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A CORRELATION STUDY BETWEEN TWO COLOR-MEASURING SPECTROPHOTOMETERS

Robin Russell St. Pere

January 1991

Final Report
February 1990 - September 1990

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13. ABSTRACT (Maximum 200 words)

The US Army recently completed a four phase effort to develop an objective computerized method for evaluating shade acceptability of dyed and printed textiles for the government quality assurance program. Rapidly emerging developments in the field of optics and computers have made older instruments obsolete. This study evaluates the repeatability and correlation between two spectrophotometers manufactured 8 years apart by Applied Color Systems of Princeton, New Jersey. The samples (20 fabric swatches, 22 porcelain tiles and a color difference pair) were measured for short- and long-term repeatability.

Each instrument was found to show a repeatability of 0.12 CIELAB color difference units or less for the two time periods studied. The largest color difference observed between the two instruments for these samples was 0.5 CIELAB color difference units. The color difference pair correlation measurements and repeatability of the instruments data were very good. Measurements in the infrared region (up to 900nm) for the two instruments demonstrated very good repeatability and correlation results.

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PREFACE

This report evaluates the repeatability and correlation between two spectrophotometers manufactured eight years apart. The investigation was conducted from 21 February 1990 to 13 September 1990, funded by program element 728012.12.

The tables, which are fundamental to the information of this report, appear together following the Conclusions because of the comparative brevity of other parts of the text.

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A CORRELATION STUDY BETWEEN TWO COLOR-MEASURING SPECTROPHOTOMETERS

INTRODUCTION

The US Army Natick Research, Development and Engineering Center has introduced an objective, computerized method for evaluating shade acceptability of dyed and printed textiles for use in the Government's quality assurance program. This method utilizes commercially available computer-operated spectrophotometers. Technological advances in both the optics and computer industries have produced a new generation of color measurement instrumentation and computers at a moderate cost. Because of this, the Army initiated a program to develop and validate an objective color measurement system for determining shade acceptability of textiles¹.

The program was executed in four phases. A survey of the commercial market was conducted in Phase 1.² Three spectrophotometers available at the time were purchased and tested. In Phase 2, a fail-safe calibration procedure and a color difference equation based on acceptability were developed under contracts with Clemson and Lehigh universities.^{3,4} A two-unit prototype system (which was later expanded to include three additional satellite units), was purchased from Applied Color Systems, Inc. (ACS) of Princeton, New Jersey, in Phase 3. These units were installed and tested for repeatability and reliability^{5,6}. In Phase 4, three industry sites were chosen and an 18-month trial study conducted. Results indicated that, overall, the instruments performed well individually and as a system.⁷

The purpose of this study was to determine the compatibility of a newer model (purchased in 1989) of the instrument to the original 1981 prototype instrument.

EXPERIMENTAL PROCEDURE

A. INSTRUMENTATION

The two instruments used in this study were the ACS Spectro-Sensor (1981) and the ACS Spectro-Sensor II, UV Enhanced (1989). Both instruments are computer-operated, high-speed, high-resolution, single-beam, scanning spectrophotometers, capable of measuring samples from 400 to 1100 nanometers for either spectral reflectance or transmission values. The two

instruments are identical in design, but the newer instrument has the added capability of detecting fluorescence in a sample by means of an ultraviolet-enhanced light source.

B. SAMPLES

A set of samples was measured on the ACS Spectro-Sensor (1981) and then again measured on the ACS Spectro-Sensor II, UV Enhanced (1989). The samples were:

1. Four 4" x 4" British Ceramic Research Associations Colour Standard Series II enamel tiles (Mid Grey, Deep Pink, Bright Yellow and Cyan);
2. Eighteen 4" X 4" porcelain enamel tiles consisting of six standards (two tan, two green and two blue) with a full and thin limit sample for each standard;
3. Twenty 4" X 10" Nycotex twill fabric swatches, 10 tan and 10 green;
4. A pair of tan polyester gelcoat plaques

C. MEASUREMENT PROCEDURES

The tiles and fabric samples were measured for long- and short-term results. The short-term test consisted of measuring both the tiles and fabric swatches once a day for 10 days. The long-term test measured the tiles once a week for 10 weeks, and twice a week for 5 weeks for the fabric swatches. The tan color difference pair was measured on 10 separate days over a three-week period.

The fabric samples were marked with four circles across their length. Arrows were drawn to indicate the fill direction, so twill lines were oriented parallel with the horizontal plane when presented to the sample port to minimize the influence of surface texture on the data. The samples were backed with two layers of the same shade and fabric during the measurement, and the four readings were averaged. The tiles were marked on the back with a circle to ensure that the same area would be measured each time. A total of three measurements were taken without moving the tile and the data averaged. The tan color difference pair was marked on one side with a circle, measured three times and the resulting data averaged. A grey tile was used to back these samples because they were slightly translucent.⁵

A simulated daylight (D65) source was used to illuminate both the tiles and fabric swatches polychromatically, and measurements were taken using the large area view (LAV) mode. The 10^o 1964 CIE Supplementary Standard Observer and CIE Standard Illuminant D65 were used for all tristimulus value calculations. The CIE 1976 L*a*b* (CIELAB) color space was used for all color difference calculations. The two-sample Student t test was used to determine the significance of the difference between two means.⁸

RESULTS AND DISCUSSION

A. SHORT-TERM COMPARISON OF THE TWO INSTRUMENTS

Tables 1a, 1b, and 1c contain the mean and standard deviation of tristimulus values (X,Y,Z), the mean color difference from the mean (MCDM) of a set of samples and the ΔE results for the tiles and fabric samples. The tristimulus values on the ACS I are slightly higher than those on the ACS II, for both the tiles and fabric samples. The MCDMs are about the same between the two instruments, except for one instance on the SG509 Standard tile where the MCDM value on the ACS I is considerably higher. The largest ΔE (CIELAB color difference between the two means) observed was 0.5 CIELAB units. The two-sample t test showed only four instances, indicated by asterisks, when the tiles did not obtain a 95% confidence level. Overall, the two instruments demonstrated a 95% confidence between each other.

B. LONG-TERM COMPARISON OF THE TWO INSTRUMENTS

Tables 2a, 2b, and 2c contain the long-term results for the two instruments. The tristimulus values were slightly higher for the majority of both the tiles and fabric samples on ACS I. Overall the MCDM and ΔE values were slightly smaller than those reported in the short-term study. The MCDM values between the two instruments are very close to one another. The majority of color differences between the two sets range from 0.03 to 0.27 CIELAB units, with the exception of one tile exhibiting a ΔE of 0.45 CIELAB unit between instruments. The two-sample Student t test results showed only two instances where a confidence of 95% was not met and this is shown on the BCRA tile (Deep Pink), and the AG44 thin tile. Both the Green and Tan fabrics demonstrated no statistically significant differences between their means.

C. SHORT-TERM VS. LONG-TERM MEASUREMENTS ON EACH INSTRUMENT

Tables 3a - 4c show that the two instruments are in agreement with one another during both short- and long-term studies. The tristimulus values for the short- and long-term studies on each instrument exhibited almost identical values. The color differences between the sets range between 0.01 and 0.14 CIELAB units. The ΔE values were slightly higher on the ACS I. The two-sample Student t test showed no significant differences between the two instruments.

D. COLOR-DIFFERENCE PAIR MEASUREMENTS ON EACH INSTRUMENT

Table 5 shows the results for each instrument on a pair of tan polyester gelcoat plaques. The tan pair data illustrate the precision of the instruments in measuring color differences. Both instruments exhibit excellent correlation measurements and repeatability.

E. MEASUREMENTS IN THE NEAR-INFRARED REGION

Tables 6a - 9b contain data for the near-infrared wavelength region. Since the Army has near-infrared reflectance requirements for some fabrics, this wavelength region was examined. Integrated values in the infrared region on the green and tan fabric samples were obtained. This integration, which is similar to the calculations for Y and L* in the visible region, is based on the sensitivity of the starlight scope, a nighttime surveillance device.⁹ The values Ns and Ls, which are the nighttime equivalents to Y and L*, respectively, are calculated for two different illuminants: illumination representing a moonlit and a moonless sky. When determining Ns, the spectral response of the night vision device replaces the observer, and the spectral power distribution of a moonlit or moonless sky replaces the standard illuminant in the Y calculation. Values of Ns are converted to the lightness analog, Ls, to more closely relate these values to the lightness level seen through an image intensifier, in the same manner that Y is converted to L*.

Tables 6a - 7b contain the long- and short-term data between the two instruments. The long- and short-term two-sample Student t test results on the green fabric were excellent. There were only two instances where the measurements from the two instruments did not meet a 95% confidence limit.

However, the tan fabric samples for both the long- and short-term studies exhibited 14 instances where a confidence limit of 95% was not obtained.

Tables 8a-9b contain the intrainstrument repeatability data for the long- and short-term studies. The two-sample Student t test results on both the green and tan fabrics were excellent. There were no instances where a 95% confidence level was not reached.

CONCLUSIONS

A summary of the color differences and MCDM averages for all sample sets appear in Tables 10a - 10d. The two instruments show excellent repeatability agreements for the color differences and MCDM averages, both interinstrumentally and as separate units. Overall, there were no significant differences between the two instruments. This resulted in a 95% confidence between the two. Thus, the two instruments and their interchangeable use prove to be more than suitable for the Army's needs.

TABLES

The following pages contain Tables 1 through 10.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-9105 in the series of reports approved for publication.

Table 1a. Comparison of Short-Term Repeatability for the Tile Samples between ACS I and ACS II:
Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	ACS I			ACS II			MCDM	Δ E*
	X	Y	Z	X	Y	Z		
MID GREY	25.51 ±0.01	27.05 ±0.00	28.95 ±0.00	25.50 ±0.01	27.05 ±0.01	28.99 ±0.01	0.03	0.07
DEEP PINK	17.93* 0.03	14.76 0.01	14.43 0.01	18.05 0.03	14.79 0.01	14.38 0.01	0.06	0.50
BRIGHT YELLOW	60.30 0.03	62.87 0.07	11.61 0.03	60.29 0.03	62.81 0.06	11.60 0.02	0.06	0.12
CYAN	18.49 0.01	22.90 0.02	44.15 0.02	18.44 0.01	22.88 0.02	44.23 0.03	0.04	0.21
AG 44 STANDARD	9.51 0.01	10.51 0.00	11.15 0.01	9.44 0.01	10.45 0.01	11.11 0.01	0.05	0.17
AG 44 THIN	9.86* 0.00	10.90 0.01	11.54 0.01	9.79 0.01	10.84 0.01	11.49 0.01	0.04	0.16
AG 44 FULL	9.25 0.01	10.22 0.01	10.83 0.01	9.18 0.01	10.15 0.01	10.78 0.01	0.04	0.15
TAN M-1 STANDARD	26.76 0.01	27.34 0.01	20.34 0.00	26.78 0.02	27.34 0.01	20.36 0.01	0.02	0.09
TAN M-1 THIN	27.01 0.01	27.61 0.01	20.87 0.01	27.03 0.01	27.61 0.02	20.89 0.01	0.03	0.09
TAN M-1 FULL	26.21 0.00	26.80 0.01	20.53 0.00	26.22 0.02	26.80 0.01	20.55 0.01	0.03	0.06

* = The Instruments are not within 95% confidence limits for this sample
 ΔE* = CIELAB Color Difference between the two Means
 MCDM = Mean Color Difference from the Mean

Table 1a. Comparison of Short-Term Repeatability for the Tile Samples between ACS I and ACS II:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z) (cont.)

Sample:	ACS I			ACS II			MCDM	ΔE^*
	X	Y	Z	X	Y	Z		
TAN 325 STANDARD	52.57 +0.02 -0.02	54.43 +0.02 -0.02	47.31 +0.02 -0.02	52.54 +0.03 -0.03	54.39 +0.00 -0.00	47.31 +0.01 -0.01	0.02	0.05
TAN 325 THIN	53.53 0.02	55.44 0.03	47.71 0.01	53.52 0.03	55.42 0.02	47.73 0.01	0.02	0.05
TAN 325 FULL	51.92 0.03	53.77 0.00	46.94 0.01	51.91 0.02	53.74 0.02	46.96 0.02	0.02	0.07
BLUE 151 STANDARD	8.44 0.01	8.89 0.01	13.97 0.01	8.38 0.01	8.82 0.01	13.92 0.01	0.05	0.19
BLUE 151 THIN	8.55* 0.00	9.03 0.01	14.18 0.01	8.47 0.01	8.96 0.01	14.13 0.01	0.04	0.21
BLUE 151 FULL	8.23 0.01	8.66 0.01	13.52 0.02	8.16 0.01	8.59 0.01	13.46 0.01	0.05	0.17
BLUE 150 STANDARD	6.47* 0.00	6.81 0.01	8.13 0.01	6.40 0.01	6.74 0.01	8.05 0.01	0.07	0.17
BLUE 150 THIN	6.68 0.01	7.03 0.01	8.36 0.01	6.62 0.01	6.96 0.01	8.29 0.01	0.03	0.18
BLUE 150 FULL	6.30 0.00	6.63 0.01	7.91 0.01	6.24 0.01	6.56 0.01	7.84 0.01	0.04	0.18

Table 1a. Comparison of Short-Term Repeatability for the Tile Samples Between ACS I and ACS II:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z) (cont.)

Sample:	ACS I			ACS II			ΔE^*		
	X	Y	Z	MCDM	X	Y		Z	MCDM
SG 509 STANDARD	14.34 0.00	15.70 0.03	16.00 0.01	0.11	14.28 0.01	15.64 0.01	15.96 0.01	0.03	0.10
SG 509 THIN	14.74 0.01	16.11 0.01	16.51 0.01	0.03	14.68 0.01	16.06 0.01	16.48 0.01	0.03	0.12
SG 509 FULL	14.09 0.01	15.45 0.01	15.66 0.01	0.03	14.03 0.01	15.40 0.01	15.62 0.01	0.03	0.11

Table 1b. Comparison of Short-Term Repeatability for the Tan Fabric Samples between ACS I and ACS Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	ACS I			ACS II			MCDM	ΔE^*
	X	Y	Z	X	Y	Z		
TAN 511-036	24.78 ±0.03	25.02 ±0.03	18.22 ±0.03	24.76 ±0.03	24.98 ±0.03	18.22 ±0.03	0.04	0.11
TAN 313-319	23.55 0.02	23.83 0.02	17.77 0.02	23.50 0.03	23.77 0.03	17.75 0.03	0.06	0.10
TAN 313-640	23.86 0.03	24.07 0.03	17.84 0.03	23.82 0.03	24.01 0.03	17.82 0.02	0.04	0.12
TAN 511-123	24.42 0.03	24.65 0.04	18.06 0.02	24.38 0.03	24.61 0.03	18.05 0.03	0.04	0.06
TAN 313-312	23.25 0.03	23.52 0.03	17.50 0.03	23.21 0.03	23.46 0.03	17.47 0.03	0.05	0.11
TAN 313-321	24.11 0.04	24.43 0.04	18.25 0.03	24.10 0.04	24.40 0.04	18.25 0.02	0.05	0.10
TAN 313-488	23.32 0.03	23.55 0.03	17.45 0.03	23.28 0.02	23.50 0.03	17.44 0.03	0.04	0.09
TAN 313-332	23.83 0.04	24.06 0.04	17.91 0.03	23.79 0.02	24.02 0.02	17.89 0.02	0.04	0.05
TAN 511-167	25.29 0.04	25.54 0.04	18.65 0.04	25.25 0.03	25.49 0.02	18.63 0.03	0.04	0.07
TAN 519-078	23.95 0.03	24.21 0.03	17.70 0.03	23.92 0.03	24.16 0.03	17.68 0.03	0.04	0.11

Table 1c. Comparison of Short-Term Repeatability for the Green Fabric Samples between ACS I and ACS II Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	ACS I			ACS II			MCDM	ΔE^*
	X	Y	Z	X	Y	Z		
GREEN 925-618	7.10 +0.01	7.64 +0.01	5.64 +0.01	7.07 +0.01	7.60 +0.01	5.64 +0.01	0.06	0.19
GREEN 925-622	7.17 0.01	7.70 0.01	5.71 0.01	7.14 0.01	7.67 0.01	5.71 0.01	0.07	0.13
GREEN 925-617	7.11 0.01	7.63 0.01	5.63 0.01	7.07 0.01	7.60 0.02	5.63 0.01	0.06	0.17
GREEN 925-608	7.58 0.01	8.14 0.01	6.07 0.01	7.54 0.01	8.11 0.01	6.06 0.01	0.05	0.14
GREEN 925-606	7.53 0.02	8.09 0.01	6.01 0.02	7.48 0.01	8.04 0.01	6.00 0.01	0.05	0.17
GREEN 925-614	7.30 0.01	7.84 0.01	5.74 0.01	7.26 0.01	7.80 0.01	5.73 0.01	0.07	0.13
GREEN 925-613	7.38 0.01	7.93 0.01	5.90 0.01	7.34 0.01	7.89 0.01	5.89 0.01	0.06	0.13
GREEN 925-601	7.55 0.02	8.11 0.02	6.03 0.02	7.51 0.02	8.08 0.02	6.03 0.02	0.06	0.17
GREEN 600-0058	6.86 0.01	7.33 0.01	5.39 0.01	6.83 0.02	7.36 0.02	5.39 0.02	0.06	0.13
GREEN 600-057	7.10 0.02	7.57 0.03	5.52 0.03	7.09 0.03	7.56 0.03	5.55 0.03	0.08	0.17

Table 2a. Comparison of Long-Term Repeatability for the Tile Samples between ACS I and ACS II:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	ACS I			ACS II			MCDM	ΔE^*
	X	Y	Z	X	Y	Z		
MID GREY	25.50 + 0.01	27.04 +0.00	28.95 +0.00	25.51 +0.02	27.05 +0.01	29.00 +0.02	0.03	0.06
DEEP PINK	17.95* 0.02	14.76 0.01	14.43 0.01	18.06 0.03	14.79 0.02	14.38 0.01	0.06	0.45
BRIGHT YELLOW	60.31 0.04	62.90 0.07	11.62 0.03	60.29 0.03	62.83 0.08	11.61 0.03	0.07	0.12
CYAN	18.49 0.01	22.92 0.02	44.16 0.01	18.44 0.02	22.89 0.02	44.25 0.03	0.04	0.20
AG 44 STANDARD	9.51 0.01	10.51 0.01	11.16 0.01	9.44 0.01	10.45 0.01	11.11 0.01	0.05	0.16
AG 44 THIN	9.86* 0.00	10.91 0.00	11.54 0.01	9.79 0.01	10.84 0.02	11.49 0.01	0.05	0.14
AG 44 FULL	9.25 0.01	10.22 0.01	10.83 0.01	9.18 0.01	10.15 0.01	10.78 0.01	0.05	0.15
TAN M-1 STANDARD	26.75 0.01	27.33 0.01	20.34 0.01	26.78 0.02	27.34 0.03	20.36 0.02	0.04	0.09
TAN M-1 THIN	27.01 0.02	27.61 0.01	20.87 0.02	27.03 0.02	27.61 0.03	20.89 0.02	0.03	0.09
TAN M-1 FULL	26.20 0.00	26.80 0.00	20.53 0.01	26.22 0.02	26.80 0.02	20.56 0.01	0.03	0.10

Table 2a. Comparison of Long-Term Repeatability for the Tile Samples between ACS I and ACS II:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z) (cont.)

Sample:	ACS I			ACS II			MCDM	ΔE^*
	X	Y	Z	X	Y	Z		
TAN 325 STANDARD	52.56 +0.03	54.42 +0.02	47.30 +0.02	52.54 +0.02	54.39 +0.03	47.30 +0.04	0.04	0.04
TAN 325 THIN	53.52 0.02	55.44 0.00	47.70 0.03	53.51 0.03	55.42 0.04	47.72 0.03	0.02	0.05
TAN 325 FULL	51.92 0.02	53.76 0.03	46.95 0.00	51.92 0.02	53.75 0.03	46.96 0.01	0.02	0.03
BLUE 151 STANDARD	8.45 0.01	8.89 0.01	13.97 0.01	8.38 0.01	8.82 0.01	13.92 0.01	0.05	0.18
BLUE 151 THIN	8.55 0.01	9.04 0.01	14.19 0.02	8.47 0.01	8.96 0.02	14.13 0.01	0.05	0.20
BLUE 151 FULL	8.23 0.01	8.66 0.01	13.51 0.01	8.16 0.01	8.59 0.01	13.45 0.01	0.05	0.17
BLUE 150 STANDARD	6.48 0.01	6.81 0.01	8.13 0.01	6.40 0.01	6.74 0.01	8.06 0.01	0.08	0.22
BLUE 150 THIN	6.69 0.01	7.03 0.01	8.36 0.01	6.62 0.01	6.96 0.01	8.29 0.01	0.03	0.17
BLUE 150 FULL	6.31 0.01	6.63 0.01	7.91 0.02	6.24 0.01	6.56 0.01	7.84 0.01	0.06	0.17

Table 2a. Comparison of Long-Term Repeatability for the Tile Samples between ACS I and ACS II:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z) (cont.)

Sample:	ACS I			ACS II			MCDM	ΔE^*
	X	Y	Z	X	Y	Z		
SG 509 STANDARD	14.34 +0.01	15.69 +0.01	16.00 +0.02	14.28 +0.01	15.65 +0.01	15.97 +0.01	0.04	0.15
SG 509 THIN	14.74 0.01	16.11 0.01	16.51 0.02	14.69 0.02	16.06 0.02	16.48 0.01	0.07	0.08
SG 509 FULL	14.09 0.01	15.46 0.02	15.66 0.01	14.04 0.02	15.41 0.02	15.63 0.01	0.04	0.09

Table 2b. Comparison of Long-Term Repeatability for the Tan Fabric Samples between ACS I and ACS II:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	ACS I			ACS II			ΔE^*		
	X	Y	Z	MCDM	X	Y		Z	MCDM
TAN 511-036	24.79 ±0.04	25.03 ±0.04	18.24 ±0.05	0.05	24.75 ±0.05	24.97 ±0.05	18.21 ±0.04	0.05	0.11
TAN 313-319	23.55 0.03	23.84 0.03	17.78 0.04	0.04	23.49 0.05	23.76 0.05	17.73 0.04	0.06	0.12
TAN 313-640	23.87 0.04	24.08 0.03	17.86 0.04	0.05	23.81 0.04	24.00 0.05	17.81 0.04	0.05	0.12
TAN 511-123	24.43 0.03	24.66 0.05	18.07 0.03	0.09	24.38 0.05	24.60 0.05	18.04 0.03	0.05	0.08
TAN 313-312	23.26 0.03	23.53 0.04	17.51 0.04	0.05	23.20 0.04	23.45 0.04	17.47 0.04	0.05	0.13
TAN 313-321	24.12 0.03	24.44 0.04	18.26 0.03	0.05	24.08 0.06	24.39 0.06	18.23 0.04	0.06	0.07
TAN 313-488	23.33 0.03	23.56 0.03	17.46 0.04	0.04	23.27 0.05	23.49 0.05	17.42 0.04	0.05	0.09
TAN 313-332	23.83 0.03	24.07 0.03	17.92 0.03	0.04	23.78 0.05	24.00 0.04	17.88 0.04	0.05	0.11
TAN 511-167	25.31 0.04	25.56 0.04	18.66 0.04	0.04	25.24 0.04	25.47 0.05	18.62 0.04	0.05	0.13
TAN 519-078	23.97 0.04	24.22 0.04	17.72 0.05	0.05	23.90 0.05	24.14 0.05	17.67 0.04	0.05	0.09

Table 2c. Comparison of Long-Term Repeatability for the Green Fabric Samples between ACS I and ACS II:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	ACS I			ACS II			MCDM	ΔE^*
	X	Y	Z	X	Y	Z		
GREEN 925-618	7.10 ±0.01	7.64 ±0.01	5.65 ±0.01	7.06 ±0.02	7.60 ±0.02	5.64 ±0.01	0.07	0.14
GREEN 925-622	7.17 0.01	7.69 0.01	5.70 0.01	7.13 0.02	7.66 0.02	5.70 0.02	0.07	0.17
GREEN 925-617	7.11 0.01	7.64 0.01	5.63 0.01	7.06 0.02	7.59 0.02	5.62 0.02	0.06	0.18
GREEN 925-608	7.59 0.02	8.15 0.01	6.07 0.02	7.53 0.02	8.10 0.02	6.06 0.02	0.06	0.21
GREEN 925-606	7.53 0.02	8.09 0.02	6.01 0.02	7.47 0.03	8.03 0.03	5.99 0.03	0.07	0.18
GREEN 925-614	7.31 0.02	7.85 0.02	5.75 0.02	7.25 0.03	7.79 0.03	5.72 0.03	0.09	0.16
GREEN 925-613	7.39 0.01	7.93 0.01	5.90 0.02	7.32 0.03	7.88 0.03	5.88 0.03	0.08	0.27
GREEN 925-601	7.55 0.02	8.11 0.02	6.03 0.02	7.50 0.04	8.07 0.04	6.02 0.04	0.09	0.18
GREEN 600-0058	6.86 0.02	7.33 0.01	5.39 0.02	6.81 0.05	7.28 0.05	5.38 0.05	0.09	0.18
GREEN 600-057	7.10 0.03	7.56 0.03	5.52 0.03	7.07 0.04	7.54 0.04	5.53 0.04	0.10	0.17

Table 3a. Comparison of Short- and Long-Term Repeatability for the Tile Samples on the ACS I:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	SHORT			LONG			MCDM	Z	MCDM	ΔE^*
	X	Y	Z	X	Y	Z				
MID GREY	25.51 + 0.01	27.05 + 0.00	28.95 + 0.00	25.50 + 0.01	27.04 + 0.00	28.95 + 0.00	0.02	28.95 + 0.00	0.02	0.02
DEEP PINK	17.93 0.03	14.76 0.01	14.43 0.01	17.95 0.02	14.76 0.01	14.43 0.01	0.05	14.43 0.01	0.05	0.11
BRIGHT YELLOW	60.30 0.03	62.87 0.07	11.61 0.03	60.31 0.04	62.90 0.07	11.62 0.03	0.09	11.62 0.03	0.08	0.05
CYAN	18.49 0.01	22.90 0.02	44.15 0.02	18.49 0.01	22.92 0.02	44.16 0.01	0.05	44.16 0.01	0.04	0.09
AG 44 STANDARD	9.51 0.01	10.51 0.00	11.15 0.01	9.51 0.01	10.51 0.01	11.20 0.01	0.04	11.20 0.01	0.04	0.14
AG 44 THIN	9.86 0.00	10.90 0.01	11.54 0.01	9.86 0.00	10.91 0.00	11.54 0.01	0.03	11.54 0.01	0.03	0.08
AG 44 FULL	9.25 0.01	10.22 0.01	10.83 0.01	9.25 0.01	10.22 0.01	10.83 0.01	0.04	10.83 0.01	0.04	0.00
TAN M-1 STANDARD	26.76 0.01	27.34 0.01	20.34 0.00	26.75 0.01	27.33 0.01	20.34 0.01	0.03	20.34 0.01	0.03	0.02
TAN M-1 THIN	27.01 0.01	27.61 0.01	20.87 0.01	27.01 0.02	27.61 0.01	20.87 0.01	0.02	20.87 0.01	0.02	0.00
TAN M-1 FULL	26.21 0.00	26.80 0.01	20.53 0.00	26.20 0.00	26.80 0.00	20.53 0.01	0.02	20.53 0.01	0.02	0.04

Table 3a. Comparison of Short- and Long-Term Repeatability for the Tile Samples on the ACS I:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z) (cont.)

Samples:	SHORT			LONG			MCDM	ΔE^*
	X	Y	Z	X	Y	Z		
TAN 325 STANDARD	52.57 +0.02	54.43 +0.02	47.31 +0.02	52.56 +0.03	54.42 +0.02	47.30 +0.02	0.02	0.01
TAN 325 THIN	53.53 0.02	55.44 0.03	47.71 0.01	53.52 0.02	55.44 0.00	47.70 0.03	0.02	0.03
TAN 325 FULL	51.92 0.03	53.77 0.00	46.94 0.01	51.92 0.02	53.76 0.03	46.95 0.00	0.02	0.03
BLUE 151 STANDARD	8.44 0.01	8.89 0.01	13.97 0.01	8.45 0.01	8.89 0.01	13.97 0.01	0.05	0.09
BLUE 151 THIN	8.55 0.00	9.03 0.01	14.18 0.01	8.55 0.01	9.04 0.01	14.19 0.02	0.06	0.09
BLUE 151 FULL	8.23 0.01	8.66 0.01	13.52 0.02	8.23 0.01	8.63 0.01	13.51 0.01	0.05	0.02
BLUE 150 STANDARD	6.47 0.00	6.81 0.01	8.13 0.01	6.48 0.01	6.81 0.01	8.13 0.01	0.06	0.11
BLUE 150 THIN	6.68 0.01	7.03 0.01	8.36 0.01	6.69 0.01	7.03 0.01	8.36 0.01	0.05	0.10
BLUE 150 FULL	6.30 0.00	6.63 0.01	7.91 0.01	6.31 0.01	6.63 0.01	7.91 0.02	0.05	0.11

Table 3a. Comparison of Short- and Long-Term Repeatability for the Tile Samples on the ACS I:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z) (cont.)

Sample:	SHORT			LONG			ΔE^*
	X	Y	Z	X	Y	Z	
SG 509 STANDARD	14.34	15.70	16.00	14.34	15.69	16.00	0.06
	± 0.00	± 0.03	± 0.01	± 0.01	± 0.01	± 0.02	
SG 509 THIN	14.74	16.11	16.51	14.74	16.11	16.51	0.00
	± 0.01	± 0.01	± 0.01	± 0.01	± 0.01	± 0.02	
SG 509 FULL	14.09	15.45	15.66	14.09	15.46	15.66	0.06
	± 0.01	± 0.01	± 0.01	± 0.01	± 0.02	± 0.01	

Table 3b. Comparison of Short- and Long-Term Repeatability for the Tan Fabric Samples on the ACS I:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	SHORT			LONG			MCDM	Z	MCDM	Δ E*
	X	Y	Z	X	Y	Z				
TAN 511-036	24.78 +0.03	25.02 +0.03	18.22 +0.03	24.79 +0.04	25.03 +0.04	18.24 +0.05	0.04	18.24 +0.05	0.05	0.03
TAN 313-319	23.55 0.02	23.83 0.02	17.77 0.02	23.55 0.03	23.84 0.03	17.78 0.04	0.03	17.78 0.04	0.04	0.04
TAN 313-640	23.86 0.03	24.07 0.03	17.84 0.03	23.87 0.04	24.08 0.03	17.86 0.04	0.05	17.86 0.04	0.05	0.03
TAN 511-123	24.42 0.03	24.65 0.04	18.06 0.02	24.43 0.03	24.66 0.05	18.07 0.03	0.07	18.07 0.03	0.09	0.01
TAN 313-312	23.25 0.03	23.52 0.03	17.50 0.03	23.26 0.03	23.53 0.04	17.51 0.04	0.04	17.51 0.04	0.05	0.01
TAN 313-321	24.11 0.04	24.43 0.04	18.25 0.03	24.12 0.03	24.44 0.04	18.26 0.03	0.05	18.26 0.03	0.05	0.01
TAN 313-488	23.32 0.03	23.55 0.03	17.45 0.03	23.33 0.03	23.56 0.03	17.46 0.04	0.04	17.46 0.04	0.04	0.01
TAN 313-332	23.83 0.04	24.06 0.04	17.91 0.03	23.83 0.03	24.07 0.03	17.92 0.03	0.08	17.92 0.03	0.04	0.04
TAN 511-167	25.29 0.04	25.54 0.04	18.65 0.04	25.31 0.04	25.56 0.04	18.66 0.04	0.04	18.66 0.04	0.04	0.02
TAN 519-078	23.95 0.03	24.21 0.03	17.70 0.03	23.97 0.04	24.22 0.04	17.72 0.05	0.04	17.72 0.05	0.05	0.05

Table 3c. Comparison of Short- and Long-Term Repeatability for the Green Fabric Samples on the ACS I: Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	SHORT			LONG			MCDM	Δ E*
	X	Y	Z	X	Y	Z		
GREEN 925-618	7.10 ±0.01	7.64 +0.01	5.64 +0.01	7.10 + 0.01	7.64 +0.01	5.65 + 0.01	0.07	0.04
GREEN 925-622	7.17 0.01	7.70 0.01	5.71 0.01	7.17 0.01	7.69 0.01	5.70 0.01	0.09	0.09
GREEN 925-617	7.11 0.01	7.63 0.01	5.63 0.01	7.11 0.01	7.64 0.01	5.63 0.01	0.07	0.10
GREEN 925-608	7.58 0.01	8.14 0.01	6.07 0.01	7.59 0.02	8.15 0.01	6.07 0.02	0.06	0.04
GREEN 925-606	7.53 0.02	8.09 0.01	6.01 0.02	7.53 0.02	8.09 0.02	6.01 0.02	0.12	0.00
GREEN 925-614	7.30 0.01	7.84 0.01	5.74 0.01	7.31 0.02	7.85 0.02	5.75 0.02	0.07	0.02
GREEN 925-613	7.38 0.01	7.93 0.01	5.90 0.01	7.39 0.01	7.93 0.01	5.90 0.02	0.06	0.10
GREEN 925-601	7.55 0.02	8.11 0.02	6.03 0.02	7.55 0.02	8.11 0.02	6.03 0.02	0.07	0.00
GREEN 600-0058	6.86 0.01	7.33 0.01	5.39 0.01	6.86 0.02	7.33 0.01	5.39 0.02	0.09	0.00
GREEN 600-057	7.10 0.02	7.57 0.03	5.52 0.03	7.10 0.03	7.56 0.03	5.52 0.03	0.09	0.10

Table 4a. Comparison of Short- and Long-Term Repeatability for the Tile Samples on the ACS II:
Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	SHORT			LONG			MCDM	Z	MCDM	ΔE^*
	X	Y	Z	X	Y	Z				
MID GREY	25.50 +0.01	27.05 +0.01	28.99 +0.01	25.51 +0.02	27.05 +0.01	29.00 +0.02	0.03	0.03	0.04	
DEEP PINK	18.05 0.03	14.79 0.01	14.38 0.01	18.06 0.03	14.79 0.02	14.38 0.01	0.06	0.06	0.05	
BRIGHT YELLOW	60.29 0.03	62.81 0.06	11.60 0.02	60.29 0.03	62.83 0.08	11.61 0.03	0.06	0.07	0.05	
CYAN	18.44 0.01	22.88 0.02	44.23 0.03	18.44 0.02	22.89 0.02	44.25 0.03	0.04	0.04	0.05	
AG 44 STANDARD	9.44 0.01	10.45 0.01	11.11 0.01	9.44 0.01	10.45 0.01	11.11 0.01	0.05	0.05	0.00	
AG 44 THIN	9.79 0.01	10.84 0.01	11.49 0.01	9.79 0.01	10.84 0.02	11.49 0.01	0.04	0.05	0.00	
AG 44 FULL	9.18 0.01	10.15 0.01	10.78 0.01	9.18 0.01	10.15 0.01	10.78 0.01	0.04	0.05	0.00	
TAN M-1 STANDARD	26.78 0.02	27.34 0.01	20.36 0.01	26.78 0.02	27.34 0.03	20.36 0.02	0.02	0.04	0.00	
TAN M-1 THIN	27.03 0.01	27.61 0.02	20.89 0.01	27.03 0.02	27.61 0.03	20.89 0.02	0.03	0.03	0.00	
TAN M-1 FULL	26.22 0.02	26.80 0.01	20.55 0.01	26.22 0.02	26.80 0.02	20.56 0.01	0.03	0.03	0.02	

Table 4a. Comparison of Short- and Long-Term Repeatability for the Tile Samples on the ACS II: Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z) (cont.)

Sample:	SHORT			LONG			MCDM	Z	MCDM	E*
	X	Y	Z	X	Y	Z				
TAN 325 STANDARD	52.54 ±0.03	54.39 ±0.00	47.31 ± 0.01	0.02	52.54 ± 0.02	54.39 ± 0.03	47.30 ± 0.04	0.04	0.01	0.01
TAN 325 THIN	53.52 0.03	55.42 0.02	47.73 0.01	0.02	53.51 0.03	55.42 0.04	47.72 0.03	0.02	0.03	0.03
TAN 325 FULL	51.91 0.02	53.74 0.02	46.96 0.02	0.02	51.92 0.02	53.75 0.03	46.96 0.01	0.02	0.01	0.01
BLUE 151 STANDARD	8.38 0.01	8.82 0.01	13.92 0.01	0.05	8.38 0.01	8.82 0.01	13.92 0.01	0.05	0.00	0.00
BLUE 151 THIN	8.47 0.01	8.96 0.01	14.13 0.01	0.04	8.47 0.01	8.96 0.02	14.13 0.01	0.05	0.00	0.00
BLUE 151 FULL	8.16 0.01	8.59 0.01	13.46 0.01	0.05	8.16 0.01	8.59 0.01	13.45 0.01	0.05	0.02	0.02
BLUE 150 STANDARD	6.40 0.01	6.74 0.01	8.05 0.01	0.07	6.40 0.01	6.74 0.01	8.06 0.01	0.08	0.03	0.03
BLUE 150 THIN	6.62 0.01	6.96 0.01	8.29 0.01	0.03	6.62 0.01	6.96 0.02	8.29 0.01	0.03	0.00	0.00
BLUE 150 FULL	6.24 0.01	6.56 0.01	7.84 0.01	0.04	6.24 0.01	6.56 0.01	7.84 0.01	0.06	0.00	0.00

Table 4a. Comparison of Short- and Long-Term Repeatability for the Tile Samples on the ACS II:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z) (cont.)

Sample:	SHORT			LONG			MCDM	ΔE^*
	X	Y	Z	X	Y	Z		
SG 509 STANDARD	14.28	15.64	15.96	14.28	15.65	15.97	0.04	0.06
	+0.01	+0.01	+0.01	+0.01	+0.01	+0.01		
SG 509 THIN	14.68	16.06	16.48	14.69	16.06	16.48	0.07	0.06
	0.01	0.01	0.01	0.02	0.02	0.01		
SG 509 FULL	14.03	15.40	15.62	14.04	15.41	15.63	0.04	0.01
	0.01	0.01	0.01	0.02	0.02	0.01		

Table 4b. Comparison of Short- and Long-Term Repeatability for the Tan Fabric Samples on the ACS II: Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	SHORT			LONG			MCDM	Z	MCDM	ΔE^*
	X	Y	Z	X	Y	Z				
TAN 511-036	24.76 +0.03	24.98 +0.03	18.22 +0.03	24.75 +0.05	24.97 +0.05	18.21 +0.04	0.04	0.05	0.01	
TAN 313-319	23.50 0.03	23.77 0.03	17.75 0.03	23.49 0.05	23.76 0.05	17.73 0.04	0.06	0.06	0.03	
TAN 313-640	23.82 0.03	24.01 0.03	17.82 0.02	23.81 0.04	24.00 0.05	17.81 0.04	0.04	0.05	0.01	
TAN 511-123	24.38 0.03	24.61 0.03	18.05 0.03	24.38 0.05	24.60 0.05	18.04 0.03	0.04	0.05	0.04	
TAN 313-312	23.21 0.03	23.46 0.03	17.47 0.03	23.20 0.04	23.45 0.04	17.47 0.04	0.05	0.05	0.02	
TAN 313-321	24.10 0.04	24.40 0.04	18.25 0.02	24.08 0.06	24.39 0.06	18.23 0.04	0.05	0.06	0.05	
TAN 313-488	23.28 0.02	23.50 0.03	17.44 0.03	23.27 0.05	23.49 0.05	17.42 0.04	0.04	0.05	0.03	
TAN 313-332	23.79 0.02	24.02 0.02	17.89 0.02	23.78 0.05	24.00 0.04	17.88 0.04	0.04	0.05	0.05	
TAN 511-167	25.25 0.03	25.49 0.02	18.63 0.03	25.24 0.04	25.47 0.05	18.62 0.04	0.04	0.05	0.05	
TAN 519-078	23.92 0.03	24.16 0.03	17.68 0.03	23.90 0.05	24.14 0.05	17.67 0.04	0.04	0.05	0.02	

Table 4c. Comparison of Short- and Long-Term Repeatability for the Green Fabric Samples on the ACS II:
 Mean and Standard Deviation (+/-) of Tristimulus Values (X,Y,Z)

Sample:	SHORT			LONG			MCDM	ΔE^*
	X	Y	Z	X	Y	Z		
GREEN 925-618	7.07 +0.01	7.60 +0.01	5.64 +0.01	7.06 +0.02	7.60 +0.02	5.64 +0.01	0.07	0.10
GREEN 925-622	7.14 0.01	7.67 0.01	5.71 0.01	7.13 0.02	7.66 0.02	5.70 0.02	0.07	0.02
GREEN 925-617	7.07 0.01	7.60 0.02	5.63 0.01	7.06 0.02	7.59 0.02	5.62 0.02	0.06	0.02
GREEN 925-608	7.54 0.01	8.11 0.01	6.06 0.01	7.53 0.02	8.10 0.02	6.06 0.02	0.06	0.04
GREEN 925-606	7.48 0.01	8.04 0.01	6.00 0.01	7.47 0.03	8.03 0.03	5.99 0.03	0.07	0.02
GREEN 925-614	7.26 0.01	7.80 0.01	5.73 0.01	7.25 0.03	7.79 0.03	5.72 0.03	0.09	0.02
GREEN 925-613	7.34 0.01	7.89 0.01	5.89 0.01	7.32 0.03	7.88 0.03	5.88 0.03	0.08	0.11
GREEN 925-601	7.51 0.02	8.08 0.02	6.03 0.02	7.50 0.04	8.07 0.04	6.02 0.04	0.09	0.02
GREEN 600-0058	6.83 0.02	7.30 0.02	5.39 0.02	6.81 0.05	7.28 0.05	5.38 0.05	0.09	0.06
GREEN 600-057	7.09 0.03	7.56 0.03	5.55 0.03	7.07 0.04	7.54 0.04	5.53 0.04	0.10	0.05

Table 5. CIELAB Color Differences for Tan Color
Difference Pair

<u>Observation</u>	<u>ACS 1</u>	<u>ACS II</u>
1	1.91	1.91
2	1.89	1.91
3	1.90	1.91
4	1.90	1.92
5	1.91	1.92
6	1.91	1.92
7	1.90	1.91
8	1.91	1.90
9	1.92	1.90
10	1.94	1.94
Average	1.91	1.91

Table 6a. Comparison of Short-Term Infrared Repeatability for the Green Fabric Samples Between ACS I and ACS II: Mean and Standard Deviation (+/-) of Starlight Scope Values (Ns, Ls)

Sample:	ACS I			ACS II				
	Moonlit	Moonless	Moonless	Moonlit	Moonlit	Moonless		
	Ns	Ls	Ns	Ls	Ns	Ls		
GREEN 925-618	7.68 +0.01	33.30 +0.02	8.88 +0.01	35.75 +0.02	7.65 +0.01	33.25 +0.02	8.84 +0.01	35.67 +0.02
GREEN 925-622	7.79 0.01	33.55 0.01	9.03 0.01	36.05 0.02	7.78 0.01	33.49 0.06	9.00 0.02	35.98 0.03
GREEN 925-617	7.70 0.01	33.35 0.03	8.92 0.01	35.83 0.02	7.67 0.01	33.29 0.03	8.87 0.01	35.74 0.03
GREEN 925-608	8.24 0.01	34.48 0.02	9.54 0.01	37.00 0.03	8.22 0.01	34.44 0.02	9.50 0.01	36.94 0.01
GREEN 925-606	8.20 0.01	34.41 0.03	9.50 0.02	36.94 0.03	8.17 0.01	34.34 0.03	9.45 0.01	36.84 0.03
GREEN 925-614	7.93 0.01	33.84 0.02	9.21 0.01	36.39 0.02	7.91 0.01	33.78 0.02	9.17 0.01	36.30 0.02
GREEN 925-613	8.06 0.01	34.11 0.02	9.34 0.01	36.36*	8.03 0.01	34.04 0.01	9.29 0.01	36.53 0.01
GREEN 925-601	8.25 0.02	34.49 0.04	9.56 0.02	37.04 0.04	8.23 0.02	34.45 0.03	9.52 0.02	36.96 0.03
GREEN 600-0058	7.37 0.01	32.65 0.03	8.60 0.01	35.21 0.03	7.35 0.02	32.59 0.04	8.55 0.02	35.11 0.03
GREEN 600-057	7.61 0.02	33.16 0.05	8.89 0.02	35.77 0.04	7.60 0.02	33.13 0.04	8.85 0.02	35.70 0.04

* Sample 925-613 was not within 95% confidence limits for this sample

Table 6b. Comparison of Short-Term Infrared Repeatability for the Tan Fabric Samples between ACS I and ACS II:
 Mean and Standard Deviation (+/-) of Starlight Scope Values (Ns, Ls)

Sample:	ACS I			ACS II				
	Moonlit Ns	Ls	Moonless Ns	Ls	Moonlit Ns	Moonless Ns		
Tan 511-036	31.32 ±0.03	62.78 ±0.00	38.24* ±0.03	68.19* ±0.03	31.23 ±0.03	62.70 ±0.00	38.07 ±0.03	68.07 ±0.00
TAN 313-319	30.07 0.02	61.71 0.02	36.63 0.02	67.00 0.02	29.98 0.03	61.63 0.03	36.47 0.05	66.88 0.03
TAN 313-640	30.32 0.03	61.93 0.03	36.98 0.04	67.26 0.00	30.23 0.03	61.86 0.03	36.82 0.04	67.14 0.00
TAN 511-123	30.49 0.03	62.08 0.00	37.11 0.04	67.36* 0.02	30.40 0.03	62.00 0.03	36.94 0.04	67.24 0.00
TAN 313-312	29.79 0.03	61.47 0.03	36.36 0.03	66.79 0.00	29.69 0.04	61.39 0.04	36.19 0.04	66.66 0.04
TAN 313-321	30.64 0.03	62.21 0.02	37.22 0.03	67.44 0.02	30.56 0.04	62.14 0.03	37.07 0.05	67.33 0.03
TAN 313-488	29.87 0.03	61.55 0.03	36.50 0.03	66.89 0.03	29.80 0.03	61.48 0.02	36.35 0.04	66.78 0.04
TAN 313-332	30.25 0.04	61.88 0.03	36.87 0.03	67.18 0.00	30.18 0.03	61.81 0.03	36.70 0.04	67.06 0.04
TAN 511-167	31.57 0.02	62.99 0.00	38.39* 0.02	68.30 0.00	31.47 0.03	62.90 0.00	38.21 0.03	68.18 0.03
TAN 519-078	30.51 0.02	62.10* 0.00	37.37* 0.03	67.55 0.04	30.40 0.03	62.00 0.02	37.17 0.03	67.41 0.03

Table 7a. Comparison of Long-Term Infrared Repeatability for the Green Fabric Samples between ACS I and ACS II
 Mean and Standard Deviation (+/-) of Starlight Scope Values (Ns,Ls)

Sample:	ACS I				ACS II			
	Moonlit		Moonless		Moonlit		Moonless	
	Ns	Ls	Ns	Ls	Ns	Ls	Ns	Ls
GREEN 925-618	7.68 ±0.01	33.31 ±0.02	8.89 ±0.01	35.76 ±0.02	7.65 ±0.02	33.24 ±0.02	8.84 ±0.01	35.67 ±0.02
GREEN 925-622	7.79 0.01	33.55 0.00	9.04 0.01	36.05 0.02	7.77 0.02	33.49 0.05	8.99 0.02	35.96 0.04
GREEN 600-0058	7.38 0.01	32.65 0.03	8.60 0.01	35.21 0.02	7.35 0.02	32.59 0.03	8.54 0.02	35.11 0.03
GREEN 600-057	7.61 0.02	33.15 0.03	8.89 0.01	35.77 0.02	7.60 0.03	33.14 0.06	8.86 0.03	35.70 0.02
GREEN 925-613	8.06 0.01	34.12 0.02	9.34 0.01	36.64* 0.00	8.03 0.01	34.04 0.01	9.28 0.01	36.53 0.02
GREEN 925-601	8.25 0.02	34.51 0.03	9.56 0.02	37.05 0.03	8.23 0.02	34.46 0.03	9.52 0.02	36.98 0.03
GREEN 925-617	7.70 0.01	33.35 0.02	8.92 0.01	35.84 0.03	7.66 0.01	33.27 0.03	8.87 0.02	35.73 0.03
GREEN 925-614	7.93 0.02	33.85 0.02	9.22 0.02	36.41 0.03	7.89 0.03	33.74 0.07	9.15 0.03	36.27 0.05
GREEN 925-608	8.24 0.01	34.48 0.01	9.54 0.01	37.00 0.03	8.21 0.03	34.41 0.05	9.48 0.02	36.90 0.04
GREEN 925-606	8.21 0.01	34.42 0.02	9.51 0.01	36.95 0.02	8.17 0.02	34.32 0.04	9.43 0.03	36.82 0.04

Table 7b. Comparison of Long-Term Infrared Repeatability for the Tan Fabric Samples between ACS I and ACS II
 Mean and Standard Deviation (+/-) of Starlight Scope Values (Ns,Ls)

Sample:	ACS I				ACS II			
	Moonlit		Moonless		Moonlit		Moonless	
	Ns	Ls	Ns	Ls	Ns	Ls	Ns	Ls
TAN 511-036	31.32 + 0.02	62.78 + 0.00	38.24 + 0.03	68.19 + 0.03	31.23 + 0.04	62.70 + 0.02	38.07 + 0.04	68.07 + 0.04
TAN 313-319	30.06 0.01	61.71 0.03	36.62* 0.02	67.00 0.00	29.95 0.06	61.62 0.04	36.44 0.04	66.86 0.05
TAN 313-640	30.32 0.02	61.94 0.00	36.98 0.03	67.26 0.02	30.22 0.03	61.84 0.04	36.81 0.04	67.13 0.04
TAN 511-123	30.49 0.03	62.08* 0.00	37.11 0.04	67.36* 0.00	30.39 0.04	61.98 0.02	36.92 0.05	67.22 0.03
TAN 313-312	29.79 0.02	61.47 0.03	36.36* 0.03	66.79* 0.03	29.68 0.03	61.39 0.03	36.18 0.03	66.65 0.00
TAN 313-321	30.61 0.04	62.18 0.04	37.18 0.04	67.42 0.03	30.54 0.03	62.14 0.03	37.06 0.04	67.32 0.02
TAN 313-488	29.86 0.04	61.53 0.04	36.49 0.02	66.88 0.02	29.79 0.03	61.47 0.03	36.34 0.04	66.78 0.02
TAN 313-332	30.25 0.04	61.89 0.02	36.87 0.04	67.18 0.02	30.18 0.03	61.80 0.04	36.70 0.04	67.04 0.04
TAN 511-167	31.56 0.01	62.98 0.02	38.38* 0.02	68.30* 0.02	31.48 0.03	62.90 0.02	38.21 0.03	68.17 0.00
TAN 519-078	30.51 0.03	62.09 0.00	37.37* 0.04	67.54 0.03	30.39 0.04	61.99 0.03	37.16 0.05	67.41 0.02

Table 8a. Comparison of the Short- and Long-Term Infrared Repeatability for the Tan Fabric Samples on the AC Mean and Standard Deviation (+/-) of Starlight Scope Values (Ns, Ls)

Sample:	Short			Long				
	Moonlit		Moonless	Moonlit		Moonless		
	Ns	Ls	Ns	Ls	Ns	Ls		
TAN 511-036	31.32 +0.03	62.78 +0.00	38.24 +0.03	68.20 +0.03	31.32 +0.02	62.78 +0.00	38.24 +0.03	68.19 +0.03
TAN 313-319	30.07 0.02	61.71 0.02	36.63 0.02	67.00 0.02	30.06 0.01	61.71 0.03	36.62 0.02	67.00 0.00
TAN 313-640	30.32 0.03	61.93 0.03	36.98 0.04	67.26 0.00	30.32 0.02	61.94 0.00	36.98 0.03	67.26 0.02
TAN 511-123	30.49 0.03	62.08 0.00	37.11 0.04	67.36 0.02	30.49 0.03	62.08 0.00	37.11 0.04	67.36 0.00
TAN 313-312	29.79 0.03	61.47 0.03	36.36 0.03	66.79 0.00	29.79 0.02	61.47 0.03	36.36 0.03	66.79 0.03
TAN 313-321	30.64 0.03	62.21 0.02	37.22 0.03	67.44 0.02	30.61 0.04	62.18 0.04	37.18 0.04	67.42 0.03
TAN 313-488	29.87 0.03	61.55 0.03	36.50 0.03	66.89 0.03	29.86 0.04	61.53 0.04	36.49 0.02	66.88 0.02
TAN 313-332	30.25 0.04	61.88 0.03	36.87 0.03	67.18 0.00	30.25 0.04	61.89 0.02	36.87 0.04	67.18 0.02
TAN 511-167	31.57 0.02	62.99 0.00	38.39 0.02	68.30 0.00	31.56 0.01	62.98 0.02	38.38 0.02	68.30 0.02
TAN 519-078	30.51 0.02	62.10 0.00	37.37 0.03	67.55 0.04	30.51 0.03	62.09 0.00	37.37 0.04	67.54 0.03

Table 8b. Comparison of the Short- and Long-Term Infrared Repeatability for the Green Fabric Samples on the Mean and Standard Deviation (+/-) of Starlight Scope Values (Ns, Ls)

Sample:	Short						Long							
	Moonlit			Moonless			Moonlit			Moonless				
	Ns	Ls	Ns	Ls	Ns	Ls	Ns	Ls	Ns	Ls	Ns	Ls		
GREEN 925-618	7.68 +0.01	33.30 +0.02	8.88 +0.01	35.75 +0.02	7.68 +0.01	33.31 +0.02	8.89 +0.01	35.76 +0.02	7.79	33.55	9.04	36.05	0.01	0.02
GREEN 925-622	7.79	33.55	9.03	36.05	7.79	33.55	9.04	36.05	7.79	33.55	9.04	36.05	0.01	0.02
GREEN 925-617	7.70	33.35	8.92	35.83	7.70	33.35	8.92	35.84	7.70	33.35	8.92	35.84	0.01	0.03
GREEN 925-608	8.24	34.48	9.54	37.00	8.24	34.48	9.54	37.00	8.24	34.48	9.54	37.00	0.01	0.03
GREEN 925-606	8.20	34.41	9.50	36.94	8.21	34.42	9.51	36.95	8.21	34.42	9.51	36.95	0.01	0.02
GREEN 925-614	7.93	33.84	9.21	36.39	7.93	33.84 ^c	9.22	36.41	7.93	33.84 ^c	9.22	36.41	0.02	0.03
GREEN 925-613	8.06	34.11	9.34	36.63	8.06	34.12	9.34	36.64	8.06	34.12	9.34	36.64	0.01	0.00
GREEN 925-601	8.25	34.49	9.56	37.04	8.25	34.51	9.56	37.05	8.25	34.51	9.56	37.05	0.02	0.03
GREEN 600-0058	7.37	32.65	8.60	35.21	7.38	32.65	8.60	35.21	7.38	32.65	8.60	35.21	0.01	0.02
GREEN 600-057	7.61	33.16	8.89	35.77	7.61	33.15	8.89	35.77	7.61	33.15	8.89	35.77	0.02	0.04

Table 9a. Comparison of the Short- and Long-Term Infrared Repeatability for the Tan Fabric Samples on the AC Mean and Standard Deviation (+/-) of Starlight Scope Values (Ns, Ls)

Sample:	Short				Long			
	Moonlit		Moonless		Moonlit		Moonless	
	Ns	Ls	Ns	Ls	Ns	Ls	Ns	Ls
TAN 511-036	31.24 +0.03	62.71 +0.00	38.09 +0.03	68.08 +0.00	31.23 +0.04	62.70 +0.02	38.07 +0.04	68.07 +0.04
TAN 313-319	29.98 0.03	61.63 0.03	36.47 0.05	66.88 0.03	29.95 0.06	61.62 0.04	36.44 0.04	66.86 0.05
TAN 313-640	30.23 0.03	61.86 0.03	36.82 0.04	67.14 0.00	30.22 0.03	61.84 0.04	36.81 0.04	67.13 0.04
TAN 511-123	30.40 0.03	62.00 0.03	36.94 0.04	67.24 0.00	30.39 0.04	61.98 0.02	36.92 0.05	67.22 0.03
TAN 313-312	29.69 0.04	61.39 0.04	36.19 0.04	66.66 0.04	29.68 0.03	61.39 0.03	36.18 0.03	66.65 0.00
TAN 313-321	30.56 0.04	62.14 0.03	37.07 0.05	67.33 0.03	30.54 0.03	62.14 0.03	37.06 0.04	67.32 0.02
TAN 313-488	29.80 0.03	61.48 0.02	36.35 0.04	66.78 0.04	29.79 0.03	61.47 0.03	36.34 0.04	66.78 0.02
TAN 313-332	30.18 0.03	61.81 0.03	36.70 0.04	67.06 0.04	30.18 0.03	61.80 0.04	36.70 0.04	67.04 0.04
TAN 511-167	31.47 0.03	62.90 0.00	38.21 0.03	68.18 0.03	31.46 0.03	62.90 0.02	38.21 0.03	68.17 0.00
TAN 519-078	30.40 0.03	62.00 0.02	37.17 0.03	67.41 0.03	30.39 0.04	61.99 0.03	37.16 0.05	67.41 0.02

Table 9b. Comparison of the Short- and Long-Term Infrared Repeatability for the Green Fabric Samples on the Mean and Standard Deviation (+/-) of Starlight Scope Values (Ns, Ls)

Sample:	Short				Long			
	Moonlit		Moonless		Moonlit		Moonless	
	Ns	Ls	Ns	Ls	Ns	Ls	Ns	Ls
GREEN 925-618	7.65 +0.01	33.25 +0.02	8.84 +0.01	35.67 +0.02	7.65 +0.02	33.24 +0.02	8.84 +0.01	35.67 +0.02
GREEN 925-622	7.78 0.01	33.49 0.06	9.00 0.02	35.98 0.03	7.77 0.02	33.49 0.05	8.99 0.02	35.96 0.04
GREEN 925-617	7.67 0.01	33.29 0.03	8.87 0.01	35.74 0.03	7.66 0.01	33.27 0.03	8.87 0.02	35.73 0.03
GREEN 925-608	8.22 0.01	34.44 0.02	9.50 0.01	36.94 0.01	8.21 0.03	34.41 0.05	9.48 0.02	36.90 0.04
GREEN 925-606	8.17 0.01	34.34 0.03	9.45 0.01	36.84 0.03	8.17 0.02	34.32 0.04	9.43 0.03	36.82 0.04
GREEN 925-614	7.91 0.01	33.78 0.02	9.17 0.01	36.30 0.02	7.89 0.03	33.74 0.07	9.15 0.03	36.27 0.05
GREEN 925-613	8.03 0.01	34.04 0.01	9.29 0.01	36.53 0.01	8.03 0.01	34.04 0.01	9.28 0.01	36.53 0.02
GREEN 925-601	8.23 0.02	34.45 0.03	9.52 0.02	36.96 0.03	8.23 0.02	34.46 0.03	9.52 0.02	36.98 0.03
GREEN 600-0058	7.35 0.02	32.59 0.04	8.55 0.02	35.11 0.03	7.35 0.02	32.59 0.03	8.54 0.02	35.11 0.03
GREEN 600-057	7.60 0.02	33.13 0.04	8.85 0.02	35.70 0.04	7.60 0.03	33.14 0.06	8.86 0.03	35.70 0.02

Table 10a. Comparison of Average Short-Term Values*
for the Two Instruments

Sample	Average MCDM		Average ΔE
	ACS I	ACS II	
Tiles	0.04	0.04	0.14
	± 0.02	± 0.02	0.10
Greens	0.06	0.06	0.16
	± 0.02	± 0.01	0.02
Tans	0.05	0.04	0.09
	± 0.01	± 0.01	0.02

Table 10b. Comparison of Average Long-Term Values
for the Two Instruments

Sample	Average MCDM		Average ΔE
	ACS I	ACS II	
Tiles	0.04	0.04	0.14
	± 0.02	± 0.02	0.10
Greens	0.08	0.08	0.18
	± 0.02	± 0.01	0.03
Tans	0.05	0.05	0.10
	± 0.01	± 0.01	0.02

*MCDM = Mean Color Difference from the Mean

* ΔE = CIELAB Color Difference between the Two Means

Table 10c. Comparison of Average Long- and Short-Term
Values for the ACS I Instrument

Sample	Average MCDM		Average ΔE
	SHORT	LONG	
Tiles	0.04	0.04	0.05
	± 0.02	± 0.02	0.04
Greens	0.07	0.08	0.05
	± 0.01	± 0.02	0.04
Tans	0.05	0.05	0.03
	± 0.01	± 0.01	0.01

Table 10d. Comparison of Average Long- and Short-Term
Values for the ACS II Instrument

Sample	Average MCDM		Average ΔE
	SHORT	LONG	
Tiles	0.04	0.04	0.02
	± 0.01	± 0.02	0.02
Greens	0.06	0.08	0.05
	± 0.01	± 0.01	0.03
Tans	0.04	0.05	0.03
	± 0.01	± 0.01	0.01

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