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The Comparative Evaluation of Soil Removal

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오염제거 평가의 비교

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Abstract

본 연구의 목적은 기계에 의한 객관적 오염제거 평가와 육안에 의한 주관적 오염제거 평가를 비교하기 위한 것이다. 본 연구를 위해 백색의 순면직물과 65%/35% 폴리에스테르/면 직물 시료에 9가지의 오염을 각각 처리한 오염포를 제작한 후, 세탁 실험을 하였다. 주관적 오염제거의 평가는 오염시키지 않은 포를 기준시료로 하여 오염포와 같은 조건으로 세탁한 후, 오염제거도를 AATCC Gray Scale for Staining으로 평가하였다. 세탁 후 오염제거도를 객관적으로 평가하기 위해서 각 시료의 K/S values, CIELAB, CMC, ASTM E313 Whiteness Index(WI), ASTM E313 Yellowness Index, and CIE tristimulus values를 구하였고, 세탁에 의한 control 시료의 반사율 변화에 대한 오염포의 반사율 변화를 비교한 오염제거율(PSR)을 구하였다. 육안에 의한 주관적 평가 결과와 기계에 의한 객관적 평가의 결과와의 관계를 파악하고자 상관분석을 실시하였다.

본 연구 결과, 주관적 평가와 객관적 평가 사이에 유의적인 상관관계가 확인되었으며, 주관적 평가 결과 중 WI가 주관적 평가 결과와 가장 상관관계가 높았으며, PSR과 주관적 평가 결과와의 상관이 상대적으로 가장 낮은 것으로 나타났다. 따라서 백색포의 오염 판정이 필요한 산업체에서 현재 많이 사용하고 있는 PSR 보다는 WI나 다른 색차를 이용하여 객관적 오염 평가를 하는 것이 주관적인 오염평가 결과에 더 근접할 수 있음을 알 수 있었다.

Key words: soil removal, laundering, whiteness, color difference; 오염제거, 세탁, 백도, 색차

I. Introduction

The appearance of textile products following laundering and stain removal is one of the major criteria used in evaluating the efficacy of the laundering process. While wrinkles, appearance of seams and other structural and design characteristics, and odor are im-portant criteria used in evaluating laundering, overall soil removal and specific stain removal and their evaluation were the focus of this research.

Many types of optical measurement systems are available to judge the effectiveness of the soil removal process. Optical measurements of soil level include visual comparison with standards and instrumental measurements. It is generally assumed that the soil measurements derived from instrumental devices correlate with subjective visual ratings, since ultimately laundered textiles are

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evaluated by human eye. Although instrumental methods of measuring soil level have advantages over visual assessment owing to an instrument capacity to produce quantitative and reproducible data, the fundamental underlying assumption that instruments will produce results identical to that of the human judge is not completely verified.

Popson et al.(1995) reported that the human eye is more sensitive to color in near-white materials. As more soil is removed during laundering, it is expected that the eye is better able to detect small changes in hue. However, there is a lack of information about correlations between instrumental measurement and the visual assessment in the evaluation of soil removal from white fabrics.

Although the amount of soil present on the fabric is a major concern of optical evaluation, the whiteness rather than the soil content can be more important to consumers. Both industry and consumers prefer clean fabric. The perception of whiteness is the result of a combination of high lightness and low chroma. Strenuous efforts have been put forth to develop visual and instrumental means for assessing whiteness that are reliable and reproducible.

The assessment of chromaticity has become increasingly important owing to the evaluation of apparent soils using more realistic soils, such as clays and grape juice rather than carbon black. Color difference could be regarded as an indicator of soil removal or whiteness retention of fabrics, if it was measured instrumentally and the relationship between color difference and visual assessment established. Uchida(1998) proposed the CIE whiteness formula with modified coefficient, which was found to be inversely correlated to visual estimations of many observers.

The CIE colorimetric standards, X, Y, Z were derived from the spectral stimuli, R, G, B of wavelengths 700.0, 546.1, and 435.8 nm. In most industrial applications, the smallest of the three tristimulus values(X, Y, or Z) is chosen and is used in place of the % R value in the following equation: $K/S=(1-R)^2/2R$. Normally the Y value is used as the color strength value related to the visual lightness function, although either X or Z may be chosen since absorption characteristics are known and fall into widely separated regions of the visible spectrum. While the tristimulus color strength values, X, Y, Z are used in the textile industry, no scientific support of its use can be found in AATCC Technical Manual (1984).

Even though use of the CIELAB equation provides industry with a 'standard' means of calculating and communicating color-differences, it is recognized that CIELAB color-difference values correlate poorly with visual assessments. The CMC formula is a modification of the corresponding CIELAB color-difference formula. The improvement in correlation between visual and instrumental color-difference reports yielded by CMC equation will usually permit the adoption of a single-number tolerance for judging the acceptability of a color match in most situations, regardless of both the color of the standard and the direction of the color difference of any trial from it.

In 1982, the CIE whiteness formula is usually written in the form: $WI=Y+800(x_n-x)+1700(y_n-y)$. The higher the value of WI, the higher the whiteness of the specimens. This method yields reports of whiteness that are relative, not absolute, implying that it can be used only to compare specimens (Hayhurst & Smith, 1995). Hayhurst & Smith (1995) indicated that the comparison of specimens should not differ much in colour or in fluorescence, and the specimens must be measured on the same instrument at nearly the same time.

In this study, the instrumental color measurement of fabric is considered and the relationships between visual assessments and several color parameters are studied, in order to determine which objective methods can be a useful criterion to determine the visual appearance of whiteness retention for fabrics. An all cotton fabric and a 65%/35% polyester/cotton fabric were soiled with nine types of soils and subjected to laundering under five sets of laundering conditions, and evaluated by both instrumental measurements and visual assessment.

II. Materials And Methods

We purchased the fabrics from Test Fabrics Inc: 100% cotton #40 and 65% polyester/35% cotton #7435 WRL(P/C fabric). Both fabrics were scoured and bleached white. Scientific Service S/D, Inc soiled sufficient quantity of fabric with the nine soils commonly found on household textiles and apparel: clay, dust sebum, gravy, grape juice, spaghetti sauce, cocoa mix, blood, grass, and make-up. The samples were stored in nitrogen to block oxidation of stains between the time of staining.

We used swatches approximately 4×4 inches as test specimens. We coded each swatch so that its measurement and evaluation after washing could be matched with its instrumental measurement before washing.

We laundered soiled samples in an Atlas Launder-O-meter under five sets of laundry conditions following modified AATCC 151 Soil Redeposition Launder-O-meter Method. One specimen(4×4 in.) was used for each container. Two wash temperatures reflected consumer practices: 16°C(60°F), warm, and 82°C(180°F), hot. One of three quantities of steel balls simulated agitation levels of home laundering: soak, 50 balls, or 250 balls. Two common household detergents were used. Both detergents were granule types and according to their labels, contain cleaning agents(anionic surfactant, nonionic surfactant, fluorescent whitening agent, and enzyme) and water softeners. Detergent I is claimed by the manufacturer to be effective in hard water, especially with 12~15g/gallon hardness(american system), and is specifically designed for high efficiency washing machines and contains suds suppressing agents. Detergent II is a typical heavy-duty powder detergent that is claimed to be effective in up to 8 grains of hardness. High water level(525ml) or low water level(131ml) was used corresponding to consumer washing machine levels. For detergent levels, amounts were based on recommendations from detergent manufacturers: 8g/gallon(half the recommendation), 16g/gallon as recommended, and 32g/gallon(twice the recommendation). The hard water(8grains/gallon) or soft water (0grain/gallon) was used. To evaluate the effec-tiveness of soil removal, five different wash cycles were completed for each soiled fabric. Each test fabric was removed with tweezers and dipped ten times in three successive beakers of cold soft water at 80°F. Excess water was squeezed from specimen by hand and line dried.

Six female graduate students whose major were clothing and textiles participated in the visual tests. Each panel evaluated using total of one hundred specimens (10 stained types including 1 unstained control×5 laundry conditions×2 replicates) for visual rating. Panels graded each group of swatches in terms of residual stain using AATCC Gray Scale for Staining and AATCC Evaluation Procedure 2. Within each group, we included a control specimen that had been washed but not soiled. This gray scale includes five grades with intermediate decimal half grades for subjectively rating as follows:

5: Stain undetectable
4: Very slight staining
3: Slight staining
2: Moderate staining
1: Heavy staining

We determined the percentage soil removal rate(PSR) by measuring the percentage of incident light reflected from the swatches of soiled and of unsoiled before and after washing. We used the relative difference in strength between control and washed samples using the CIE Tristimulus Y values. We used the Kubelka-Munk values (K/S values) to calculate the relative soil removal rate between the unsoiled control and the soiled specimens. We considered the control to be a standard:

$$\text{Percent Soil Removal} = 100(K/S_{soiled} - K/S_{washed})/(K/S_{soiled} - K/S_{unsoiled})$$

Table 1. Laundry conditions for this study

Laundering Identification No.	Temp. (F)	Agitation steel ball	Time (min)	Detergent Amount (g/gallon)	Water hardness (grain/gallon)	Detergent Type*	Water Level (ml)
1	60	Soak	10	8	0	II	525
2	60	Soak	10	8	8	II	131
3	60	50	45	32	8	II	131
4	60	Soak	10	8	0	I	131
5	180	250	10	16	8	II	131

*Detergent Type I contain suds suppressing agent and detergent Type II is a typical heavy-duty detergent.

The sample was placed in Colorimeter[R] with a light source D65, focused on the surface of the sample at an angle of 45 degree. CIE tristimulus values, CIE_{LAB}, CMC, ASTM E313 Whiteness formula and ASTM E313 Yellowness formula [5] were used to specify the color of the samples.

All the color difference values were obtained comparing with the washed control. We evaluated the relationship between the color values and visual rates using Pearson's correlation analysis and regression analysis. All these statistical studies were performed with SPSS_Win10.0.

III. Results And Discussion

Table 2 and 3 show values of whiteness index (WI), yellowness index (YI), DE_{CMC}, DE_{XYZ} and DE_{L*a*b*} of cotton fabrics We found significant differences between the nine stains, evaluated by visual observation and when evaluated by instrumental reflectance and colorimetry. In stain removal, food stains, such as gravy, spaghetti sauce, and cocoa mix showed better removal than blood, grass,

Table 2. Color difference data for washed cotton fabrics

Stains	Wash	GS	DE_{Lab}	YI	DE_{CMC}	WI	PSR	DE_{XYZ}
Clay	1	3	11.41	11.60	12.01	41.33	49.06	42.5
	2	3.5	10.76	9.32	11.02	49.33	55.28	34.0
	3	3.5	13.18	9.06	12.97	48.47	53.18	38.9
	4	3	13.64	3.00	13.64	31.41	33.89	55.4
	5	3.5	8.90	5.51	9.39	65.44	66.45	27.6
Dust Sebum	1	3.5	9.83	7.96	7.54	51.64	49.05	46.0
	2	3.5	6.76	4.61	6.38	67.95	59.77	31.7
	3	3.5	7.20	1.94	5.47	76.71	20.24	29.7
	4	3	16.69	11.20	0.00	33.89	15.34	73.4
	5	3.5	6.62	0.43	4.36	82.27	67.89	26.7
Gravy Sauce	1	4	1.72	2.50	2.11	84.09	65.86	8.97
	2	5	1.69	−0.00	2.11	95.11	68.79	3.62
	3	5	1.16	−3.10	1.27	108.06	81.09	1.98
	4	4.5	2.84	11.2	10.77	74.02	50.41	14.0
	5	5	0.68	−4.10	0.69	112.20	80.76	2.27
Cocoa Mix	1	5	0.68	0.84	0.51	92.10	85.38	9.83
	2	4.5	4.05	1.42	0.93	82.66	83.61	18.4
	3	5	3.66	−0.50	3.29	93.04	72.87	12.7
	4	5	4.51	4.74	4.33	67.98	67.86	29.5
	5	4	5.86	1.81	5.40	81.39	33.90	18.9
Spagetti Sauce	1	4.5	0.45	0.72	0.54	94.65	70.69	25.0
	2	5	1.38	−0.60	1.72	97.82	77.85	13.6
	3	5	0.93	−3.30	1.06	110.17	70.64	23.5
	4	4.5	1.49	3.24	2.19	83.17	57.15	32.9
	5	4.5	2.72	−1.10	2.94	99.13	55.64	36.3
Garpe Juice	1	5	0.97	1.09	1.05	89.62	81.32	8.21
	2	5	1.72	0.94	1.55	95.46	67.55	5.43
	3	4.5	6.41	3.06	3.70	76.48	79.76	19.4
	4	4	5.02	6.70	5.96	64.16	52.84	23.3
	5	3.5	12.13	5.34	9.82	58.41	74.07	46.5
Grass	1	4.5	3.07	4.54	4.17	76.29	78.57	20.8
	2	4	6.7	6.92	8.47	65.02	77.85	26.9
	3	2.5	15.93	14.40	15.61	30.38	79.28	50.7
	4	3.5	18.35	12.90	11.85	2.28	38.25	46.6
	5	1.5	36.18	17.61	19.69	10.08	57.19	116.0
Blood	1	4	4.36	6.62	6.00	68.19	86.01	15.7
	2	4.5	3.50	2.33	4.22	83.18	79.68	10.8
	3	4	4.12	1.76	2.84	86.23	65.57	13.7
	4	2.5	17.07	22.70	22.19	40.82	68.73	51.0
	5	3	11.73	10.72	13.92	48.32	13.83	32.7

Table 2. Continued

Stains	Wash	GS	DE_{Lab}	YI	DE_{CMC}	WI	PSR	DE_{XYZ}
Make-Up	1	3	19.66	16.85	22.09	14.33	27.61	64.0
	2	3	11.93	10.92	13.26	44.93	55.96	37.2
	3	3	14.63	12.58	15.93	38.25	48.79	46.9
	4	2	20.89	21.83	24.54	8.57	21.25	69.0
	5	2.5	11.73	10.69	13.82	48.32	23.16	42.7

Gray scale (GS), E_{L*a*b*} (DE_{LAB}), yellowness index (YI), E_{CMC} (DE_{CMC}), whiteness index (WI), E_{XYZ}, (DE_{XYZ}), PSR of fabrics were obtained after one laundering. Negative values indicate increased whiteness.

Table 3. Color difference data for washed polyester/cotton fabrics

Stains	Wash	GS	DE_{Lab}	YI	DE_{CMC}	WI	PSR	DE_{XYZ}
Clay	1	3.5	12.32	4.19	11.31	39.39	59.28	36.60
	2	4.5	3.93	2.03	4.31	78.83	76.88	12.30
	3	3.5	12.12	9.87	11.92	43.50	79.49	38.60
	4	4.0	5.81	4.19	5.82	88.90	81.27	17.20
	5	4.7	1.53	-0.10	1.94	68.20	35.13	16.66
Dust Sebum	1	2.0	14.72	5.37	7.80	48.25	73.44	51.11
	2	4.0	5.38	3.60	5.64	70.99	86.73	16.82
	3	4.0	4.96	4.04	5.61	70.59	81.11	12.20
	4	4.5	9.28	6.78	16.66	82.27	82.26	9.28
	5	2.5	2.89	1.60	3.34	42.03	29.20	63.10
Gravy Sauce	1	4.0	0.9	-0.80	1.13	92.34	75.75	1.60
	2	5.0	1.47	-0.80	1.80	93.13	84.40	2.13
	3	4.5	2.09	0.74	2.62	87.10	80.56	3.86
	4	4.5	0.60	-0.25	1.96	90.60	82.40	1.60
	5	5.0	1.19	-1.20	1.04	84.09	53.32	3.04
Coccoa Mix	1	3.0	9.23	10.20	10.73	46.95	85.38	28.20
	2	3.5	8.13	6.66	8.43	57.77	83.61	29.10
	3	3.5	8.29	5.46	7.11	59.10	72.87	30.10
	4	3.5	9.78	8.76	9.78	49.25	33.90	9.98
	5	4.0	5.31	3.49	5.23	69.01	66.85	32.70
Spagetti Sauce	1	3.5	5.92	6.70	7.86	64.37	73.68	36.80
	2	4.0	3.80	2.68	4.91	79.80	85.20	27.40
	3	4.0	4.63	4.49	6.02	72.37	88.54	6.13
	4	4.5	4.74	4.12	5.91	72.36	63.25	30.40
	5	4.5	3.50	2.85	4.59	79.66	64.95	25.20
Grape Juice	1	4.5	5.51	4.44	6.00	67.48	67.47	16.10
	2	5.0	1.26	-1.30	1.40	94.00	82.17	3.35
	3	4.5	1.09	-10.00	1.20	92.93	53.32	3.68
	4	4.5	3.63	2.04	3.63	78.87	63.54	36.70
	5	3.5	10.11	8.57	10.25	58.41	66.43	10.30
Grass	1	1.0	30.82	14.90	15.79	14.61	70.89	101.01
	2	1.0	34.09	14.30	16.76	13.89	76.59	109.03
	3	1.5	27.56	17.00	17.23	13.66	75.96	90.30
	4	1.0	36.20	17.60	19.70	10.08	70.89	119.02
	5	1.5	36.04	23.80	21.44	10.08	61.16	114.03
Blood	1	4.5	3.70	2.60	4.16	76.16	11.46	15.54
	2	4.0	4.36	2.61	4.88	76.35	40.44	17.44
	3	4.5	3.12	1.82	3.72	81.06	10.26	11.10
	4	2.5	16.21	18.50	16.06	18.77	10.33	48.80
	5	3.0	15.78	18.31	18.36	18.82	2.94	43.60
Make-Up	1	1.0	26.62	24.30	26.08	1.59	32.95	77.10
	2	1.5	20.84	18.50	20.96	16.30	71.75	61.50
	3	4.0	5.08	12.60	4.05	71.50	75.48	16.10
	4	2.6	22.42	20.59	22.42	42.50	72.24	63.50
	5	3.0	11.58	10.90	13.31	42.50	21.25	31.72

Gray scale (GS), E_{L*a*b*} (DE_{LAB}), yellowness index (YI), E_{CMC} (DE_{CMC}), whiteness index(WI), E_{XYZ}, (DE_{XYZ}), PSR of fabrics were obtained after one laundering. Negative values indicate increased whiteness.

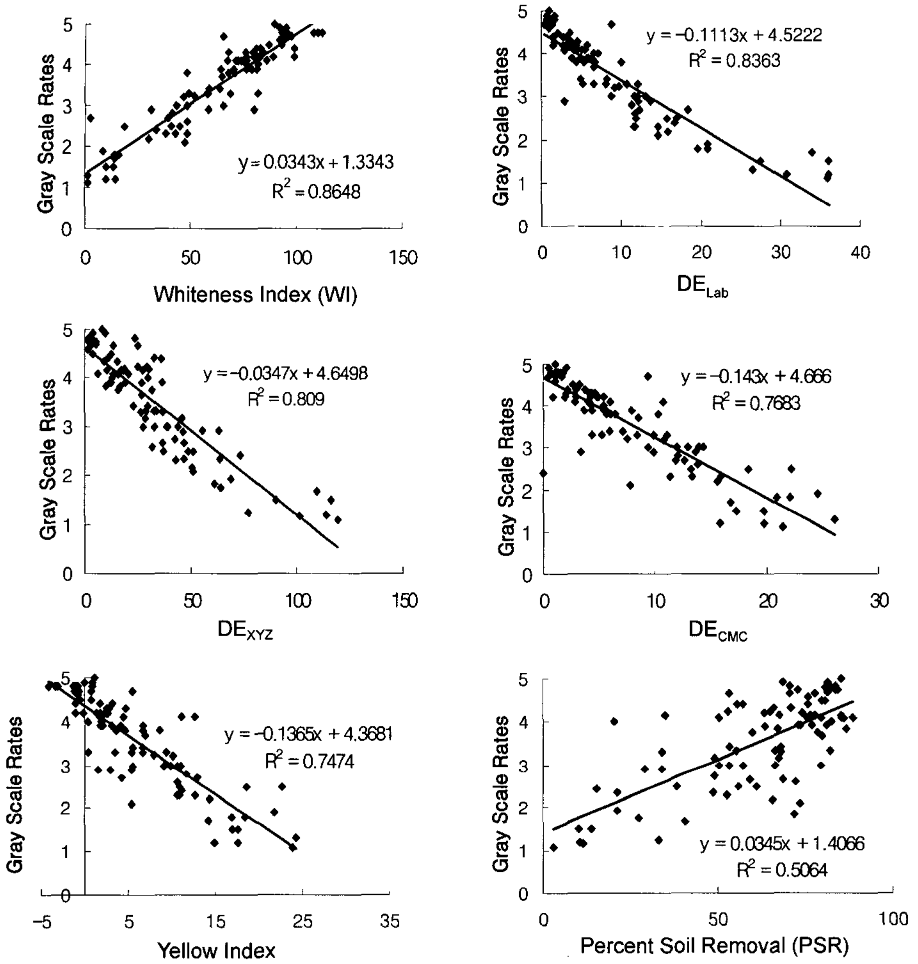

Fig. 1. Gray scale rates vs. corresponding soil removal values.

and make-up. After one laundering some stained fabrics showed relatively high or medium whiteness values.

In general, the laundered control samples were whiter and brighter than the unlaundered control. This was probably due to the fluorescent whitening agent (FWA) in the detergent. The FWA enlarged the range of whites far beyond the whiteness of the perfect diffuser, thus the whiteness values could be more than 100 and yellowness values could be less than 0.

We scatter-plotted the mean visual ratings for the washed samples as a function of WI, YI, DE_{CMC}, DE_{XYZ}, DE_{Lab}, and PSR(Fig. 1). The linear correlation between the subjective assessment mean and the above instrumental values was highly significant. The linear fit of the equation for the visually assessed gray scale as a function of various values of color difference can be determined from the values of R-squared that result from the regression analyses. The linear intercepts of the equation to the instrumental color difference data are shown in Table 4. The R^2s were in this order: WI> DE_{Lab}>DE_{XYZ}>DE_{CMC}>YI>PSR. The WI was found to have the highest correlation coefficient as well as the highest R^2. The DE_{Lab}, DE_{XYZ}, DE_{CMC}, and YI were well correlated with the visual gray scale rates by means of Pearson's correlation. These results suggest that the standard instrumental evaluation technique produce a good match that is close to that of human eye assessment. This means that visual assessment of soil

Table 4. Models for the estimation of visual gray scale rates (n = 90)

Models	R^2	*r*
G.S.=1.217+0.037*WI	0.865	0922
G.S.=4.483–0.074*DE_{Lab}	0.836	0.914
G.S.=4.65 –0.035*DE_{XYZ}	0.809	0.899
G.S.=4.046–0.008*DE_{CMC}	0.768	0.876
G.S.=4.514–0.135*YI	0.747	0.864
G.S.=2.77 +0.015*PSR	0.506	0.711

All r and R^2 were significant at p=0.05.

removal is a reliable and valid method. Since the human eye is the final determinant of acceptable soil removal for consumers, our results provide support for researchers reliance on the simple instrumental analysis.

The lowest correlation was disclosed between PSR and the visual scale rates. This results support that the simple measurement of PSR based on Y values only was not a reliable measurement of the amount of soil removal from fabrics. This may have been due to the FWA effect, which mainly increases the blue reflectance, in which increases the whiteness and decreases the yellowness of the washed fabrics. However, compared to the PSR and the YI, the WI takes into account the consumer's perception that bluer might be perceived whiter.

The CMC formula was not shown any significant improvement over CIE_{LAB} nor CIE_{XYZ}. In other words, WI following CIE_{LAB} can be used in order to evaluate most accurately soil release appearance of laundered white fabrics.

IV. Conclusion

Correlation analysis showed strong correlation between subjective visual ratings and the measurements from instrumental devices. This result indicates that if one has gray scale results, one can estimate instrumental results or vice versa depending on needs. Since the detergent and washing machine industries often use one instrumental value and the textile industry often uses another instrumental values or visual assessment, it is possible to estimate results from one constituency group to another. The WI was found to have the highest significant correlation coefficient. The lowest correlation was disclosed between PSR and the visual rates. The most widely used PSR method of making green reflectance measurements lead to poor estimation of the visual evaluation of apparent soils with real soils. Compared to the PSR and the YI, the WI and DE_{Lab} takes into account a consumers perception. We recommend the WI or DE_{Lab} as good instrumental means for the evaluation of soil removal that correlate well with subjective visual ratings.

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