9910	-0.3750	4.7
20° geometry	0.9932	1.0336	0.9661	10.9

5.2 Comparison between Gloss Values and Differences in Luminance Factor

Fig. 13 shows the difference in luminance factor, ΔY , plotted as a function of the gloss value measured using the Sheen gloss meter. Data for all 84 samples are plotted. It can be seen that the relationship is not linear in that there appears to be a break point in the region of 20-30 gloss units. The line shown plotted on the figure comprises two least squares lines that have calculated to give optimum values of the coefficient of determination, r^2 , resulting in a break point at a gloss value of 21. The values of the associated statistics are shown in Table IX.

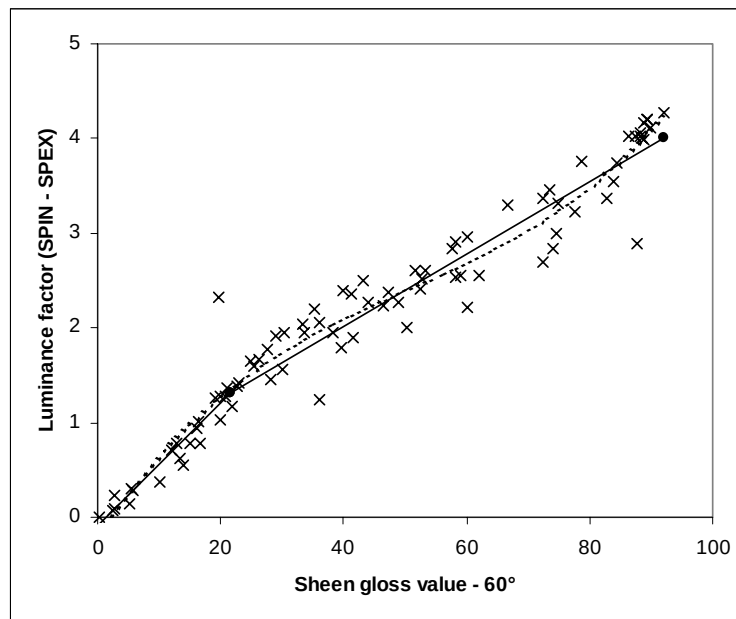


Figure 13. Parameter, ΔY , derived from measurements obtained using a spectrophotometer as a function of measurements using a conventional gloss meter with 60° geometry.

Full line: 3-part, linear, least-squares fit. Dashed line: cubic fit.

Table IX. The statistics of least-squares lines relating the measurements made using a gloss meter and a spectrophotometer, considering all 84 samples, and just the 18 neutral samples.

	<i>n</i>	<i>r</i> ²	<i>m</i>	<i>c</i>
18 Neutral samples				
Gloss < ~ 20	8	0.9765	0.0690	-0.0926
Gloss > ~ 20	10	0.9608	0.0392	0.5573
66 Coloured samples				
Gloss < ~ 20	11	0.5576	0.0803	0.2839
Gloss > ~ 20	55	0.9039	0.0365	0.5816
All samples				
Gloss < ~ 20	19	0.8527	0.0653	-0.0864
Gloss > ~ 20	65	0.8639	0.0382	0.4967

It should be noted that there are only a relatively small number of coloured samples with a gloss value less than ~20. An alternative way of considering the trend shown by the data is to fit a cubic function, also shown in Fig. 13. This yields values of the coefficient of determination of 0.9507, 0.9914 and 0.9290 for all the samples, the neutral and the colours respectively. This point will be addressed in a later section of this paper.

5.3 Comparison between Visually Scaled Data and Measured Gloss Meter Data

Fig. 14 shows the mean of the observers scaled gloss data, for all 84 samples, plotted as a function of the gloss values measured using the Sheen gloss meter. Again, it appears that there is a break point in the data at a gloss value of approximately 20 units, and possibly another at a value of approximately 80 units. These data show the same form as that demonstrated by Obein et al.²⁹ and described above. To facilitate comparison with their results, the data plotted in Fig. 14 were normalised such that the maximum value of each scale was unity, Fig. 15, and least-squares lines fitted to the three separate sections of the data. The values of the coefficient of determination were optimised for the three section sand the resulting lines are also shown in Fig. 15 and their statistics in Table X.

Table X. The statistics of least-squares lines relating the normalised visual data with the measurements made using a gloss meter, considering all 84 samples, and comparison statistics for the data of Obein et al.²⁹.

	<i>n</i>	<i>r</i> ²	<i>m</i>	<i>c</i>
All samples				
Gloss < ~0.20	25	0.8402	1.4210	0.0508
Gloss > ~0.20 < ~0.85	36	0.9051	0.6291	0.2861
Gloss > ~0.85	23	0.7076	1.0131	-0.0156
Obein et al.				
Gloss < ~0.20	3	0.9788	3.1571	0.0229
Gloss > ~0.20 < ~0.85	7	0.9938	0.5842	0.2633
Gloss > ~0.85	2	1.0000	1.4344	-0.4344

It can be seen that, while the overall trends in the two sets of data are similar, the values of the slope and intercept of the fitting lines are different. As before, the data can also be fitted with a cubic function giving a coefficient of determination of 0.9746 with a corresponding value of 0.9751 for the Obein et al.²⁹ data.

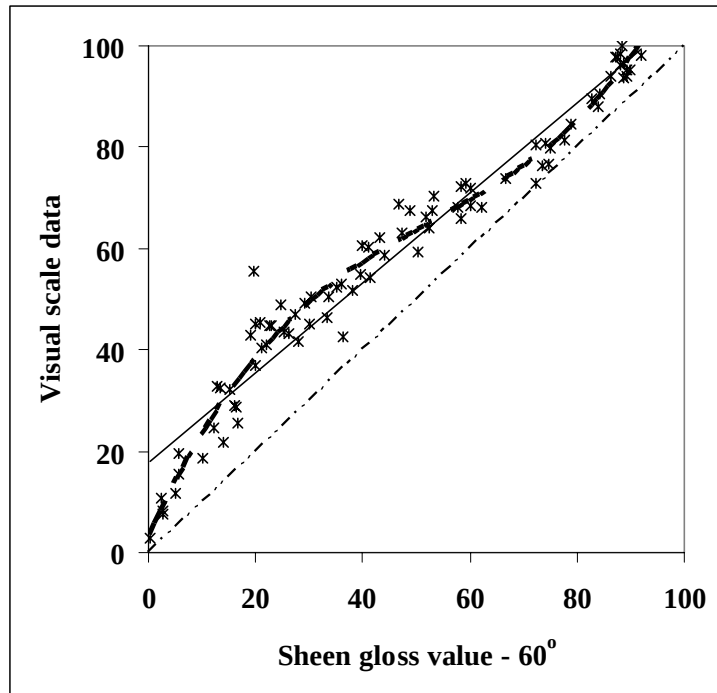


Figure 14. Visual scale data as a function of measurements made using a conventional gloss meter with 60° geometry.
Full line: 3-part, linear, least-squares fit. Dashed line: cubic fit. (Double dashed line is 45° line).

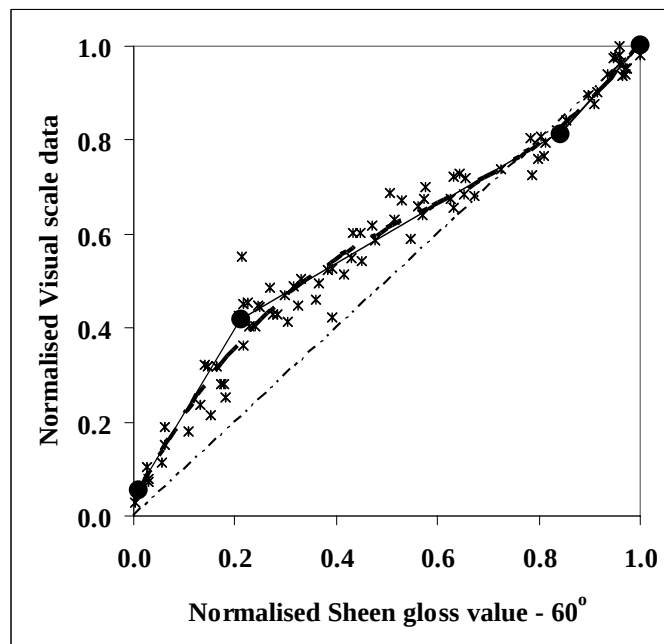


Figure 15. Normalised visual scale data as a function of normalised measurements made using a conventional gloss meter with 60° geometry.
Full line: 3-part, linear, least-squares fit. Dashed line: cubic fit. (Double dashed line is 45° line).

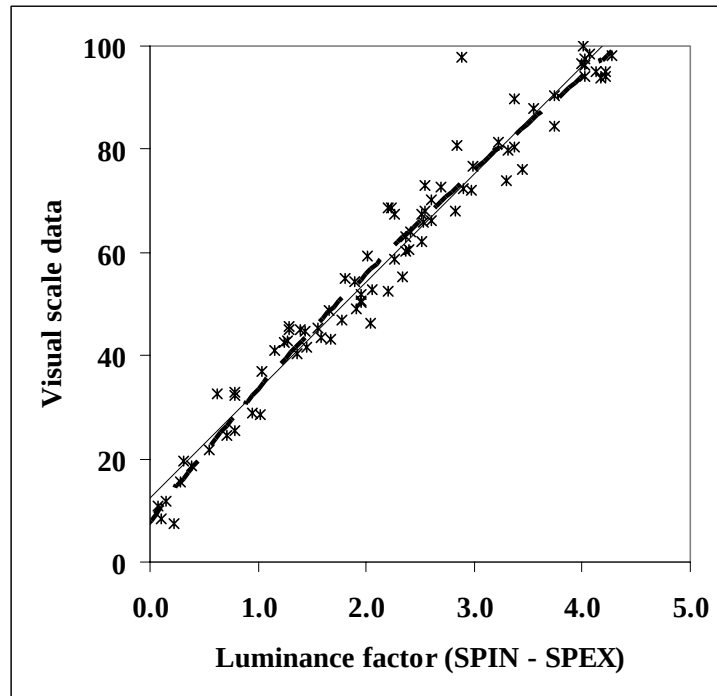


Figure 16. Normalised visual scale data as a function a parameter derived from measurements made using a spectrophotometer.

Full line: 3-part, linear, least-squares fit. Dashed line: cubic fit.

5.4 Comparison between a Visual Scale Data and Differences in Luminance Factor

Fig. 16 shows the visually scaled data plotted as a function of ΔY , the difference in the luminance factor for specular included and specular excluded measurements. As might be implied from the comparisons presented above, there is an approximate linear relationship between these two sets of data. A least square fit line is also shown and the associated statistics are given in Table XI.

Table XI. The statistics of least-squares lines relating the visual data with the measurements made using a spectrophotometer, considering all 84 samples.

	<i>n</i>	<i>r</i> ²	<i>m</i>	<i>c</i>	<i>CV</i> %
Measured/scaled data					
Neutral samples	18	0.9864	20.8503	9.9003	-
Coloured samples	66	0.9459	20.7561	13.4861	-
All samples	7	0.9585	20.9439	12.3455	-
Normalised data					
Neutral samples	18	0.9865	0.8965	0.0948	16.3
Coloured samples	66	0.9459	0.8938	0.1296	17.8
All samples	7	0.9585	0.9013	0.1186	17.6

Also shown in Table XI are the statistics associated with the same data, but after normalisation to give a maximum value of unity for each set. The procedure enables the coefficient of variation to be calculated because the normalisation process brings both of the measures to the same scale. Applying a cubic to the data shown plotted in Fig. 16 improves

the value of the coefficient of determination only marginally to 0.9634 when applied to the total data set of 84 samples, 0.9888 for the neutral samples and 0.9484 for the coloured samples.

5.5 Scaled Visual Gloss as a Function of Measured Reflection Haze

The Panaspect Appearance Meter measures reflection haze by detecting the reflected light that falls on the detector within the angles from 58° to 59° and 61° to 62° on either side of the specular peak at 60° . Fig 17 shows the scaled visual gloss data plotted as a function of the measured reflection haze for the 18 neutral samples. It can be seen that the data define a cusp such that the value of haze increases with value of gloss up to a maximum value when, as the gloss further increases, the haze decreases. The cusp, as drawn, is a 5th order polynomial relating haze and gloss and the same approximately shape fits the white, grey and black samples that comprise the neutral set. When the coloured samples are added, Fig. 18, then it can be seen that some fall on the cusp, some outside of it, especially at low values of gloss and haze, together with median to high gloss and high haze, and many fall within the cusp. Most of the latter are high gloss, coloured samples. In addition, it was also found that sprayed and unsprayed samples are approximately equally likely to fall on the cusp.

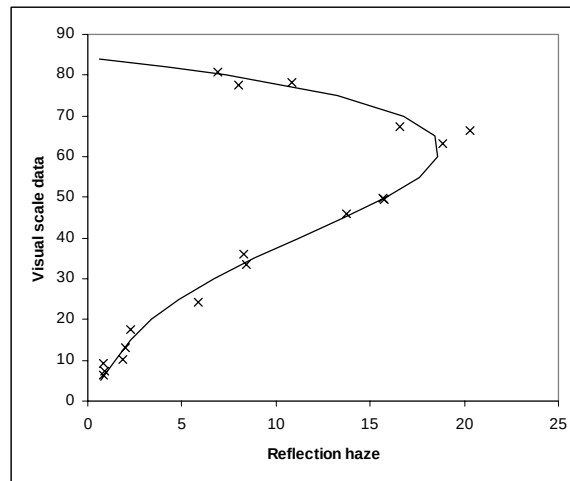


Figure 17. Visual scale data as a function of measured reflection haze for 18 neutral samples, together with a visual fit to the data.

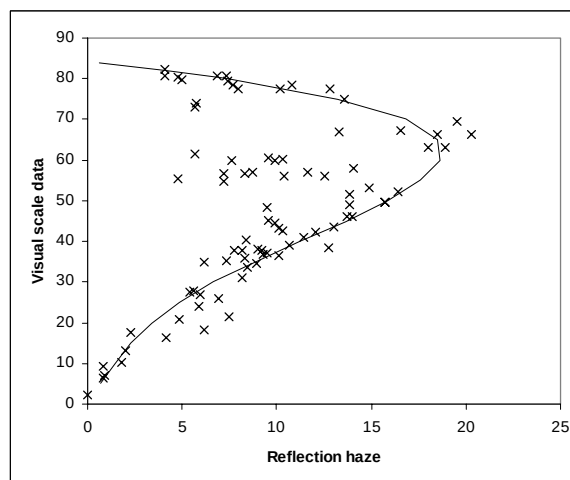


Figure 18. Visual scale data as a function of measured reflection haze for 84 test samples, together with the visual fit shown in Fig. 17.

6. Discussion

From the above comparisons, it can be concluded that the two gloss meters are giving broadly similar results both for measurements at 60° and at 20°. The measure derived from spectrophotometric measurements is not linearly related to the gloss measurements and can be considered to have a break point or, perhaps more likely, to be described a cubic relationship. Similarly, the visual scale data are related to the measured gloss values by a combined linear function or a cubic function. This suggests, and it is subsequently found to be the case, that the visual scale data should be related to the luminance factor difference by a linear function.

While the visual scale data are linearly related to the measured gloss values for samples of moderate to high gloss, values above ~20 gloss units, the gloss of samples with lower measured gloss is perceived by the observers to decrease at a faster rate than the measurements would imply. There is some spread in the data which is described by the statistics presented above; the trends suggested by the least-squares and cubic curve fitting routines that have been applied to the data all have reasonably high values of coefficient of determination and, where relevant, coefficient of determination, to be considered robust.

The finding that the visual scale data are related to measured data via a combination of linear functions, or a cubic function, is not new. Obein et al.²⁹ have demonstrated the former and Billmeyer and O'Donnell²² the latter. Ferwerda et al.²⁴ also describe data that might be better fitted by a combination of linear functions rather than the single linear function they suggest.

The question arises as to why the better correlation is found for a measurement based on an integrating sphere as opposed to an instrument that uses specular illumination and detection. A possible answer may be that the illumination using the integrating sphere is diffuse and, while the instrument measures that light which is reflected at the specular angle, it is only light which is diffusely illuminating the sample. This is likely to be much less than that considered in the measurement made using the conventional gloss meter.

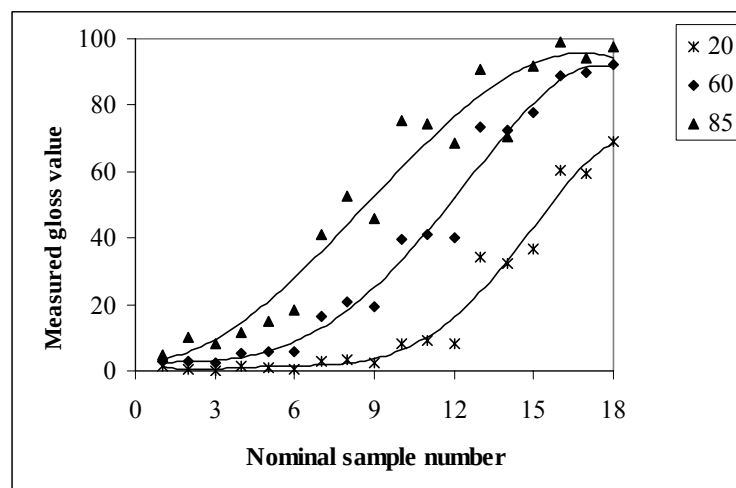


Figure 19. Measurements of a series of samples, at three angles of illumination, as a function of the rank order of a visual assessment of their gloss. Similar to Fig.1 but based on the data described in the paper.

In the opening part of this paper, a rationale was suggested as to why different angles of illumination should be used according to the level of the gloss. Figure 1 shows a set of data that attempt to support the argument that the sample should first be measured with 60° geometry and then at 20° if the gloss value is higher than 70 or at 85° if less than 10. It is of interest to plot the measured gloss data by Sheen gloss meter on 18 neutral samples accumulated in this work as a function of the nominal sample numbers (rank order) which relates to the gloss of the samples, Fig. 19. It can be seen that this graph shows a passing resemblance to Fig. 1; the points are fitted with cubic functions to illustrate the trend of the data. The spacing between the three data sets is, however, less than that implied by Fig. 1 and this suggests that the argument for using different angles for measurements at different levels of gloss is not strongly supported.

7. Conclusions

The following have been demonstrated in this work:

- Measurements of gloss made using a conventional specular illumination gloss meter and 20° and 60° geometries are highly correlated with an instrument using a green LED for illumination and a linear photo-diode array as a detector.
- Measurements made using a spectrophotometer, and the subsequent calculation of the difference between the luminance factor for specular included and specular excluded detection, do not correlate with the conventional gloss meter measurements over the entire range. At relatively low values of gloss (< ~20 units) the rate of change falls at a higher rate.
- Visually scaled gloss data are also not correlated with measured gloss data over the entire range and show a sharper fall of at low values of gloss. A cubic function better fits the data than two linear lines changing gradient at a breakpoint. This results is consistent with that found by other workers.
- Visually scaled gloss data are correlated with the measure derived from measurements made using a spectrophotometer. In this instance, a cubic fit does not give a significantly higher correlation.
- The relationship between visual scaled gloss and measured reflection haze is shown to give results that are bounded by a cusp such that the value of haze increases with value of gloss up to a maximum value when, as the gloss further increases, the haze decreases.
- No appreciable difference was found between the visual data derived using neutral samples and that derived using coloured samples. Equally, some of the samples were constructed by spraying coloured papers to provide a range of gloss values and no appreciable difference was found between the visual data derived using unsprayed samples and sprayed samples.

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