MONITORING COLOUR CHANGE IN TEXTILES ON DISPLAY

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Abstract—The extent of colour change associated with the display, under museum conditions, of Asian textiles over a three-month period was quantitatively monitored using a portable tristimulus colour analyzer. The results for most dyes loosely agree with previous studies based on accelerated aging; however, significant individual exceptions were found, confirming that not only the identity but also the history of the dyed textile is an important determinant of fading.

1 Introduction

Photochemically induced colour change in natural textile dyes has been the subject of numerous studies, usually involving accelerated aging of dyed test fabrics [1–4]. For technical reasons, however, it has not been feasible to monitor the same behaviour in museum conditions over relatively short periods of time, for example, during the span of a typical temporary exhibition.

Textile dyes have been chemically identified, and the fading characteristics of laboratory-dyed test samples established under conditions designed to accelerate their deterioration. However, there are a number of variables known to affect the applicability of those studies to 'real' dyed fabrics. These include botanical origin and growing conditions [5], dye preparation, mordant type and concentration [6, 7], humidity [6], depth of shade [8], air pollutants [9, 10], catalysts [11], spectral output of lights [12], and the extent to which a particular dye has already faded [2]. It would be useful to be able to determine, under normal museum display conditions, the sensitivity to light of specific items without resort to extrapolation from accelerated aging studies or observations based on 'similar' textiles. Museums could then set limits for the display of significant individual items with confidence.

In this study, the feasibility of monitoring colour changes of dyes in an exhibition of Asian textiles over a fourteen-week period, using a portable tristimulus colour analyzer, was investigated. Four ISO blue wool fading standards (ISO R105, standards 1–4) were concurrently exposed in order to provide a comparative fading rate scale [12–15].

The exhibition, entitled 'Tradition, Trade and Transformation'*, ran from mid July to mid November 1990 at the Australian National Gallery, Canberra. It featured a remarkable range of textiles from Southeast Asia and India, incorporating many different textile traditions, dyes and techniques [16]. The fading project was initiated at short notice to take advantage of the exhibition and the recent acquisition of a colour measurement instrument.

2 Experimental

2.1 Textile dyes

For the purposes of this study, dye identities were assigned by conservation and curatorial staff on the basis of their colour, geographic and cultural origin, and period. Consequently there is a degree of uncertainty as to their identity, particularly in relation to the common red-brown colours, for which a variety of natural dyestuffs are available in the Asian region.

Table 1 gives some general information about the natural dyes commonly used in Southeast Asia. Relevant information regarding the individual textiles is summarized in Tables 4 and 5. Most of the textiles are illustrated and/or referred to (by accession number) in Maxwell's publication [16], where details of provenance, methods of manufacture, and dyeing can be found.

2.2 Fading standards

British Standards Institute blue wool fading standards (also ISO R105) 1–4 [17] were mounted on the wall in a typically lit area of the

*The curator was Robyn Maxwell (see [16]) and mounting and conservation were managed by Josephine Carter, both of the Australian National Gallery.

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Table 1 Botanical source, common names, chemical name and colour of natural dyes in this study [5]

Botanical name	*Common name(s)*	*Chemical name*	*Colour*
Indigofera galegoides, suffruticosa, tinctoria *Marsdenia tinctoria*	indigo	indigotin	blue
Lakshadia chinensis	lac	laccaic acid	red
Morinda citrifolia, bracieata, umbellata	menkudu mang kudu kumbu	morindone	red-brown
Peltoferum ferrugineum	soga	tannin	brown
Curcuma longa, zedoaoria	turmeric	curcumin	yellow-orange
Caesalpinia sappan	sappanwood	brasilein	red-brown
Rubia tinctorum	madder	alizarin	red-brown
Mud dyes	—	Fe?, tannin?	brown, black blue-black

exhibition (95 lux). The total exposure time was 945 hours resulting in a cumulative exposure of $89{\cdot}77 \times 10^3$ lux hours.

2.3 *Lighting*

The textiles were lit by unfiltered 200 or 500 watt tungsten-halogen spots to an average level of 95 lux, ranging from 54 to 172 lux. In all cases UV levels were below 60μW/lumen. Visible light levels were recorded at the point of colour measurement using a Gossen 'Mavolux' light meter, and UV levels were measured using a Crawford UV monitor type 760. Total exposure time was 945 hours. Neither of the meters had been recently calibrated; however, comparative colour change would be unaffected by constant calibration errors. It was assumed that the Gossen provided a linear response over the measured lux range.

2.4 *Colour measurement instrument*

The instrument used to measure the colour coordinates of the dyed textiles was a Minolta 'Chroma Meter' CR-200 portable tristimulus colour analyzer. It features an 8mm-diameter measuring area diffusely lit by a pulsed xenon arc lamp, and detection is achieved with silica photocells filtered to match the CIE Standard Observer Response. It can replicate CIE illuminants C or D_{65}, and measurements can be taken or converted to any of the Munsell, L*a*b*, Yxy, or DxDyDz systems [18].

2.5 *Colour measurement procedure*

Replicate measurements of the colour coordinates of selected areas of the textiles and the blue wool fading standards were recorded as L*a*b*, using CIE illuminant C. Colour difference (ΔE) in CIELAB units was calculated according to equation 1 below in conformity with BS 1006:1978 [17].

$$\Delta E_{CIELAB} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{\frac{1}{2}} \qquad (1)$$

where:

ΔL^* = lightness-darkness difference
Δa^* = redness-greenness difference
Δb^* = yellowness-blueness difference

and ΔE is the calculated total colour difference.

Textiles to be measured were selected according to the evenness of colour within the test area, and the ease of relocating the same spot. It was necessary for the recording head of the 'Chroma Meter' to be positioned over exactly the same 8mm-diameter area of sample for each of the replicate readings before and after fading. This was achieved by taking Polaroid photographs of the general area on the fabric and marking the point at which the measurement was made for later reference; the recording head was then precisely positioned according to detailed drawings relating the pattern of the fabric to the orientation of marks on the exterior of the recording head (Figure 1). Fortunately most of the fabrics featured intricate designs, facilitating reproducible positioning. Nevertheless this procedure was responsible for the greatest component of the observed deviations of the replicates.

In order to ensure that each replicate measurement was independent, i.e. each measurement contained both positioning errors and instru-

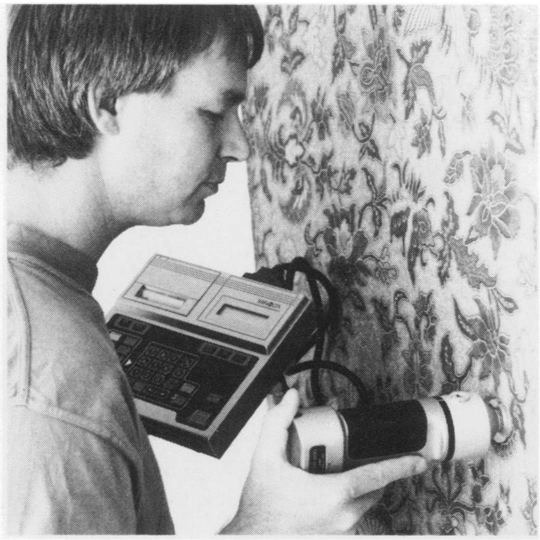

Figure 1 The use of the Minolta Chroma-Meter for the measurement of the colour co-ordinates of dyed textiles on display. The colour head is accurately positioned by relating marks on the circular Perspex template to designs on the textile.

mental errors, the measuring head was removed and repositioned for each measurement, instead of simply recording the colour co-ordinates several times without moving it. This enabled the statistical significance of differences in each of the three co-ordinates before and after fading to be tested.

The textiles were measured *in situ* on gallery walls or inside display cases. The use of a uniform backing for the textiles to be measured, as recommended by Feller [14], was not possible under the circumstances, while time constraints limited measurements to three or four replicates at the start of the exhibition, although the final co-ordinates were based on five readings each. In retrospect it would have been better, for statistical reasons, to base the initial values on more readings.

Calibration was performed every 15 minutes during measurement, using a standard white ceramic plate supplied with the instrument. In order to achieve greatest accuracy for absolute colour co-ordinates, standards approximating the colour of the samples are desirable [18]; however, the value and significance of colour difference was judged to be far more dependent on reproducibility than on the absolute value (chromatic accuracy) of the colours.

2.6 Significance assessment

ΔL^*, Δa^* and Δb^* were tested for significance using a two-sample Student's t test at the 0·05 level.

In Table 3, the Student's t values for ΔL^*, Δa^* and Δb^* are given as t_{L^*}, t_{a^*} and t_{b^*} respectively. This figure is a measure of the probability that a given value has not occurred by chance at the level of confidence selected. In terms of this study there is a 95% probability that any measurement with a value of t greater than 2·45 did not occur by chance (for a total of eight readings before and after measurement).

Calculated values of ΔE were accepted or rejected as being significant or not according to whether the major contributory co-ordinate change or changes (i.e. ΔL^*, Δa^* or Δb^*) were significant. In this way, total colour differences based on large co-ordinate changes which were nevertheless not significant owing to replication problems were filtered out, while values which were not significant due to small co-ordinate changes rather than large errors were retained. All samples with a total colour change less than 0·26 were included in Table 5 (see 3.2).

3 Results

3.1 Reproducibility of the 'Chroma Meter'

The colour co-ordinates of a piece of blue wool fading standard were measured five times over 15 minutes (three minutes between readings). This was repeated at intervals of one week for four weeks in order to measure long-term reproducibility. Care was taken to reposition the measuring head in exactly the same place for each replicate measurement. This was achieved

Table 2 Reproducibility of 'Chroma Meter'

		$\bar{x}$	σ_x		$\bar{x}$	σ_x
Week 1	L*	33·63	0·03	Week 3	33·69	0·02
	a*	24·84	0·05		24·79	0·05
	b*	−54·24	0·03		−54·16	0·04
Week 2	L*	33·72	0·03	Week 4	33·77	0·05
	a*	24·77	0·03		24·78	0·05
	b*	−54·17	0·04		−54·21	0·04

$\bar{x}$ = mean and σ_x = standard deviation

Table 3 Colour change (ΔE), Student's t values, individual co-ordinate changes and light levels for all textiles measured

Textile accession number	*(ΔE)*	t_{L^*}	*ΔL**	t_{a^*}	*Δa**	t_{b^*}	*Δb**	*Lux*
1989.2248(4)	2·23	13·37	+1·02	13·29	+0·31	3·00	+1·95	107
1984.1246	1·76	24·00	+1·51	73·46	+0·16	40·55	+0·90	115
1984.1996(1)	1·61	2·18	−0·58	2·11	−0·61	5·36	+1·38	64
1984.3114	1·48	5·58	+1·33	0·72	+0·17	1·81	+0·63	110
1989.2248(1)	1·40	5·58	+0·44	12·06	−0·77	6·70	+1·08	107
1984.619	1·36	0·92	+0·60	1·49	−0·79	1·17	+1·07	145
1989.407(1)	1·33	0·14	+0·02	3·39	−0·46	3·51	−1·25	120
1984.729(1)	1·10	9·86	+0·88	10·13	+0·39	5·38	−0·51	82
1987.1824	1·10	0·49	+0·11	0·44	+0·12	1·06	−1·08	65
1987.1074(3)	0·99	7·68	+0·70	4·51	−0·28	6·03	−0·65	75
1989.405	0·97	0·02	+0·01	2·65	−0·66	5·30	−0·70	81
1984.3140(4)	0·94	4·03	+0·73	1·45	+0·19	3·37	+0·57	115
1984.573(2)	0·83	2·60	+0·77	0·18	+0·02	1·23	+0·29	60
1989.2248(2)	0·82	2·09	+0·48	2·93	+0·62	4·32	+0·25	107
1984.729(2)	0·75	7·20	−0·74	0·08	−0·02	1·44	−0·13	82
1984.573(1)	0·75	2·35	+0·29	0·06	−0·01	1·49	−0·31	60
1984.1996(2)	0·74	8·20	−0·65	0·46	+0·03	11·37	−0·36	64
1082.1300(2)	0·72	1·37	−0·15	5·91	+0·71	0·27	−0·03	66
1987.347	0·71	0·93	+0·27	1·40	+0·35	0·01	0·00	130
1986.2116(1)	0·71	4·27	+0·53	18·62	+0·30	4·41	+0·37	79
1984.3093	0·67	0·00	+0·60	0·27	+0·10	0·66	+0·25	60
1989.2248(3)	0·65	4·83	−0·31	1·57	+0·06	11·91	+0·57	107
1984.3122(a)	0·63	0·93	+0·41	0·14	+0·03	0·91	+0·48	70
1986.2116(2)	0·62	2·65	+0·12	0·29	+0·05	5·87	+0·61	79
1989.407(3)	0·61	0·17	+0·04	2·47	−0·59	1·38	−0·14	120
1977.112(3)	0·58	4·08	+0·32	2·80	−0·13	4·11	−0·47	180
1989.2248(5)	0·57	1·60	+0·21	6·10	+0·46	3·22	−0·27	107
1989.2248(6)	0·57	5·65	+0·24	17·26	+0·47	5·75	−0·22	107
1984.3101(1)	0·55	7·90	+0·46	0·02	0·00	6·31	−0·30	100
1984.3140(3)	0·54	0·16	+0·07	1·05	+0·34	0·93	+0·41	115
1989.2250	0·51	3·47	+0·09	6·85	+0·47	0·40	+0·19	70
1984.3140(2)	0·47	0·20	+0·05	3·05	+0·12	0·20	−0·08	115
1989.1872(1)	0·37	2·13	+0·05	8·26	+0·36	1·37	+0·06	172
1980.1654	0·37	2·75	+0·22	3·34	+0·28	1·05	+0·12	74
1987.1074(2)	0·35	1·72	+0·35	0·43	+0·01	1·23	−0·04	75
1984.3684(b)	0·34	0·97	−0·24	1·00	+0·02	1·04	−0·24	75
1984.3191	0·33	3·44	+0·30	0·10	+0·03	2·11	−0·14	70
1977.112(1)	0·32	0·08	+0·01	1·87	+0·27	1·58	−0·17	180
1984.3101(2)	0·33	2·63	+0·32	0·02	0·00	1·57	−0·05	100
1984.3122(2)	0·28	0·26	−0·07	1·49	−0·16	1·10	−0·21	70
1987.1074(1)	0·27	0·21	−0·05	1·25	+0·27	0·28	+0·01	75
1989.407(2)	0·24	4·62	−0·22	0·29	+0·07	2·54	+0·08	120
1977.112(2)	0·23	3·77	+0·11	1·84	+0·20	0·58	−0·02	180
1981.1141	0·23	3·94	+0·21	2·44	−0·08	7·42	−0·09	165
1986.1235	0·23	0·46	+0·06	1·26	−0·13	1·32	−0·20	82
1984.3140(1)	0·23	1·94	+0·18	1·95	+0·12	0·91	+0·08	115
1989.1872(2)	0·21	0·08	+0·01	2·16	−0·20	1·13	+0·07	172
1982.1300(1)	0·20	3·34	−0·13	2·85	−0·13	3·45	−0·07	66
1981.1147	0·19	1·65	−0·05	3·01	+0·15	2·34	+0·10	93

Table 3 (continued)

Textile accession number	*(ΔE)*	t_{L*}	*ΔL**	t_{a*}	*Δa**	t_{b*}	*Δb**	*Lux*
1984.609	0·18	7·69	+0·16	0·16	−0·01	6·49	−0·01	130
1988.1593	0·14	3·10	+0·12	0·17	−0·02	1·85	+0·09	70
1983.3684(a)	0·01	0·01	+0·01	0·12	0·00	0·00	0·00	75
Blue wool fading standards (BWFS)								
BWFS1	8·17	14·33	+0·68	51·95	−5·15	67·85	+6·31	95
BWFS2	3·64	3·93	+0·39	17·05	+2·27	32·33	−2·82	95
BWFS3	1·13	4·17	+0·29	8·06	−0·76	10·59	+0·79	95
BWFS4	0·24	0·41	+0·02	6·96	+0·24	0·56	+0·02	95

Table 4 Colour change (ΔE) per Mluxhr, and details of the dyes and textiles for which colour change was judged to be significant

Textile accession number	*ΔE/ Mluxhr*	*Colour**	*Period*	*Fabric*	*Dye*	*Description*
1984.1996(1)	28·02	Br	early 19C	cotton	turmeric	Shouldercloth, Madras, India
1989.2248(4)	23·22	Ye	mid 20C	cotton	synthetic	Manuscript cover, Tai Yuan people, Thailand
1984.1246	17·05	Bl/Bk	early 20C	cotton	ferric mud	Woman's ceremonial skirt, Sumba, Indonesia
1984.573(2)	15·40	Bl	late 19C	cotton	indigo	Wall hanging, Pamingir people, Sumatra, Indonesia
1984.3114	14·98	Br	1920–30	cotton	soga	Skirtcloth, Javanese, Indonesia
1984.729(1)	14·95	Bl	late 19C	cotton	indigo	Woman's skirt, Abung people, Sumatra, Indonesia
1987.1074(3)	14·70	Bl	18C	cotton	indigo	Wall hanging, Coromandel coast, India
1989.2248(1)	14·57	Pu	mid 20C	cotton	synthetic	Manuscript cover, Tai Yuan people, Thailand
1989.405	13·33	Gr	late 19C early 20C	silk	synthetic(?) turmeric/ indigo(?)	Ceremonial skirtcloth, Balinese, Indonesia
1984.1996(2)	12·88	Re	early 19C	cotton	madder	Shouldercloth, Madras, India
1989.407(1)	12·34	Or	early 20C	silk	turmeric (?) (synthetic?)	Ceremonial skirt cloth, Balinese, Indonesia
1982.1300(2)	12·15	Mo	early 20C	wool	synthetic	Woman's skirt, Maloh people, Kalimantan, Indonesia
1984.729(2)	10·18	Br	late 19C	silk	natural brown	Woman's skirt, Abung people, Sumatra, Indonesia
1986.2116(1)	10·01	Ye	mid 20C	rayon	sappan-wood	Woman's skirt, Magindanao people, Mindanao, Philippines
1984.3140(4)	9·10	Br/Or	1940s	cotton	synthetic	Skirtcloth, Perankan Chinese, Java, Indonesia
1986.2116(2)	8·24	Re	mid 20C	rayon	sappan-wood	Woman's skirt, Magindanao people, Mindanao, Philippines
1989.2250	8·12	Pu	early 20C	silk	stick lac	Skirtcloth, Khmer people, Thailand

Table 4 (continued)

Textile accession number	*ΔE/ Mluxhr*	*Colour**	*Period*	*Fabric*	*Dye*	*Description*
1989.2248(2)	7·81	Pu	mid 20C	cotton	synthetic	Manuscript cover, Tai Yuan people, Thailand
1989.2248(3)	6·77	Or	mid 20C	cotton	synthetic	Manuscript cover, Tai Yuan people, Thailand
1984.3101(1)	6·13	Re	late 19C	cotton	morinda	Hanging, Cirebon region, Java, Indonesia
1984.2248(5)	5·93	Bl/Gr	mid 20C	cotton	synthetic	Manuscript cover, Tai Yuan people, Thailand
1984.2248(6)	5·93	Ye	mid 20C	cotton	synthetic	Manuscript cover, Tai Yuan people, Thailand
1989.407(3)	5·66	Br	early 20C	silk	sappan-wood early synthetic (?)	Ceremonial skirtcloth, Balinese, Indonesia
1980.1654	5·56	Or	mid 20C	silk	synthetic	Shawl, Malay people, Sumatra, Indonesia
1984.3191	5·25	Or	mid 20C	cotton	wood dye (sappan?)	Elephant headcloth, Tai Lue people, Laos
1977.112(3)	3·58	Or	early 20C	cotton	synthetic (?)	Wall hanging, Burma
1984.3101(2)	3·56	Br/Or	late 19C	cotton	oiled unbleached	Hanging, Cirebon region, Java, Indonesia
Blue wool fading standards (BWFS)						
BWFS1	95·80					
BWFS2	42·68					
BWFS3	13·25					
BWFS4	2·81					

*Bk = black, Bl = blue, Or = orange, Re = red, Pu = purple, Mo = maroon, Ye = yellow, Br = brown, Gr = green

by marking the cloth with registration points which could be lined up exactly with corresponding marks on the template of the measuring head. The results are presented in Table 2 and discussed in section 4.1.

3.2 Colour change results

Table 3 lists the individual co-ordinate changes, their Student's t values, light levels, and total colour change for all of the textiles in the study.

Table 4 lists those dyed textiles—with their colour, dye identity, textile type and light levels—for which the colour change was significant, based on the criteria in section 2.6.

The average of the standard deviations for the individual co-ordinate measurements, including those which were judged not to be significant, was 0·15. This figure in itself would give a total colour change of ΔE = 0·26 if substituted into equation 1 as co-ordinate differences. On this basis, Table 5 lists the dyes with total colour change less than ΔE = 0·26. These are judged to have undergone negligible change, their low significance having been due to small co-ordinate changes rather than errors of measurement.

In Tables 4 and 5, total colour change (ΔE) has been divided by exposure expressed as Mluxhr, that is, light level (lux) multiplied by exposure time (hours). This corrects the relative ranking of the results for the different light levels.

4 Discussion

4.1 Method

Of the 52 dyed areas tested, 39 were judged either to have faded significantly or to have faded very

Table 5 Colour change (ΔE) per Mluxhr, and details of the dyes and textiles for which colour change was judged to be negligible

Textile accession number	*ΔE/ Mluxhr*	*Colour**	*Period*	*Fabric*	*Dye*	*Description*
1984.1300(1)	3·37	Bk	early 20C	cotton	synthetic	Woman's skirt, Maloh people, Kalimantan, Indonesia
1986.1235	3·12	Or	early 20C	silk	synthetic?	Woman's skirt, Magindanao people, Mindanao, Philippines
1989.1872(1)	2·40	Re	early 20C	cotton	morinda	Hanging, Perankan Chinese, Java, Indonesia
1981.1147	2·28	Or/Re	late 19C	cotton	morinda	Cloth, Toraja people, Sulawesi, Indonesia
1989.407(2)	2·23	Pu	early 20C	silk	synthetic (?)	Ceremonial skirtcloth, Balinese, Indonesia
1984.3140(1)	2·23	Gr	1940s	cotton	synthetic	Skirtcloth, Perankan Chinese, Java, Indonesia
1988.1593	2·23	Mo	mid 20C	silk	synthetic	Woman's skirt, Maranao people, Mindanao, Philippines
1981.1141	1·55	Bl	late 19C	cotton	indigo	Woman's skirt, Ngada people, Flores, Indonesia
1984.609	1·54	Re	19C	silk	lac	Shouldercloth, Malay, Sumatra, Indonesia
1977.112(2)	1·46	Re	early 20C	wool	synthetic	Wall hanging, Burma
1989.1872(2)	1·36	Bl	early 20C	cotton	indigo	Hanging, Perankan Chinese, Java, Indonesia
1983.3684(a)	0·15	Br	early 20C	cotton	mud?	Banner, Toraja, Sulawesi, Indonesia

*Bk = black, Bl = blue, Or = orange, Re = red, Pu = purple, Mo = maroon, Br = brown, Gr = green

little; for the remaining 13, the errors involved in replication were so large as to render them non-significant according to the criteria adopted. Many of these 'unsuccessful' readings were due to a coarse or loose weave or some other irregularity within the test area, and some fabrics lacked a local pattern suitable to reposition the measuring head with sufficient accuracy.

The average standard deviation for the blue wool fading standards exposed during the test was 0·11, compared with 0·16 for all other measurements. No special precautions were taken to relocate the measuring head during the measurement of the exposed standards, it being assumed that they were evenly dyed and faded. The inadequacy of this assumption is indicated by the fact that the mean of the standard deviations in the reproducibility test was only 0·04, representing a best case for measurement. All but one of the standard deviations of the colour co-ordinates in the reproducibility test fell within the 0·07 CIELAB units standard deviation reported by the manufacturers for short-term repeatability on the standard white plate, indicating that the instrument is suitable in principle for measuring evenly dyed areas on textiles of relatively fine surface texture and close weave.

Another instrument in the same range of Minolta colour analyzers, the CR-210, is configured especially for textile colour measurement, having a much larger measuring area ($50mm^2$) to average readings over a wider area which would give a more uniform response. This would certainly improve results where reproducibility was poor due to surface irregularities; however, it would limit the areas which could be measured, by virtue of its larger size.

4.2 *Fading of blue wool standards*

It is apparent that ΔE does not halve for successively higher blue wool fading standards, although this relationship is roughly true for standards 1 and 2. This could be due to several factors, including the choice of ΔE itself as a measure of total colour change [14, 19], the very small changes involved in the study, especially for the higher numbered standards, and the fact that the relationship was designed to be true for daylight exposure, not artificial light [1, 20]. The greatest contribution to ΔE comes from Δa^* (red-green change) and Δb^* (yellow-blue) and not ΔL^* (lightness-darkness change).

The colour changes for the standards are comparable to those recently obtained under accelerated aging conditions by Sinclair and Stirling [12, table 3]. The Sinclair and Stirling results used for this comparison were obtained using a Philips Trucolour 37 fluorescent lamp at 1800 lux for 100 hours for blue wool standards 1–3. The validity of the comparison depends on a linear response of the blue wool standards to different levels and lengths of exposure, and comparable spectral outputs for the different light sources. While these assumptions are almost certainly not strictly correct, it was felt that, in the absence of other comparative data, the comparisons would at least provide an 'order of magnitude' check. The results are summarized in Table 6.

Table 6 Change in total colour (ΔE) per 10^6 lux hours compared with accelerated aging results [3]

Colour change units (ΔE) per Mluxhr (10^6 lux hours) (ΔE/Mluxhr)		
	Present study	*Sinclair & Duff* [3]
1	95·8	72·2
2	42·7	33·3
3	13·3	11·1
4	2·8	—

4.3 Fading results

The two principal aims of measuring colour change in real objects are to enable storage, display and treatment strategies to be formulated for individual items, and to gather data applicable to the classification of dyes in relation to their fastness. On the basis of the fading figures alone, some tentative conclusions can be drawn regarding comparative rates of fading. However, because of the small number of examples of each dye, the heterogeneity of the items in the exhibition in terms of age, origin and technique, and the subjective assignment of dye identity, it would be wrong to place too much weight on specific results.

It should also be recognized that a single measurement of colour change may give a false impression of the long-term rate of change of a dye, which depends on the shape of the fading curve and the position on that curve occupied by a dye at a particular stage of its life [2]. It is also conceivable that colour may initially change rapidly when removed from dark storage into the light, due, for example, to photochemical acceleration of thermally initiated processes in storage, or to the rapid photochemical reaction of thermal reaction products. In this case the colour change observed during a short period of display after dark storage would tend to exaggerate the dangers of long-term display.

Adopting total colour change per Mluxhr as a basis for comparison, all of the dyes below 1989.405 in Tables 4 and 5 fall into Feller's Class B [20], that is, of intermediate photochemical stability. Dyes which have faded more than blue wool fading standard 3, that is, those with values of ΔE/Mluxhr above 13·25, are classified as fugitive, or class C, materials and may be expected to fade considerably over a number of years under museum lighting conditions. Crews [2] observes that 'most natural dyes have poor to moderate light fastness, while synthetic dyes represent the full range of light fastness properties from poor (fugitive) to excellent (stable)'.

In the present study synthetic dyes are found at both ends of the colour change spectrum, which is not surprising as there is a good deal of variation in their fastness [2, 21]. In particular the coloured areas of the second textile listed in Table 4 (1989.2248) were comprised of hand-spun cotton threads, apparently rather poorly dyed with inferior quality synthetic pot-dyes. As a manuscript cover it was not an 'everyday' textile and thus it was unlikely to be subject to washing and exposure to sunlight. The dyes were probably chosen for effect rather than longevity. The most stable synthetic dyes (1988.1593, 1984.3140, 1977.112, 1982.1300) are thought to be commercially dyed with European dyes, the last two being factory-dyed in Europe.

The third most fugitive dye (1984.1246), from a Sumbanese woman's ceremonial skirt, was dyed using a black mud process about which little is known. The colour may be due to iron staining or plant dyes such as tannins or both, since the dye bath contains a mixture of mud and plant material [16]. Once again, being a ceremonial item, colour may have been considered more important than fastness.

Turmeric only appears towards the top of Table 4, and it is interesting that 1984.1996 darkened (negative ΔL^*) rather than faded. Four other dyes which underwent significant colour change also darkened, including an indigo (1984.729), two synthetics (1989.407, 1982.1300) and a morinda (1981.1147). Although the change was not considered significant because of large errors in measurement, a second colour textile 1982.1300, also a synthetic dye, darkened. Padfield and Landi found that iron oxide browns darkened upon exposure [1] and it has been reported that initial darkening of blue wool standards may occur before fading [13], although it was not observed in this study. Initial darkening may be associated with thermal reactions during storage, as mentioned above.

Indigo is surprisingly well represented among the rapid faders, despite its reputation as one of the most light-fast of the natural dyes. One of the two most labile indigo dyes (1987.1074) is pale and already obviously very faded. Pale indigo dyes have previously been reported to fade more rapidly [5]. The other (1984.729) is probably not a commonplace item of wear as it is heavily embroidered with gold thread. A third (1984.573) which faded more than average during the exhibition is a rich dark blue with no obvious reason for fading. The identification of these dyes as indigo, based on their provenance, is considered reliable. There are clearly factors which can adversely affect the usually good stability of indigo [5], and it should not be automatically assumed that it can bear longer light exposure than other natural dyes.

The only dye known definitely to be soga (1984.3114), represented in Tables 4 and 5, is of poor light-fastness, whereas Kajitani [5] classes the tannin dyes on the whole as 'good'.

Morinda, lac and madder all occur at the bottom end of Table 4 or in Table 5, while sappanwood dyes are of intermediate fastness.

These results conform quite well to Padfield and Landi's observations concerning the relative light-fastness of natural dyes [1, Tables 3 and 4], according to which turmeric has very poor light-fastness, morinda (*mengkudu* or *mang kudu*) and lac dyes are both relatively stable, and brazilwood (sappanwood), although more stable than turmeric, is fugitive.

Specific comparison of numerical values from this study (corrected for exposure) with Padfield and Landi's results is difficult because of the different scales adopted. However, none of the dyes appear to have faded as rapidly as BS fastness grade 1 (using the conversion $\Delta E \leq 20$ for grey scale contrast 3 [14]) which might have been expected of turmeric; sappanwood probably faded less than published values for brazilwood; morinda falls into BS fastness grade IV which is in agreement with Padfield and Landi's results; and indigo is consistently more faded than accelerated aging studies would indicate. It is significant that many of the ΔL^* values for the least fast dyes in this study were greater than that of blue wool standard 1 and that a total colour change biased more heavily towards reflectance values would bring the results (apart from indigo) in line with expectations.

In most cases the results agree with Kajitani's summary [5], in which the comparative photochemical stability of Indonesian natural dyes is classed as 'good', 'fair' and 'fades'. The exceptions are lac, which is described as 'fair' according to Kajitani (but 'fast' according to Padfield and Landi), and soga and indigo, which have already been discussed.

5 Conclusions

Application of the Minolta 'Chroma Meter' CR-200 to the short-term monitoring of colour change in a wide range of Asian textiles is feasible, although highly textured and unevenly dyed areas may not be suitable candidates. The most critical part of the measurement process is the precise location and relocation of the colour head, made possible in many textiles by the pattern on the fabric. The portability of the instrument allows measurements to be made *in situ* under reproducible conditions.

It is reassuring that the total colour change of the blue wool fading standards was consistent with results obtained for comparable exposures during accelerated aging studies [12], highlighting the usefulness of the latter for comparative purposes in studies of this kind.

The technique enables the fading of individual textiles to be monitored over typical display periods in the museum environment, which raises several interesting possibilities. 'Complete knowledge of all the dyes, pigments and fibres and a knowledge of their permanence in such conditions' [1] is less essential when colour change can be monitored under conditions which do not seriously damage the object. At the same time, where dye, mordant and textile identification can be carried out, and the age and cultural origins are known, more specific information about the performance and fate of dyed textiles stands to be gained.

Measurement must inevitably lead to the establishment of guidelines for exhibiting individual textiles, based on limits of acceptable colour change projected over the expected lifetime of the object, introducing a much needed quantitative element into the subjective assessment that conservators and curators presently make in relation to display. Questions which must be faced are how to establish what is an acceptable degree of fading in relation to unknown future significance and display requirements, and how the lifetime of a dyed textile is to be established (or even defined)?

While the results of this study are in general agreement with other observations regarding the relative fading of textile dyes, including those based on accelerated aging studies, the general numerical spread of results and the notable individual exceptions, particularly some indigos, necessitate caution in the selection of display and lighting conditions based on the observation of the behaviour of textiles and dyes assumed to be 'similar' under real or accelerated aging conditions.

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Materials and suppliers

Minolta 'Chroma Meter' CR-200: Minolta Camera Company, Japan; Australian agent: Abbey Chemical Agencies, P.O. Box 63, Concord West, NSW 2138.

British Standards Institution Blue Wool Fading Standards (ISO R105): British Standards Institution, 2 Park Street, London W1A 2BS, UK.

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Résumé—L'importance de la variation de couleur dans certains textiles asiatiques exposés pendant trois mois dans les conditions muséales a été mesurée quantitativement par un analyseur de couleur portable à triple stimulation. Les résultats obtenus sur des échantillons ont largement confirmés les études précédentes basées sur le vieillissement artificiel. Cependant on a trouvé des exceptions individuelles significatives qui montrent que non seulement l'identité mais aussi l'histoire de chaque textile teint peuvent agir comme déterminantes du fadissement.

Zusammenfassung—Über drei Monate hinweg wurde mit Hilfe eines tragbaren Farbmeßgerätes Farbveränderungen auf—unter musealen Bedingungen ausgestellten—asiatischen Textilien verfolgt. Die an den einzelnen Farbstoffen gewonnenen Ergebnisse decken sich im wesentlichen mit Erkenntnissen, die in der Vergangenheit an künstlich gealterten textilen Proben gewonnen wurden. In Einzelfällen wurden jedoch signifikante Abweichungen gefunden, die bestätigen, daß nicht nur das textile Material selbst sondern auch die Geschichte des gefärbten Textiles als wichtiger Faktor in den Prozess des Ausbleichens eingehen.