J Forensic Sci, July 2007, Vol. 52, No. 4
doi: 10.1111/j.1556-4029.2007.00469.x
Available online at: www.blackwell-synergy.com

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Validation of LAB Color Mode as a Nondestructive Method to Differentiate Black Ballpoint Pen Inks*

ABSTRACT: Nondestructive digital processing methods such as lab color mode (available in Adobe® Photoshop®) are emerging as alternative methods for forensic document examiners to use when attempting to differentiate writing instrument inks. Although these techniques appear to be viable, little data currently exists regarding the known or potential error rates associated with these techniques. Without adequate data, the validity and reliability of these techniques, including lab color, can not be established. In an attempt to begin to address these issues, 44 black ballpoint ink pens were obtained and used to create 990 pen-pair samples for analysis using established lab color mode techniques. No erroneous findings of "different" were reported following the examination of the known pen-pair combinations in which the same pen was used to create the samples ($n = 44$). Of the remaining 946 samples, 737 pen-pair samples were differentiated using the lab color mode method, while 209 samples were unable to be differentiated and were recorded as either being "similar" ($n = 153$) or "unsure" ($n = 56$). Comparison of the lab color mode results with the results obtained through additional testing using traditional infrared reflectance and infrared luminescence test methods showed that lab color differentiated 102 pen-pair samples (11%; 102/946) that were not differentiated using a VSC-4C.

KEYWORDS: forensic science, questioned documents, ink examination, writing inks, nondestructive ink differentiation, ballpoint pens, Adobe® Photoshop® CS, lab color, Video Spectral Comparator-4C

Forensic document examiners (FDEs) are often faced with the task of attempting to differentiate between various handwritten entries suspected of being created with multiple writing instruments. Although various ink differentiation methods are available, FDEs may prefer to employ nondestructive test methods over methods that will cause damage to a document or to the ink(s). In these instances FDEs often rely upon various optical techniques, to include the use of ultraviolet and/or infrared (e.g., reflected infrared and infrared luminescence) sources, when attempting to discriminate inks (1). In recent years, however, there has been a growing interest in nondestructive ink differentiation techniques that rely solely on digital technology (e.g., flat-bed scanners and digital imaging software) (2–7).

Adobe® Photoshop® is a popular choice of digital imaging/enhancement software amongst FDEs. When combined with an image capture device (e.g., flat-bed scanner or digital camera) the imaging processing system provides the FDE with an economical and reliable forensic tool capable of completing numerous tasks, including the nondestructive differentiation of ballpoint pen inks.

Many of the methods utilized in digital imaging processing to discriminate between inks involve color separation (2–7). Of these, a method first reported by Manzolillo (5) known as lab color mode may be the most versatile. Lab color mode is a unique image mode (e.g., RGB, CMYK, grayscale, etc.), that allows the user to separate the brightness information from the color information within an image. It is this feature that allows this technique to discriminate between otherwise visually similar ballpoint pen inks.

Although the applications of lab color mode to forensic document examination have been reported (3–7), there exists little data concerning the known or potential error rates associated with its use. Extensive testing to assess the validity of the technique and reliability for differentiating inks is required to insure admissibility in court. The purpose of this study is to provide data to address the aforementioned issues.

Materials and Methods

Forty-four (44) black ballpoint ink pens (Table 1) were purchased from an office supply company and used to create 990 pen-pair samples. Each pen-pair sample contained a handwritten word ("light") produced from "Pen X" and a second handwritten word ("light") produced from "Pen Y" (Fig. 1). Each sample number was pre-determined by randomizing the x-y intersections on a 44 × 44 matrix (Fig. 2). The 990 samples included 44 different pen-pair combinations in which the same pen was used to create the "Pen X" and "Pen Y" entries. No pen-pair sample combinations were repeated. All of the samples were produced on Universal® Ultra Bright Multi-Purpose paper (Advantage Office Products, Jacksonville, FL) (92-brightness; 20 lb).

Over the course of 2 months, approximately 40 pen-pair samples were created per day and then set aside for 24–72 h. Following the 1–3 day "drying" period, each sample was scanned at 300 pixels per inch (ppi) using a calibrated UMAX® PowerLook 2100XL flat-bed scanner (Techville, Inc., Dallas, TX). The RGB images were saved as .tiff files.

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*A version of this paper was presented at the Annual Meeting of the American Academy of Forensic Sciences in Seattle, WA, February 2006, and at the Annual Meeting of the Southeastern Association of Forensic Document Examiners in Atlanta, GA in April 2006.

*The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army, the Department of Defense, or the U.S. Army Criminal Investigation Laboratory.

Received 4 Nov. 2006; and in revised form 30 Dec. 2006; accepted 31 Dec. 2006; published 4 June 2007.

TABLE 1—*Black ink ballpoint pens.*

No.	Manufacturer	Description	Point Size (F, M, B)*
1	Uni-ball	Jetstream	M
2	Uni-ball	Power Tank	M
3	PaperMate	DynaGrip	F
4	PaperMate	DynaGrip	M
5	PaperMate	X-tend	M
6	PaperMate	ComfortMate	F
7	PaperMate	Stick pens	F
8	PaperMate	Write Bros. Grip	F
9	PaperMate	Write Bros. Grip	M
10	PaperMate	Flexgrip Elite	F
11	PaperMate	Flexgrip Elite	M
12	PaperMate	Flexgrip Ultra	F
13	PaperMate	Flexgrip Ultra	M
14	PaperMate	Eraser Mate	M
15	PaperMate	Eraser.Max	M
16	Pentel	TKO	M
17	Pentel	R.S.V.P.	F
18	Pentel	R.S.V.P.	M
19	Pentel	Razzle-Dazzle R.S.V.P.	M
20	Bic	RoundStic	F
21	Bic	RoundStic	M
22	Bic	Round Stic Grip	F
23	Bic	Round Stic Grip	M
24	Bic	Cristal Stick	M
25	Bic	Atlantis Stick	M
26	Bic	Soft Feel	F
27	Bic	Soft Feel	M
28	Preventa	Antimicrobial	M
29	Pilot	Better	F
30	Pilot	Better	M
31	Pilot	EasyTouch	F
32	Pilot	EasyTouch	M
33	Pilot	EasyTouch	B
34	Pilot	BetterGrip	F
35	Pilot	BetterGrip	M
36	ZebraPen	Jimnie	F
37	ZebraPen	Jimnie	M
38	Universal	Comfort Grip	M
39	Universal	Economy	F
40	Universal	Economy	M
41	PaperMate	ComfortMate	M
42	PaperMate	Stick pens	M
43	Bic	Cristal Grip	M
44	Universal	Comfort Grip	F

* F, Fine (*c.* 0.7 mm); M, Medium (*c.* 1.0 mm); B, Broad (*c.* 1.2 mm).

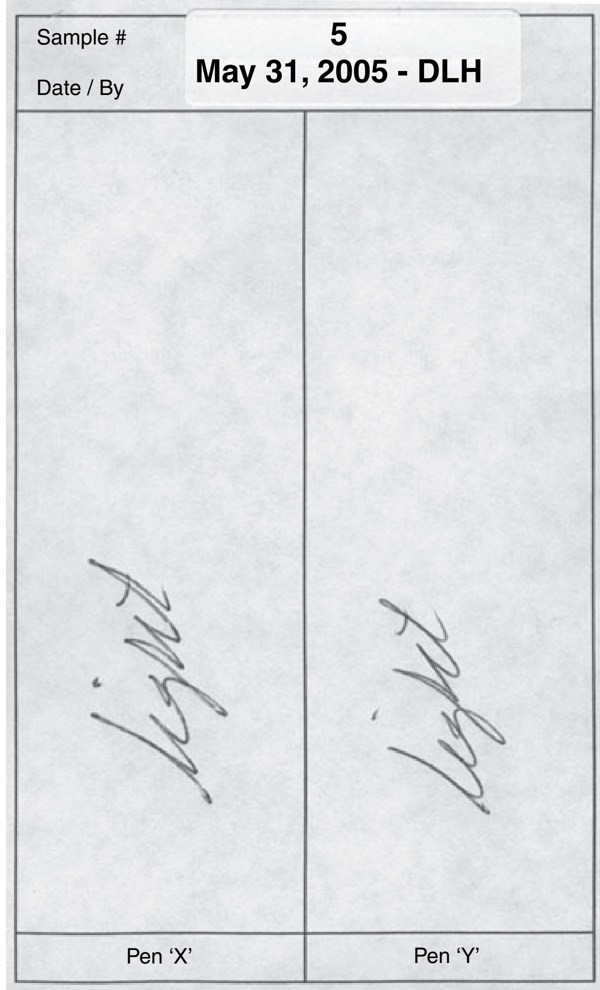

FIG. 1—*Pen-pair sample form.*

Lab Color

Adobe® Photoshop® CS was opened and a "batch command" was used to process all of the previously scanned and saved images. The "batch command" included using the pre-recorded set of "actions" listed in Table 2. The utilization of these features not only reduced the processing time (<2 sec/image) but also served as a quality control measure ensuring that each sample was subjected to the same processing techniques. The resulting "a" and "b" channel images were then examined to ascertain if the inks from the Pen "X" and Pen "Y" samples could be differentiated visually (Figs. 3–5). Results based on visual observation(s) of both the "a" and "b" channel images were recorded as "different", "similar" or "unsure." The lab color processed and enhanced (e.g., Auto Levels adjustment) images were saved.

Infrared

Immediately following lab color mode processing, each original pen-pair sample was subjected to infrared examination using a Foster & Freeman Video Spectral Comparator (VSC)-4C in accordance with the instructions in the manufacturer's User Guide. Results based on visual observation were recorded as "different," "similar" or "unsure." Images recorded as "different" were captured and saved. Images recorded as being "similar" or "unsure" were not saved as these results are inconclusive and are unlikely to have probative value.

Processing of the pen-pair samples using the VSC-4C was not undertaken as a means to validate the results obtained from lab color processing. Rather, the instrumentation was used to assess the infrared properties as a means to establish the relative discriminatory power of lab color mode by way of comparison with traditional test methods.

Results

Lab Color

No erroneous findings of "different" were reported following the examination of the 44 separate pen-pair combinations in which the same pen was used to create the "Pen X" and "Pen Y" entries. Processing of these samples using lab color mode resulted in findings of "similar" in each instance. Of the remaining 946 samples, 737 pen-pair samples were differentiated using the lab color mode

Pen 'X'

Pen 'Y'	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	797	64	384	199	739	180	184	663	459	441	171	305	193	317	689	793	614	531	415	25	200	120
2		604	472	9	737	598	770	219	297	165	123	231	321	238	168	543	268	326	380	813	669	261
3			735	106	447	685	100	506	513	744	487	111	10	574	181	659	487	514	571	86	421	718
4				765	358	124	419	210	91	325	176	807	806	115	351	496	546	166	540	709	204	519
5					648	390	703	139	433	350	80	602	173	630	611	662	376	226	213	719	227	332
6						290	694	769	607	665	552	298	482	55	493	355	2	42	495	401	269	278
7							229	138	20	18	619	151	107	791	61	156	764	49	288	553	38	819
8								366	87	775	586	768	652	403	354	577	73	410	90	435	12	722
9									58	805	337	396	731	85	322	430	484	33	135	381	481	128
10										160	147	195	142	137	798	612	605	668	561	517	417	810
11											153	224	625	702	661	244	272	104	175	187	145	41
12												483	310	515	544	242	356	222	516	232	203	629
13													772	130	348	27	524	774	281	705	628	726
14														818	817	320	360	771	785	480	275	443
15															457	436	452	163	280	167	593	344
16																679	46	776	523	763	794	578
17																	169	284	434	700	454	197
18																		687	198	440	473	501
19																			181	721	378	324
20																				385	485	412
21																					319	352
22																						211

Pen 'Y'	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
1	397	461	518	632	420	277	214	259	670	466	81	533	647	238	683	751	634	14	890	939	982	911
2	599	286	249	122	369	300	431	125	588	282	456	253	511	712	755	640	382	672	961	951	856	959
3	384	243	688	264	413	327	393	732	402	622	564	191	682	525	450	714	502	93	984	871	861	840
4	610	479	563	698	330	711	510	585	349	587	62	758	70	255	576	338	307	723	943	864	874	849
5	237	678	54	442	13	289	749	582	83	94	795	40	445	639	53	223	62	565	857	970	957	842
6	387	608	308	597	624	562	704	491	315	743	549	15	779	570	374	733	738	392	868	876	823	830
7	773	132	225	643	641	677	528	16	666	425	172	287	263	234	22	194	803	108	832	872	929	954
8	815	285	270	174	217	448	72	43	371	490	754	509	521	724	252	699	657	7	824	862	947	829
9	745	566	503	422	697	67	162	621	626	34	654	637	783	535	537	314	399	423	894	974	969	865
10	596	728	691	701	729	575	478	155	84	267	361	208	507	747	713	373	209	235	843	918	944	891
11	76	159	148	583	644	133	271	368	192	140	613	554	651	48	449	149	589	649	966	869	875	945
12	68	623	63	792	814	75	260	477	790	239	557	31	362	645	35	119	47	671	860	938	898	854
13	8	164	274	57	796	395	631	4	579	469	717	52	367	498	102	65	79	293	895	837	881	920
14	757	742	389	114	542	684	32	680	336	532	363	398	220	820	407	787	400	800	976	828	858	873
15	584	580	811	594	221	388	359	92	302	291	5	375	405	568	342	696	121	329	839	972	880	826
16	727	256	183	760	201	464	188	95	348	245	592	409	127	660	627	182	44	347	889	932	913	882
17	492	801	650	303	370	367	494	756	247	295	178	655	816	573	465	26	778	789	859	838	937	846
18	69	51	141	812	429	251	488	656	292	331	78	788	674	636	39	110	340	189	964	978	960	912
19	309	23	66	126	710	190	21	296	262	572	406	439	692	734	74	131	720	693	910	893	909	883
20	463	782	313	451	555	353	316	748	428	547	615	781	799	212	377	500	19	233	836	941	935	950
21	462	306	453	635	257	638	343	508	786	595	116	157	323	675	134	633	766	113	877	834	863	915
22	96	604	676	205	438	476	499	444	716	767	318	567	158	455	474	658	708	725	919	985	847	989
23	673	339	150	609	301	504	470	541	601	105	118	590	273	646	475	3	77	335	963	845	888	853
24		391	740	414	416	37	687	424	345	230	89	279	17	129	103	207	99	143	831	952	990	940
25			780	458	218	603	468	539	136	784	736	240	328	299	741	642	112	341	852	904	886	936
26				512	753	88	148	486	29	170	526	1	152	60	681	388	730	653	988	967	933	953
27					11	24	97	109	250	202	266	536	248	294	617	686	383	616	949	827	868	906
28						334	364	556	426	177	28	379	715	695	559	311	591	550	901	924	977	887
29							185	59	241	529	258	548	117	215	254	437	761	762	987	981	928	835
30								179	408	777	606	569	30	312	506	600	809	432	907	923	848	921
31									101	538	446	276	534	404	98	411	690	620	867	930	926	917
32										228	186	56	471	497	36	802	144	427	873	851	905	946
33											333	746	6	750	560	206	551	154	821	986	897	980
34												216	45	265	520	558	664	530	870	971	848	850
35													608	752	372	418	304	759	896	902	922	903
36														71	50	618	283	706	916	908	958	983
37															198	246	522	707	942	975	962	855
38																460	581	545	956	844	914	892
39																	365	527	884	931	825	899
40																		489	927	841	965	878
41																			822	955	885	900
42																				879	979	925
43																					934	833
44																						968

FIG. 2—*Pen-pair matrix (N = 990).*

TABLE 2—*Lab color mode action commands set.*

Step No.	Command
1	Rotate Image 90°
2	Convert Mode (lab color)
3	Hide Lightness Channel
4	Hide "a" Channel
5	Split Channels
6	Close "L" Channel Image
7	Auto Levels on "a" Channel Image
8	Auto Levels on "b" Channel Image

method while 209 samples were not differentiated and were recorded as either being "similar" ($n = 153$) or "unsure" ($n = 56$) (Figs. 6 and 7).

VSC-4C

No erroneous findings of "different" were reported following the examination of the 44 separate pen-pair combinations in which the same pen was used to create the "Pen X" and "Pen Y" entries. Semi-blind processing of these samples using infrared techniques resulted in findings of "similar" in each instance. Of the remaining 946 samples, 759 pen-pair samples were differentiated using traditional infrared techniques, while 187 samples were not differentiated and were recorded as either being "similar" ($n = 165$) or "unsure" ($n = 22$) (Figs. 7 and 8).

Lab Color Versus VSC4-C

In terms of its relative discriminatory power in differentiating black ballpoint pen inks, lab color mode processing produced results that are comparable to that of the VSC-4C (Table 3).

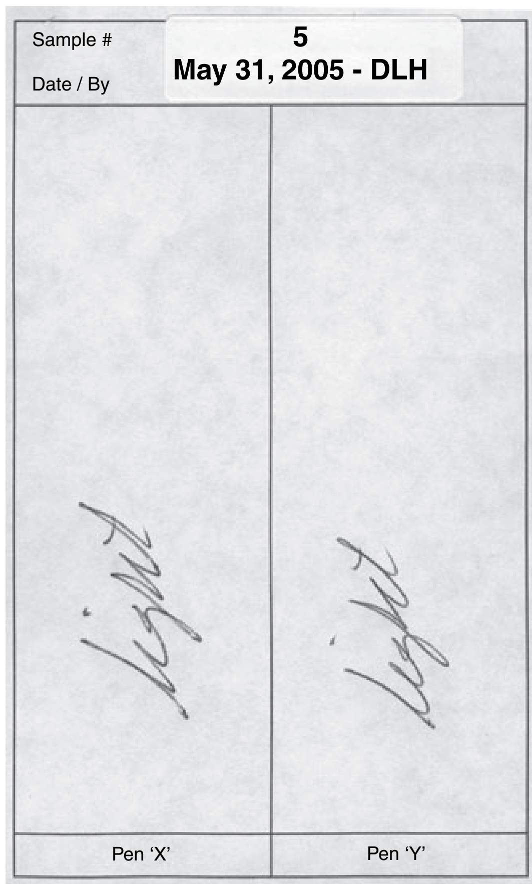

FIG. 3—*Greyscale image (Sample no. 5).*

FIG. 4—*LAB color mode – "a" channel image (Sample no. 5).*

FIG. 5—*LAB color mode – "b" channel image (Sample no. 5).*

Out of the 737 samples differentiated using the lab color mode method, 102 (11%) were not differentiated using the VSC-4C. Conversely, of the 759 samples differentiated by the VSC-4C, 124 (13%) were not differentiated using lab color (Fig. 9).

Discussion

The results of this study indicate that the use of lab color mode is a valid and reliable method to nondestructively differentiate black ballpoint pen inks. In addition, lab color mode was able to differentiate a significant number of pen-pair samples that traditional infrared techniques could not. However, traditional infrared examination methods using the VSC-4C were able to differentiate a significant number of pen-pair samples that the lab color mode technique could not. These results demonstrate the value of each technique and provide support for the recommendation that FDEs should begin to utilize both methods if the initial method employed is unable to discriminate between the samples examined. Failure to take this extra step may lead examiners to a false finding that the inks cannot be differentiated when in fact the other technique may have been capable of demonstrating otherwise.

Although the results of this study are promising, one can not predict the success or failure rate of this technique in differentiating other writing media (e.g., non-black ballpoint pen inks, gel ink pens, etc.). In addition, while variables such as the paper and the amount of time the ink was allowed to "dry" on the paper were controlled in this study, changes to these variables may have an impact on lab color mode's ability to differentiate black ballpoint pen inks.

During this project each of the samples examined were created and processed by the author, albeit not on the same day. Optimally the samples would have been created by one person and analyzed by a different person. As this was not the case, the possibility that any pre-existing knowledge on the part of the author could have influenced the results must be acknowledged.

A final limitation concerns the pens used and the actual ink formulations within those pens. The pen-pair combinations used to create the samples were known, thereby allowing the examiner to verify whether or not one pen or two were used to create each sample (Figs. 2, 6, and 8). What is still unknown is which, if any, of the pens contain the same ink. Obviously if the same pen was used to create the "Pen X" and "Pen Y" specimens, then the same ink was involved and a finding of "similar" or even "unsure" would not be misleading or incorrect. However, consideration must be given to the possibility that multiple pens, either from the same or even different manufacturers, may use the same inks. In this instance a finding of "different" would not have been accurate.

For example, Pens no. 8 and no. 9 in this study were each PaperMate® Write Bros. Grip™ (Sanford, Bellwood, IL) black ink ballpoint pens (Table 1). One has a fine point (Pen no. 8) whereas the other has a medium point (Pen no. 9). The ink(s) utilized in these two different pens could not be differentiated through examinations by either the VSC-4C or lab color. The use of each of these techniques led to recorded findings that the ink(s) were "similar" (Figs. 6 and 8). It is unknown whether these two pens use the same ink or whether the ink formulation for each is different and the techniques just failed to differentiate them.

Conversely, consider the results pertaining to Pen no. 3, a PaperMate® DynaGrip™ with a fine point, and Pen no. 4, a PaperMate® DynaGrip™ with a medium point (Table 1). Lab color mode processing was unsuccessful in differentiating the pen-pair sample containing writing from these two pens (Fig. 6). However, processing via the VSC-4C led to a finding that the sample created with these two pens was "different" (Fig. 8). Although the sample was verified as having been created using two different pens, it is unknown whether the manufacturer utilizes the same ink formulations in these pen models. Clearly, information from each of the pen and ink manufacturers, in

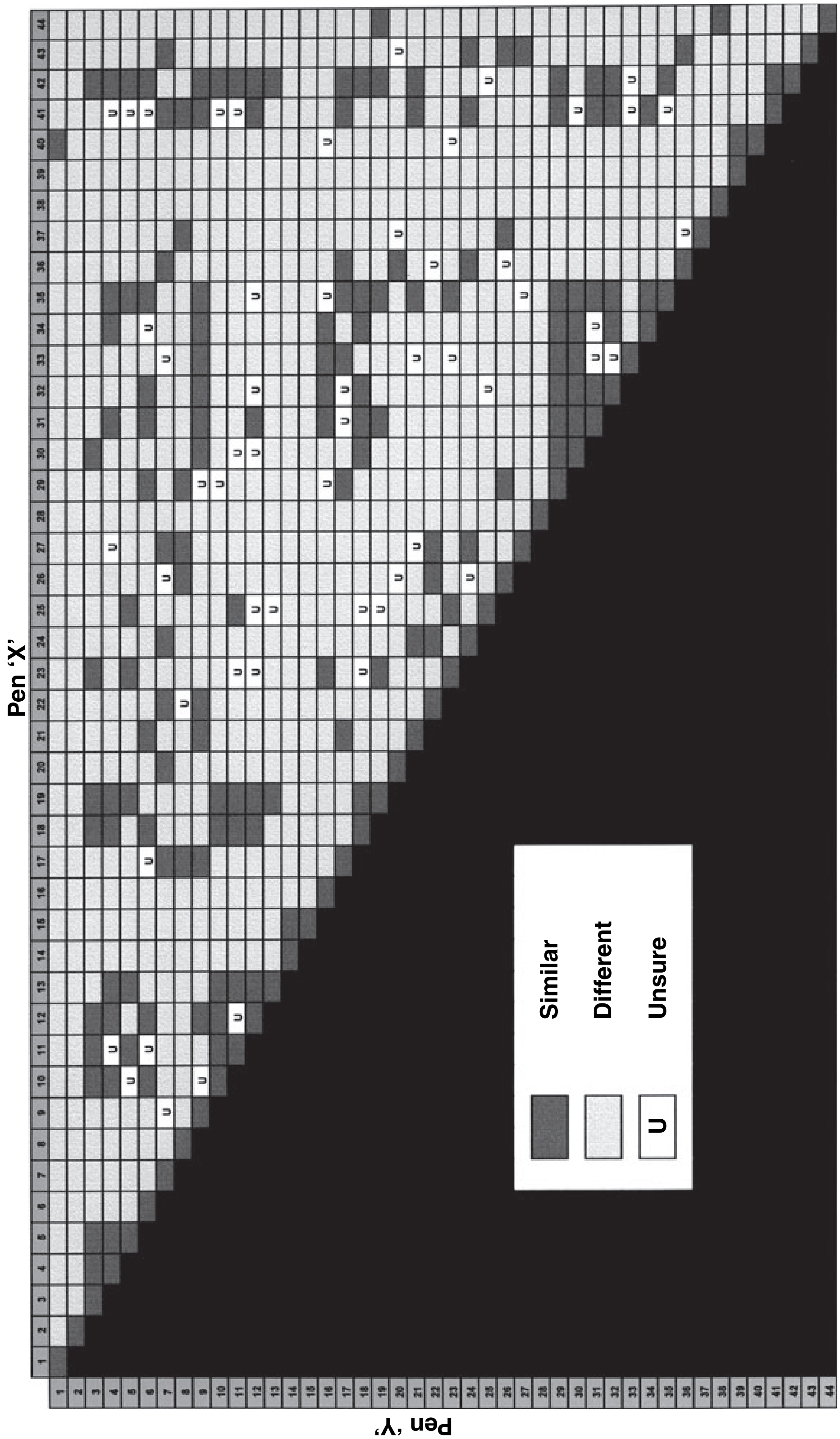

FIG. 6—*Results of LAB color mode processing.*

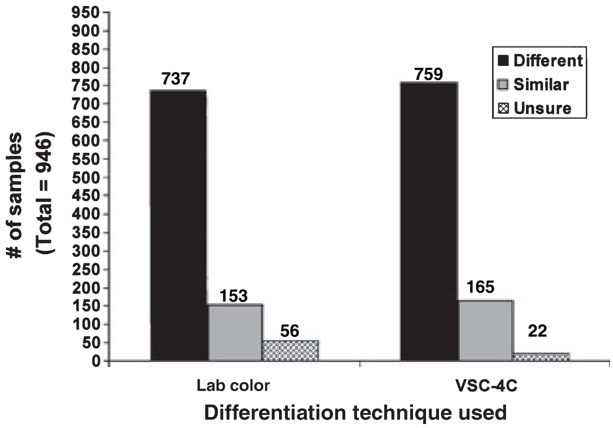

FIG. 7—*Comparison of results — LAB color mode versus VSC-4C.*

TABLE 3—*Discriminatory power.*

	No. of Samples	No. Differentiated	% Differentiated
Lab Color	946	737	78
VSC-4C	946	759	80

conjunction with destructive chemical analysis of the various inks, is required to definitively resolve this matter.

Even with due consideration given to the stated limitations of this study, the data appears to provide support for the proposition that lab color mode is a valid technique to nondestructively differentiate black ballpoint pen inks.

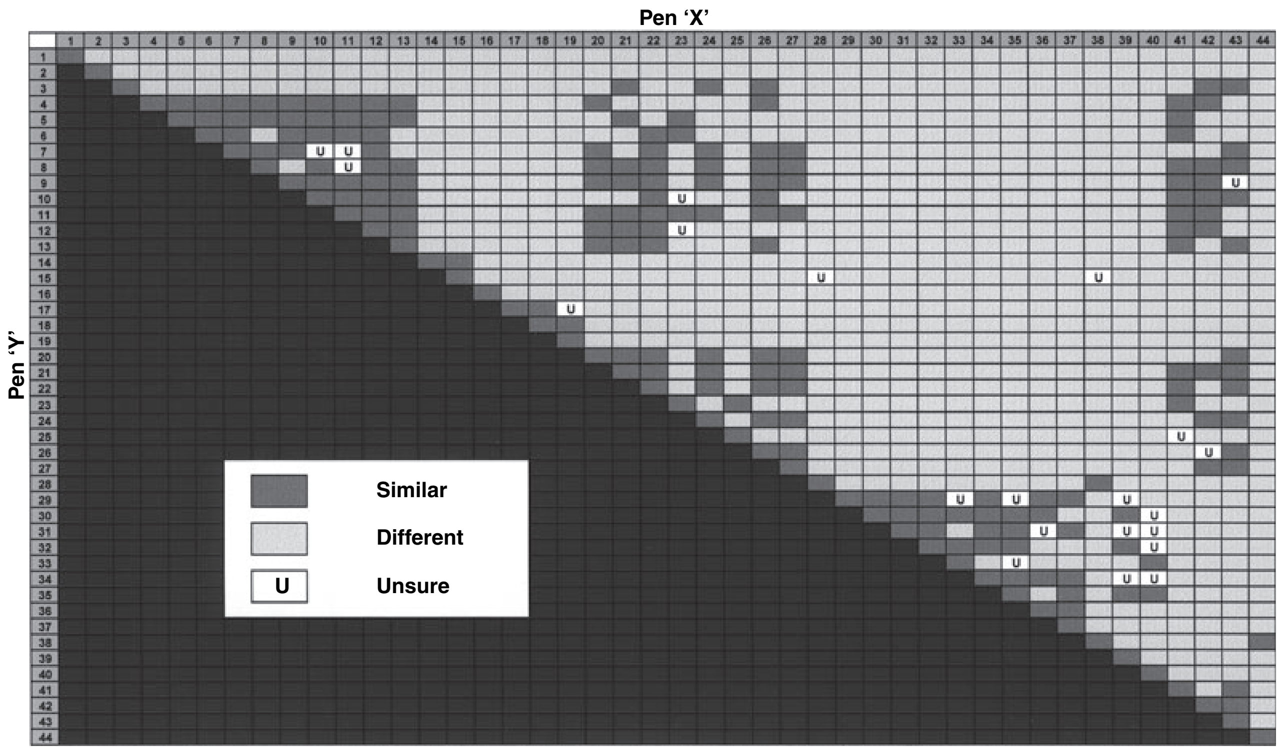

FIG. 8—*Results of VSC-4C processing.*

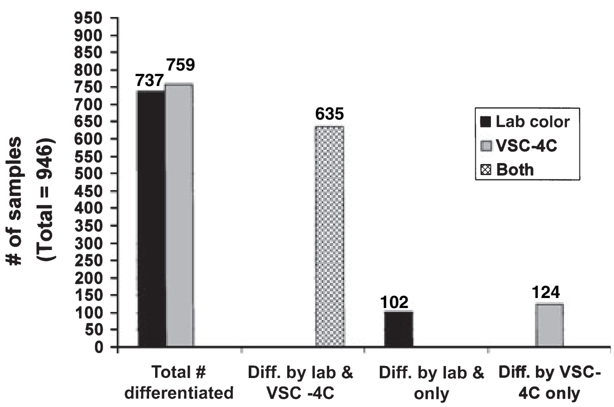

FIG. 9—*Comparison of results — LAB color mode versus VSC-4C.*

Acknowledgments

I gratefully acknowledge the assistance received from Gerry LaPorte and Joseph Stephens (U.S. Secret Service – Forensic Services Division). Their knowledge and passion for writing instrument inks was apparent during their critical review of this article. The comments and suggestions stemming from their review were thoughtful and extremely helpful in improving the overall quality of this article.

References

1. ASTM International-ASTM E 1422–05. Standard guide for test methods for forensic writing ink comparison. West Conshohocken, PA: ASTM International, 2006.
2. Bodziak WJ. Using a flatbed scanner and Adobe Photoshop software to distinguish black inks. Proceedings of the 58th Annual Meeting of the

American Society of Questioned Document Examiners; 2000 Aug 25-29 Ottawa, Canada; Long Beach, CA: American Society of Questioned Document Examiners, 2000.
3. Herbertson G. Document examination on the computer – a guide for forensic document examiners. Berkeley: WideLine, 2002.
4. Hammond DL. Color differentiation techniques using Adobe Photoshop 7.0. Proceedings of the 2004 workshop, document examination techniques in non-handwriting cases, by the American Board of Forensic Document Examiners; 2004 Oct 26-28; Las Vegas, NV. Houston, TX: American Board of Forensic Document Examiners, 2004.
5. Manzolillo PA. The use of Adobe Photoshop lab color mode in forensic document examination. Proceedings of the 58th Annual Meeting of the American Society of Questioned Document Examiners; 2000 Aug 25-29; Ottawa, Canada. Long Beach, CA: American Society of Questioned Document Examiners, 2000.
6. Hammond DL. Adobe Photoshop 7.0 lab color mode – applications in forensic document examination. Proceedings of the 56th Annual Meeting of the American Academy of Forensic Sciences; 2004 Feb 17; Dallas, TX. Colorado Springs, CO: American Academy of Forensic Sciences, 2004.
7. Chaikovsky A, Brown S, David SL, Balman A, Barzovski A. Color separation of signature and stamp inks to facilitate handwriting examination. J Forensic Sci 2003;48(6):1396–405.

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