J Forensic Sci, July 2003, Vol. 48, No. 4
Paper ID JFS2002280_484
Available online at: www.astm.org

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Characterization and Aging Study of Currency Ink and Currency Canine Training Aids Using Headspace SPME/GC-MS

ABSTRACT: Solid-phase microextraction/gas chromatography-mass spectrometry (SPME/GC-MS) was used to characterize the volatile components associated with U.S. currency, U.S. currency inks, and Canadian currency. Compounds that can be attributed to the ink-curing process include series of straight-chain aldehydes, alkenals, acids, alcohols, and ketones and a series of lactones and 2-alkyl furans. Solvent compounds include naphthenic and paraffinic hydrocarbons with a profile typical of petroleum products, alkyl cyclohexanes, various ethylene glycol alkyl ethers, and traces of chlorinated solvents. Trace levels of 2-phenoxyethanol, a solvent often used in ink formulations, were also detected. Environmental contaminants, those compounds found in circulating currency but not in currency ink, include 2,2′-diethyl-1,1′-biphenyl, methyl benzoate and salicylate, menthol, limonene, dimethyl and diethyl phthalate, and ionol. Not including simple hydrocarbons, over 100 compounds were identified in the headspace of currency-related samples.

KEYWORDS: forensic science, solid-phase microextraction, U.S. currency, ink, Canadian currency, detector canines

In addition to drug interdiction, the U.S. Customs Service plays an important role in stopping the flow of illegal profits from leaving the country. Since September 11, 2001, there has been additional interest in preventing transportation of currency that could potentially be used to support terrorist activities (1). As increased scrutiny makes electronic transactions more difficult, movement of money derived from or to support illegal activities will increasingly be accomplished by human carriers and by shipping large quantities of currency in luggage and cargo containers (2–4). Although there is no limit on the amount of money that may legally enter or exit the United States, U.S. law requires declaration of movement into or out of the U.S. of currency or other monetary instruments totaling more than $10,000 (5). Failure to do so can result in seizure and forfeiture to the United States Government of such instruments and any property involved in such transactions (6). To ensure compliance with these laws, U.S. Customs officers are allowed to search without a search warrant any conveyance or persons crossing U.S. borders; however, personnel and time constraints still limit the number of searches that can realistically be done, and some method of screening passengers and cargo is needed.

U.S. Customs has had great success with currency detector canines, which have made seizures averaging about one million U.S. dollars per team per year during each of the last two years (7). To avoid the problems often associated with probable cause when a drug detector canine alerts to currency (8), Customs currency canines are trained only on the odors associated with currency and are never explicitly exposed to drug odors during training. Currency canine training aids include shredded (circulated and uncirculated) U.S. currency, circulating U.S. currency, currency inks, and materials scented with the odor of currency, such as cotton balls. Customs canines are trained on a targeted minimum odor level so that they will not alert to everyone who is carrying currency. This project was undertaken to establish a correlation between the odor profiles and odor levels of the different currency training aids and to study the aging characteristics of currency inks to determine the useful lifetime of such training aids. While the project was underway, a representative of Canada Customs and Revenue Agency (CCRA) requested a comparative analysis between U.S. currency (US$) and Canadian currency (CA$) for the purpose of starting a currency canine program in Canada. Use of Canadian currency for laboratory analysis and canine testing provided significant clues on which headspace compounds may be important to canine detection of currency.

Materials and Methods

Based on previous work (9) and on initial results, a 1-cm, 50/30-μm divinylbenzene/Carboxen/PDMS SPME fiber (Supelco, Bellefonte, PA) was chosen for all currency analyses. Fibers were conditioned according to manufacturer's instructions until a clean chromatogram was obtained under normal run conditions. In addition, fibers were heated in the GC inlet for at least 2 min before each headspace sampling to ensure that they were free from environmental contaminants, and fibers were left in the inlet for the full length of a run to eliminate carryover.

Containers in which samples were placed for headspace analysis included glass containers ranging from 40 mL to 1 gal in volume and cardboard boxes, depending on the analysis at hand. All glass containers were steam cleaned, rinsed with acetone, and baked for at least 12 h at 150°C prior to use. Unless otherwise specified, comparative analyses were done with each sample placed in a gallon jar, the jar covered with aluminum foil, and the headspace immediately sampled at ambient conditions (typically 23°C, 40% RH) by

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Received 17 August 2002; and in revised form 14 Feb. 2003; accepted 14 Feb. 2003; published 19 May 2003.

puncturing the foil and exposing the SPME fiber inside the container for 15 min (Fig. 1*a*). For some comparisons, samples were left in the covered container for 1 h or more ("incubation" or "equilibration" time) to allow odor buildup before headspace sampling, and a longer sampling time was also used as needed to obtain a more complete headspace profile.

Tables 1 and 2 list the types of samples for which headspace data were obtained. Not listed are currency-scented cotton balls, prepared by storing from 1 to 15 large cotton balls (Wal-Mart brand) in tightly capped jars containing ink mixtures for various lengths of time from 2 h to 1 month. Ink mixtures were air-dried at least 18 h prior to being used as scenting agents for cotton balls. The hard film that was formed during the drying process still allowed odors to permeate the cotton balls but prevented any ink transfer onto the cotton balls. To determine the effect of storage on odor levels, bulk U.S. currency samples were analyzed after being stored for a week under various conditions: (1) loosely in a drawer (Fig. 1*b*), (2) tightly packed in a glass container covered with Al foil (Fig. 1*c*), or (3) tightly packed in an uncovered glass container. Ink samples were analyzed after being stored tightly capped or uncapped to determine the effect of storage on their headspace profiles. Likewise, cotton balls were analyzed either immediately after removal from the incubating ink jars or after sitting in open jars for up to 1 h to simulate setup time in a canine training session.

Data were acquired on an HP 5980/5970 GC/MSD (Hewlett Packard, Palo Alto, CA), fitted with a 30-m by 0.25-mm by 0.25-μm (5%-phenyl)-methylpolysiloxane column (XTI-5™, Restek, Bellefonte, PA, or Zebron-5™, Phenomenex, Torrance, CA) with He as the carrier gas. The inlet was operated in constant pressure mode at a pressure of 10 psi. The 0.75-mm ID inlet liner

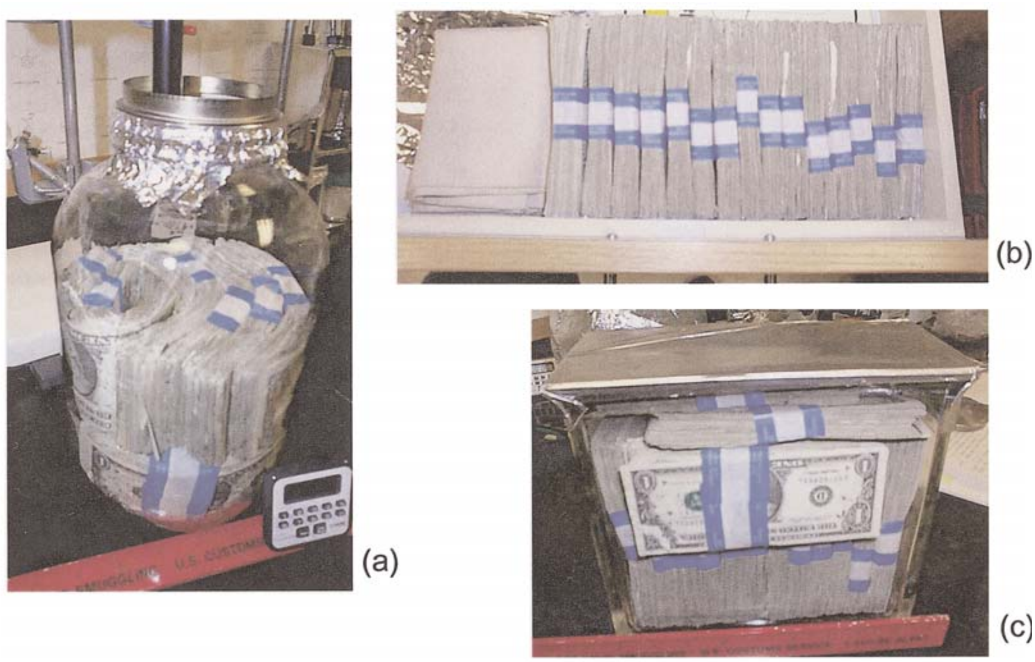

FIG. 1—*1200-US$1 in gallon jar for SPME headspace sampling* (a), *storage of 1500-US$1 in drawer* (b) *and in covered jar* (c).

TABLE 1—*U.S. and Canadian circulating currency samples analyzed by headspace SPME/GC-MS. For both the U.S. and Canadian currency, new- and old-style refer, respectively, to the most recent bill design with additional security features and to the older design.*

Currency Samples	Sample Size	Sample Source
U.S. Federal Reserve Notes		
One dollar bill (US$1)	1, 25, 50, 100, 200, 400, 500, 800, 1200, and 1500 bills	500 bills from local bank (Suntrust) 1500 bills from Federal Reserve Bank of Richmond
US$5 (new- and old-style), US$20 (new-style), US$50 (new- and old-style)	One to 20 bills	Personal cash
Shredded, uncirculated	10 to 480 g	Bureau of Engraving and Printing (Washington, DC)
Shredded, circulated	1 kg compressed brick	Federal Reserve Bank of New York (East Rutherford, NJ)
Canadian		
Five dollar bill (CA$5)	50 and 100 bills	Canada Customs and Revenue Agency
CA$10	54 old-style bills 46 new-style bills	

TABLE 2—*U.S. currency inks were made by SICPA, Inc., and provided by the Bureau of Engraving and Printing, Washington, DC. Individual inks were analyzed by spreading 0.5 g or less of ink on a microscope slide or by using the whole ink can (net weight up to 150 g). For ink mixtures, bulk quantities were made by mixing individual inks to a certain weight ratio, and smaller quantities were spread into other containers for analysis and storage.*

Ink ID	Process	Initial Odor Impression
Intaglio green (I286)		Odor most like money
Intaglio black—magnetic (I287)	Roller sheet fed	Odor like I286 but stronger
Intaglio black—nonmagnetic (I600)		Faint aldehyde odor
Currency overprinting equipment (COPE) black (I687)		Sweet, licorice odor
COPE green (I347)	Letter press—raised surface	Pungent, acrid odor reminiscent of acids
COPE green (I1201)		Faintly sweet odor
Ink mixture A: 1:1 ratio of each ink listed above (net 6 g ink per sample)		Pungent, acrid odor reminiscent of acids
Ink mixture B in approximate ratio used to print U.S. currency (net 0.4 to 3 g ink per sample)	Both of above	Odor reminiscent of new money

(Supelco) is designed specifically for SPME work. The GC oven temperature was held at 50°C for 1 min, ramped at 5°/min to 200°C, then at 35°/min to 270°C, and held for 2 min at the final temperature. The inlet and MS transfer line temperatures were 260 and 300°C, respectively. Splitless injections were done with a purge activation time of 1 min. The MS was operated in electron ionization mode with a scan range of m/z 33 to 150 from 0.75 to 10 min and m/z 40 to 440 during the rest of the run. All other MS parameters were set at auto tune values.

Headspace components were identified by comparing their mass spectra with those found in reference libraries (Wiley, 6th ed.; Pfleger, 2nd ed.; and NIST, 1998 ed.). A list of possible compounds was generated using an automated library search routine with probability-based matching (PBM) algorithm, and each mass spectrum was visually inspected to verify the match. Additionally, selected components (marked † in Table 3) were identified by both their retention times and mass spectra as generated from running standards, made from reagent grade chemicals from Aldrich (Milwaukee, WI). When a new column was installed, retention times were uniformly shifted, but standards were rerun for verification. Unless otherwise specified, all chromatograms were plotted on the same y-scale for ease of comparison.

Results and Discussion

With the exception of certain high-security inks such as the optical variable ink (OVI™, SICPA Inc., Springfield, VA) that are used only in US$10 and higher denominations, all U.S. currency is printed using the same combination of inks, and those listed in Table 2 comprise close to 100% of all the inks present on a finished bill. Consequently, it is expected that, incidental contamination from handling aside, different denomination bills will have essentially the same headspace components, and these come either from the ink aging or curing process or from solvents that were used to make the inks. Unprinted currency paper was not available for analysis, but it is expected that the paper contributes negligibly, if at all, to the headspace of printed currency (10). Figure 2 confirms the similarity in the headspace profiles of a single US$1 and a single US$20: the ink-curing products region overlaps nearly exactly between the two analyses, the major difference being in the hydrocarbon solvent region. The lower solvent level in US$20 is not surprising given that the average age of a US$20 is 4 years and that of US$1 is 22 months (11), and more solvent will have evaporated from an older bill. Currency inks, on the other hand, continue to cure during the life of a bill, and most ink curing compounds can still be found in bills that are more than 35 years old, at levels about one half to one third of those found in newer bills (Fig. 3). Table 3 lists those compounds that have been identified in various currency-related samples; most solvent compounds (branched hydrocarbons and alkyl cyclohexanes) were not specifically identified and are not listed.

Results from the present study indicate that the ink curing products, rather than the solvent components, play a critical role in canine detection of currency. First, Customs' currency canines alert only to large quantities of currency and not to many other materials (12) that also outgas hydrocarbon solvents typical of petroleum products. Second, although Customs currency canines are trained using primarily US$1, they have alerted to concealments containing other denominations such as US$20 and US$100. In preliminary tests, U.S. currency-trained canines were also able to detect hidden Canadian currency, despite the fact that there were negligible levels of hydrocarbon solvents in the headspace of Canadian currency (Fig. 4) and that, to the human nose, Canadian currency smells distinctly different (sweet) from U.S. currency (paint-like in new bills to rancid in old). Differences that may have contributed to the sweet odor include much lower levels of acids and a higher level of 2-ethylfuran (Fig. 5), and/or a much higher level of 1,3,5-triisopropylbenzene in Canadian currency. Additionally, isophorone and benzophenone were also identified in the headspace of Canadian but not U.S. currency, and both compounds are described as having a sweet smell (Table 4). Nevertheless, a comparison of the headspace profiles of Canadian and U.S. currency showed substantial similarities in the ink curing products region, indicating that it is these compounds that are important to canine detection of currency. Thus, while it is sometimes possible to establish a correlation between the odor of a training aid as perceived by a canine and as perceived by a human (13), Canadian currency test results indicate that instrumental analysis provides a more reliable indication of key canine odor compounds.

All canines have native detection thresholds below which they are unable to locate a trained odor. Through targeted training, it is possible to raise, but not lower, the level below which they will not alert. Figure 6 shows that the odor level does, in fact, increase with

TABLE 3—*Headspace compounds identified in U.S. and Canadian currency. Compounds found only in Canadian currency are marked with an asterisk (*). Those for which references were available and which were identified by both retention times and mass spectra are marked with †. Contaminants are marked with ‡. Not listed are 22 unknowns in the headspace of Canadian currency, over 50 branched and cyclic hydrocarbons, and several chlorinated solvents.*

Aldehydes
pentanal†
3-methylbutanal
hexanal†
heptanal†
octanal†
nonanal†
decanal†
2-butenal
2-pentenal†
2-methyl-2-butenal
2-hexenal†
2,4-hexadienal†
2-heptenal†
2,4-heptadienal†
2-octenal
Acids/Esters
formic acid
acetic acid†
propanoic acid†
2-methylpropanoic acid
butanoic acid†
3-methylbutanoic acid
pentanoic acid†
hexanoic acid†
heptanoic acid†
2-ethylhexanoic acid†
octanoic acid†
2-butoxyethanol acetate
3-hydroxy-3-isopropylbutyrate
methyl benzoate‡
methyl salicylate‡
Furans/Lactones
2-ethylfuran
2-butylfuran
2-pentylfuran†
2-hexylfuran
2-heptylfuran
2-octylfuran
2,3-dihydro-4-methylfuran
dihydro-2(3H)-furanone (butyrolactone)
5-methyldihydro-2(3H)-furanone (gamma-valerolactone)
5-ethyldihydro-2(3H)-furanone (gamma-caprolactone)
5-butyldihydro-2(3H)-furanone
5-pentyldihydro-2(3H)-furanone
Aromatics
1,3,5-tri(isopropyl)benzene
2,2′-diethyl-1,1′-biphenyl‡
2-t-butyl-5-ethylphenol
3,5-dimethylphenol
Benzaldehyde
benzyl alcohol
chlorobenzaldehyde
Naphthalene
phenol†
Miscellaneous
3,3-dimethylbutanamide
dimethyl phthalate (DMP)‡
diethyl phthalate (DEP)‡
benzothiazole‡
Methylpyrazine
2,6-dimethylpyrazine
Alcohols
Ethanol
butanol†
pentanol†
hexanol†
heptanol†
octanol†
2-ethylhexanol†
1,2-propanediol
Glycerol
2-octanol
Cyclohexanol
menthol†‡
butylated hydroxy toluene (BHT)
Ionol
Ketones
Acetone
2-pentanone†
methyl isobutyl ketone
2-hexanone
2-heptanone†
2-octanone†
6-methyl-2-heptanone
6-methyl-5-hepten-2-one†
2-nonanone†
2-decanone†
Undecanone
cyclohexanone†
2,3-octadione
2,6-di-t-butyl-2,5-hexadiene-1,4-dione
4-hydroxy-4-methyl-2-pentanone
3,5,5-trimethyl-2-cyclohexen-1-one (isophorone)*
geranyl acetone‡
benzophenone*
Ethylene glycol ethers and related solvents
hexaethylene glycol dimethyl ether
2-butoxyethanol
2-(2-methoxyethoxy)-ethanol
1-butoxy-2-propanol
2-(2-ethoxyethoxy)ethanol
2-phenoxyethanol
1,2-diphenoxyethane
Hydrocarbons
octane†
nonane†
decane†
Undecane
dodecane†
Tridecane
tetradecane†
Pentadecane
hexadecane†
Heptadecane
1-heptene
2,4,4-trimethyl-1-pentene
2,4,4-trimethyl-2-pentene
1-octene†
2,4-octadiene
3-ethyl-2-methyl-1,3-hexadiene
Limonene
alpha-pinene
Longifolene

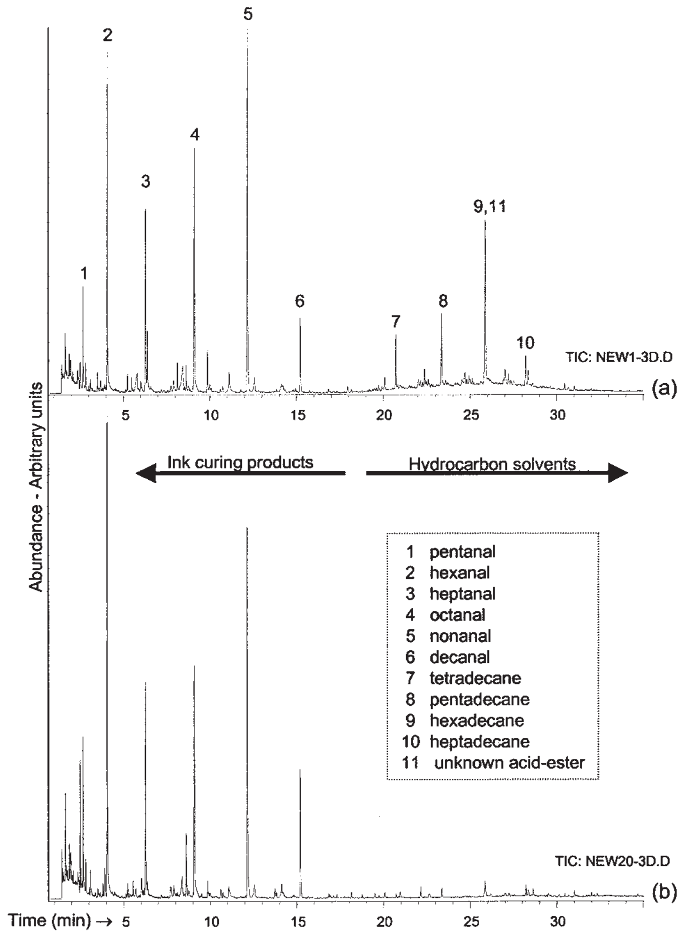

FIG. 2—*Headspace profile comparison for* (a) *a single crisp, new US$1 and* (b) *a single crisp, new US$20, both from the 1999 series. Each bill was placed in a foil-covered 40-mL vial to incubate for 3 days before being sampled by headspace SPME for 15 min. The long incubation time was necessary to allow detection of smaller components that would otherwise be missed.*

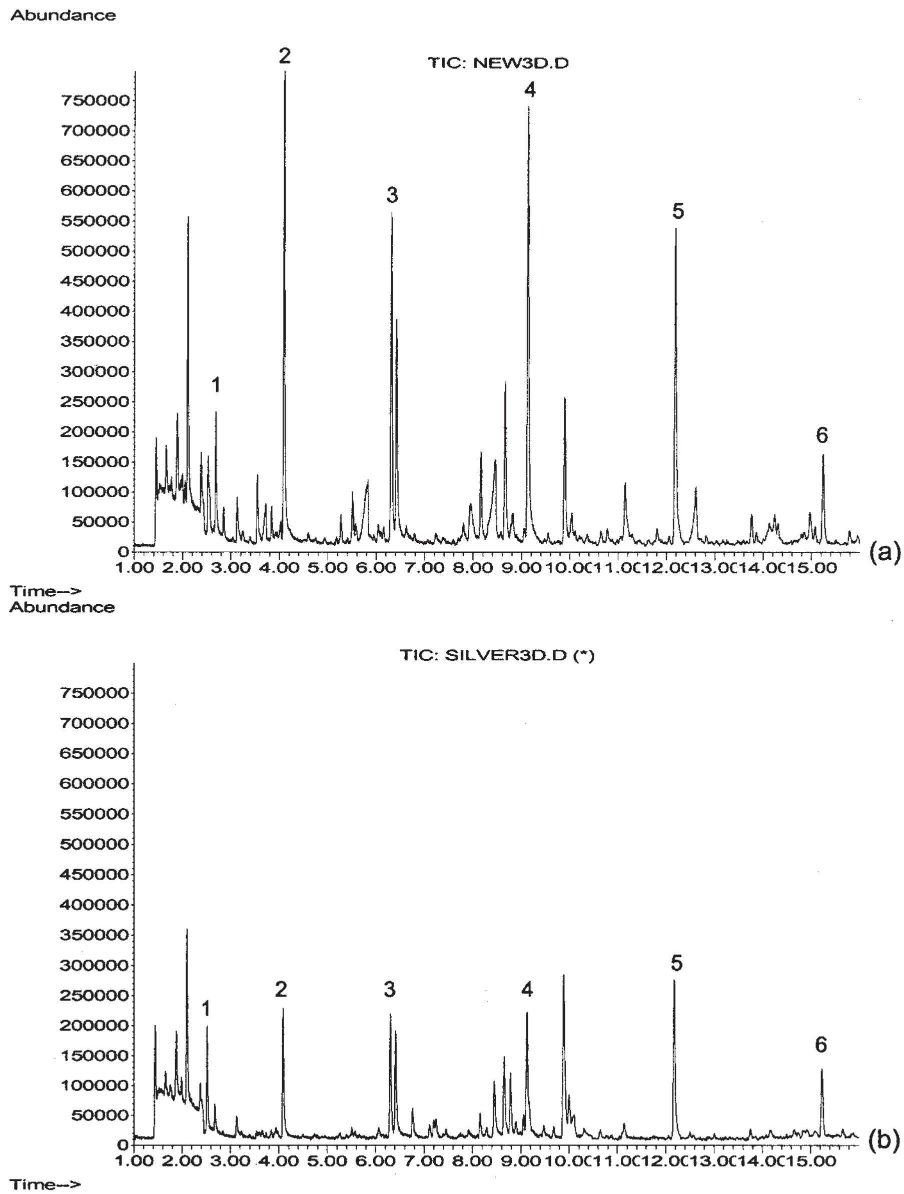

FIG. 3—*Headspace profile comparison for* (a) *two crisp, new bills (US$1 and US$5) and* (b) *two US$1 Silver Certificates (1934 series, over 35 years old). Each sample was placed in a foil-covered 40-mL vial to incubate for 3 days before being sampled by headspace SPME for 15 min. Only the ink curing products regions are shown. Compounds are as identified in Fig. 2.*

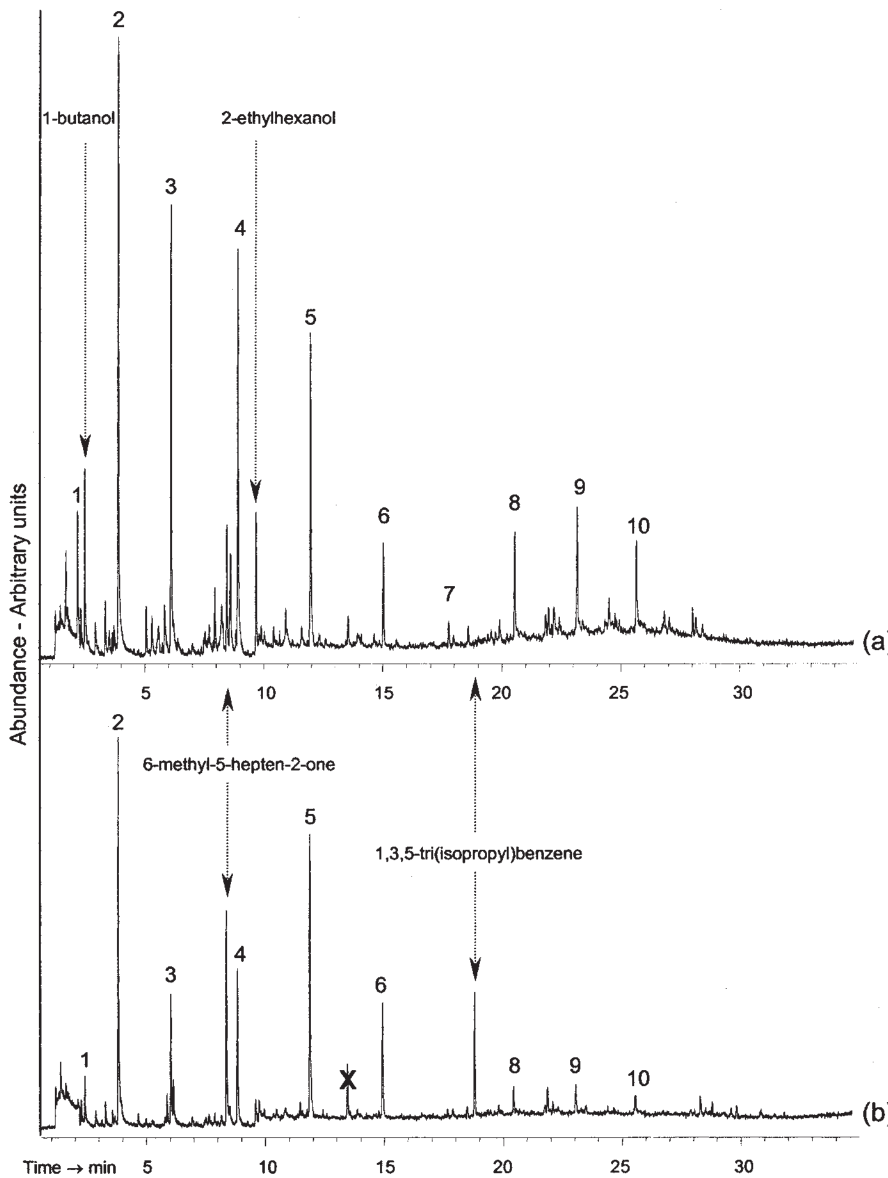

FIG. 4—*Headspace profile comparison of averaged runs from* (a) *100 US$1 with* (b) *100 Canadian bills (CA$5 OR CA$10). All bills were previously stored in uncovered jars. Numbered compounds are as identified in Fig. 2. X marks a fiber bleed signal.*

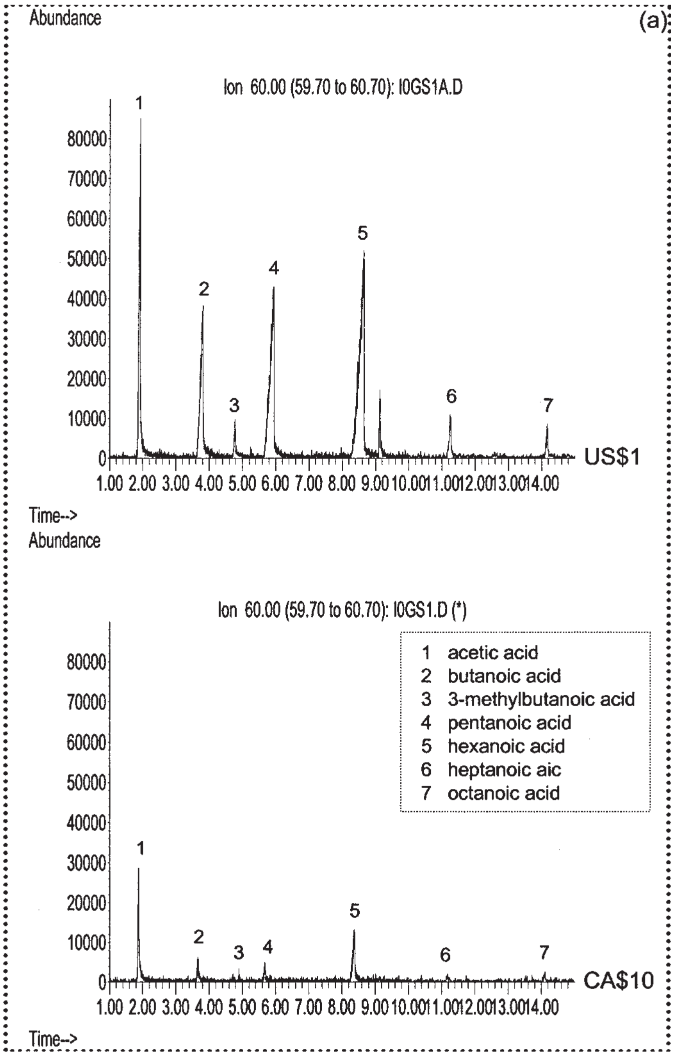

FIG. 5—*Comparison of selected* (a) *acid (ion 60) and* (b) *furan (ion 81) levels for 100-US$1 and 100-CA$10 (1 h sampling). All bills were previously stored in capped jars.*

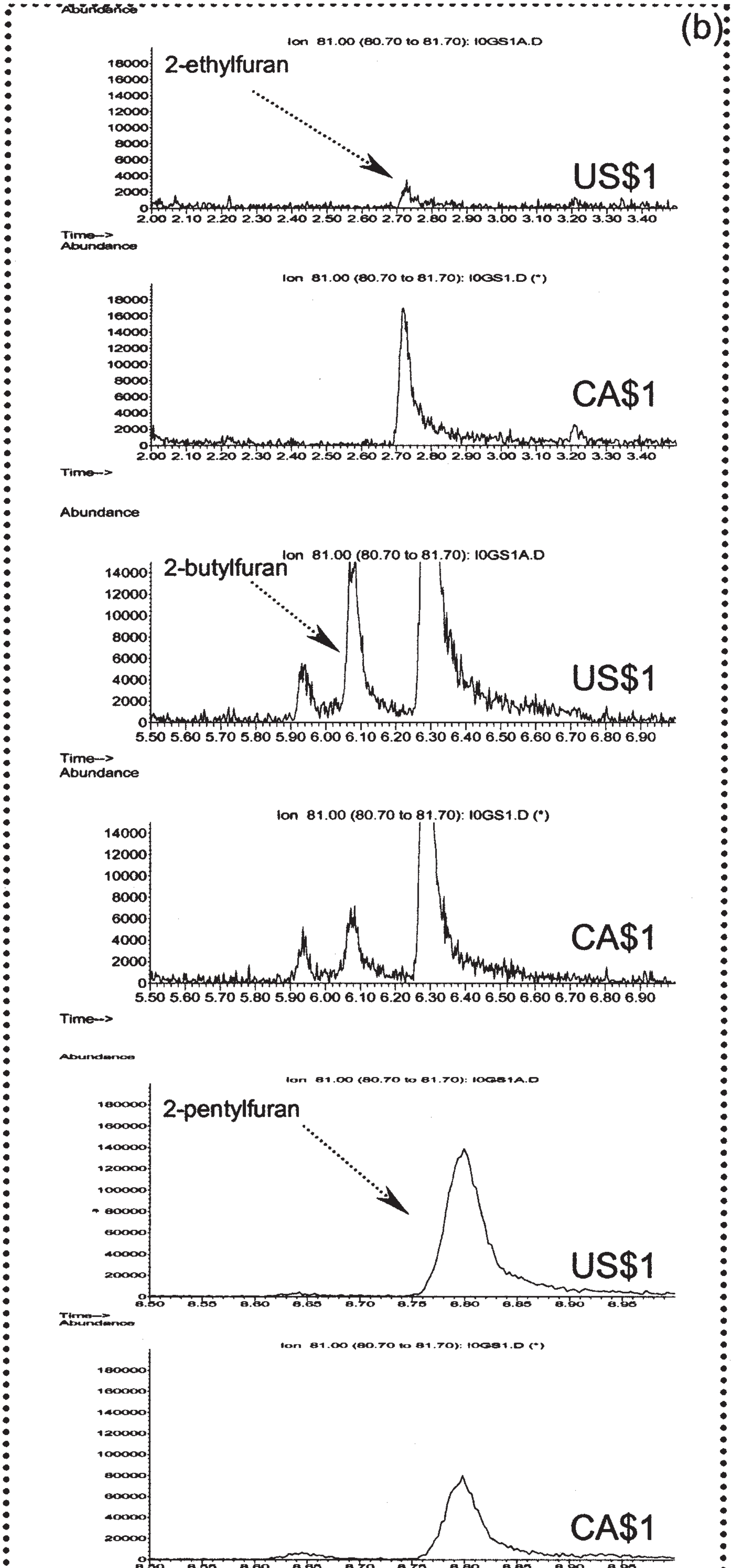

FIG. 5—*(continued)*

TABLE 4—*Odor description (14) of selected compounds from Table 3. Compounds marked with an asterisk (*) were found only in Canadian currency.*

Compound ID	Odor Description
Acids	
acetic acid	sour
propanoic acid	pungent, rancid
butanoic acid	sharp, cheesy, rancid, sweaty, putrid, sour
pentanoic acid	putrid, fecal, sweaty, rancid
hexanoic acid	sickening, sweaty, rancid, sour, sharp, pungent, cheesy, fatty
heptanoic acid	disagreeable rancid odor, sour sweat-like, fatty odor
octanoic acid	unpleasant, oily, fatty odor, rancid taste
Aldehydes	
Butanal	fruity, meaty, ethereal
Pentanal	woody, vanilla, fruity, nutty on dilution
Hexanal	fatty, green, grassy, powerful, penetrating
Heptanal	oily, fatty, heavy, woody, penetrating, sweet, nutty or fruity on dilution
Octanal	fatty, citrus, honey on dilution
Nonanal	floral, citrus, orange, rose, fatty, waxy
Decanal	penetrating, sweet, waxy, floral, citrus
Benzaldehyde	bitter almond, fragrant, aromatic, sweet
Alkenals	
2-pentenal	pungent, green, apple, orange, tomato
2-hexenal	sweet, fragrant, almond, fruity, green, leafy, apple, plum, vegetable
2-heptenal	pungent, green
2-octenal	green, herbaceous, spicy
2-nonenal	penetrating, fatty, waxy
2-decenal	orange, slightly fatty, floral, green
2,4-hexadienal	fresh, green, floral, citrus
2,4-heptadienal	fatty, cinnamon, hazelnut
Alcohols	
Butanol	medicinal
Pentanol	sweet, balsamic
Hexanol	herbaceous, woody, fragrant, mild, sweet, green
Heptanol	fragrant, woody, heavy, oily
Octanol	sharp, fatty, waxy, citrus
Undecanol	citrus, lime, orange, lemon, mandarin, black current, sweet, green
2-ethylhexanol	mild, oily, sweet, slight rose
Phenol	(medicinal)
benzyl alcohol	faint aromatic
Ketones	
Acetone	apple, pear, grape, pineapple, ethereal
2-pentanone	sweet, ethereal, fruity
2-heptanone	fruity, spicy, cinnamon
2-octanone	floral, green, herbaceous, fruity
2-nonanone	fruity, floral
6-methyl-5-hepten-2-one	herbaceous, green, oily, pungent
cyclohexanone*	powerful, minty-camphoraceous, “cool”, solvent-like
geranyl acetone	delicate, rose, slightly green, magnolia
3,5,5-trimethyl-2-cyclohexen-1-one (isophorone)*	sweet, cedarwood, fragrant, tobacco, leathery
benzophenone*	sweet, floral, fruity
Furans—Lactones	
2-ethylfuran	powerful, sweet, ethereal, burnt odor, coffee taste on dilution
2-pentylfuran	green bean, metallic, vegetable
2-heptylfuran	roasted, nutty
Butyrolactone	faint, sweet, caramel
5-methyldihydro-2(3H)-furanone	sweet, herbaceous
5-ethyldihydro-2(3H)-furanone	sweet, herbaceous, warm
Miscellaneous	
Limonene	mild, citrus, sweet, orange, lemon
methyl benzoate	fruity, fragrant
Naphthalene	“mothball”

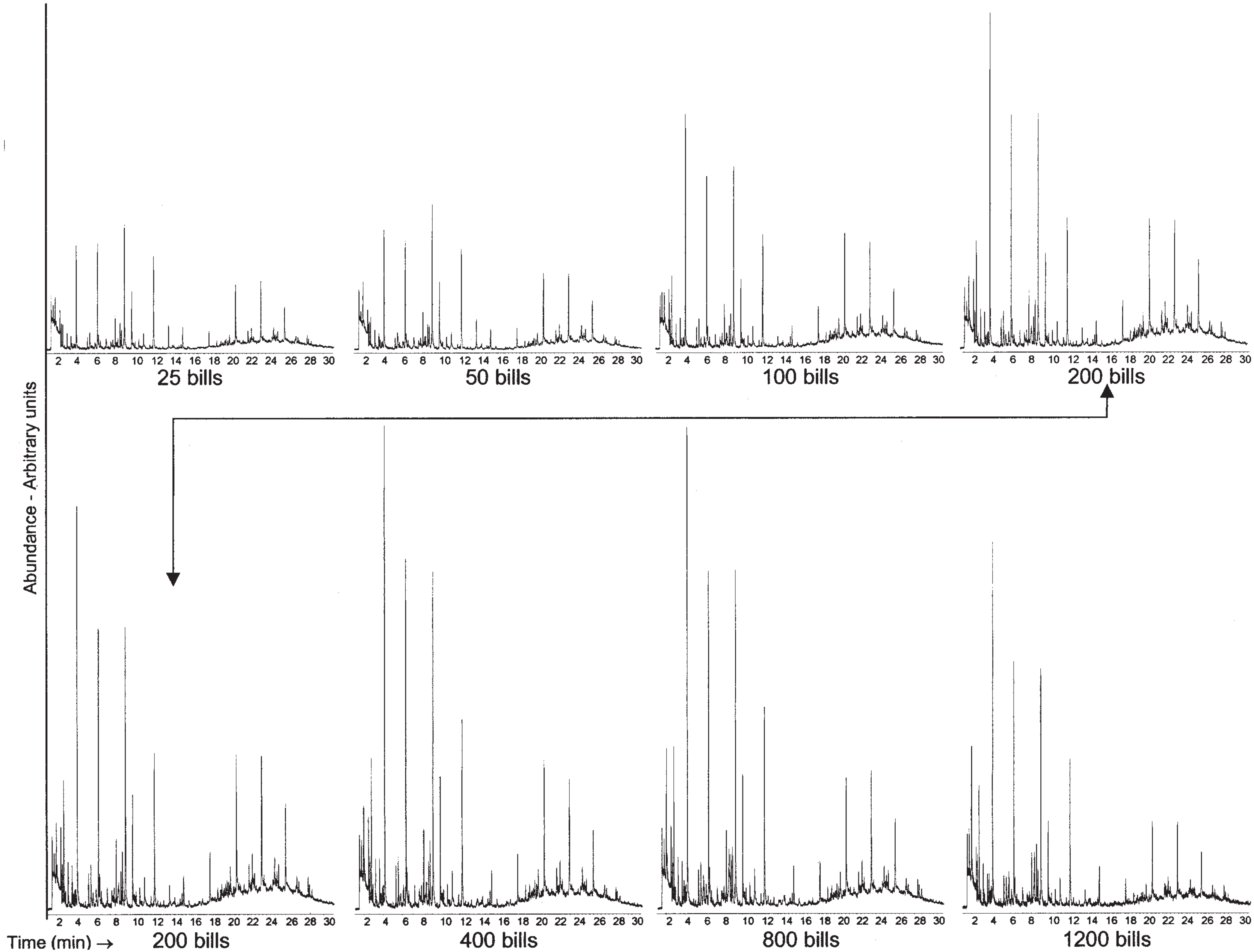

FIG. 6—*Comparison of headspace profiles as a function of the number of US$1 bills. Each curve is the average of two different runs except for 50 bills (average of three runs) and 1200 bills (one run only). 1200 bills exhibited a slightly lower odor level than 400 and 800 bills because it took longer to pack the sampling jar with 12 100-bill bundles, causing partial loss of the more volatile components. All bills had been stored for 1 week packed in uncovered jar.*

the number of bills, so that it is theoretically possible to train canines to alert only above a certain threshold. Aside from packaging and concealment methods, how the currency was stored immediately prior to concealment also affects the amount of odor that is available for detection (Fig. 7); in most cases, the chromatograms generated from currency samples previously stored packed in an uncovered jar were chosen for odor level comparison with other currency-related training aids.

Figures 8–11 compare the headspace profiles and relative odor levels from selected currency-canine training aids. Because it is still unknown which of the ink curing compounds or class of compounds plays a key role in canine detection of currency, it is important that currency-related training aids have headspace profiles (in the ink curing region) closely matching that of authentic currency. Prior to this work, currency ink training aids were made from an equal mixture of all six inks listed in Table 2, but initial analyses indicated that this ink mixture (A) had much higher levels of acids than were present in circulating currency, and the odor was correspondingly more acrid. After consultation with a staff scientist at the Bureau of Engraving and Printing (BEP), a new ink mixture (B) was made using roughly the same proportion as that on a printed bill. These samples gave odor impressions similar to new U.S. currency notes, and the corresponding headspace profiles closely matched that of large numbers of bills (Fig. 8). Likewise, cotton balls that were incubated for at least two days in capped jars containing ink mixture B also developed an odor profile similar to that of circulating currency. The odor level depended on the number of cotton balls used but not on the amount of ink that was in the jar (Fig. 9). Scented cotton balls would have provided an ideal training aid, because they do not require secured storage and are disposable, which eliminates cross-contamination problems that can occur when training aids are reused. The main drawback to using scented cotton balls is the irreversible loss of odors upon removal from the incubating ink jars, the rate of loss being dependent on where the training aids are placed (Fig. 10).

Both shredded circulated and shredded uncirculated currency gave similar profiles to circulating currency, but odor levels were somewhat lower (Fig. 11). One potential problem with using shredded currency is how the presence of shredder oil and other cleaning solvents would affect the odor profile on which canines are trained. Provided that they are frequently replaced and are obtained from different facilities, extraneous odors from the shredding process, none of which was detected in the current study, should not adversely affect canines trained on shredded currency. Random contamination does not cause a problem because the canine is not being repeatedly exposed to and rewarded on the same erroneous odor profile. Similar to cotton balls, shredded currency provides a convenient, disposable training aid, a minor drawback being its bulki-

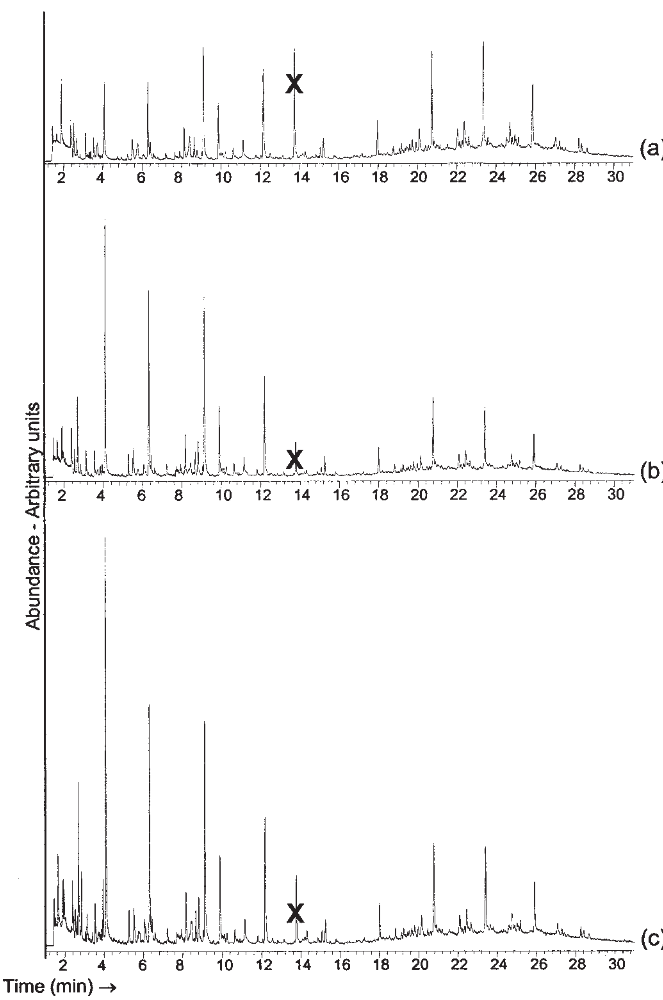

FIG. 7—*Headspace profile comparison for 400-US$1 after one week stored in* (a) *drawer,* (b) *uncovered jar, and* (c) *tightly foil-covered TLC jar. X marks fiber bleed signals.*

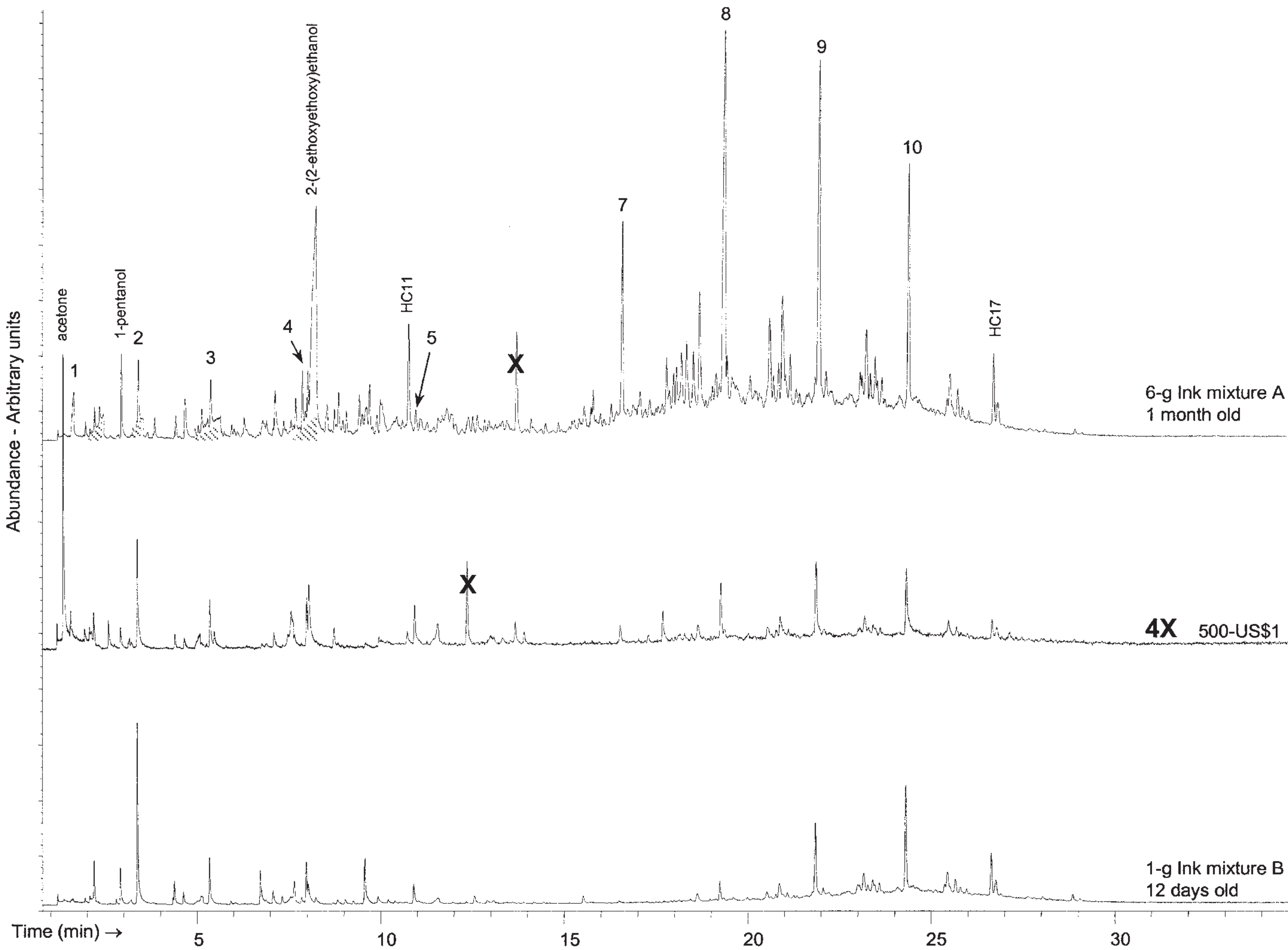

FIG. 8—*Headspace profile comparison for 500-US$1 (plotted at four times the original scale) with two currency ink mixtures. Shaded areas in ink mixture A highlights various carboxylic acids. Numbered compounds are as identified in Fig. 2. X marks fiber bleed signals.*

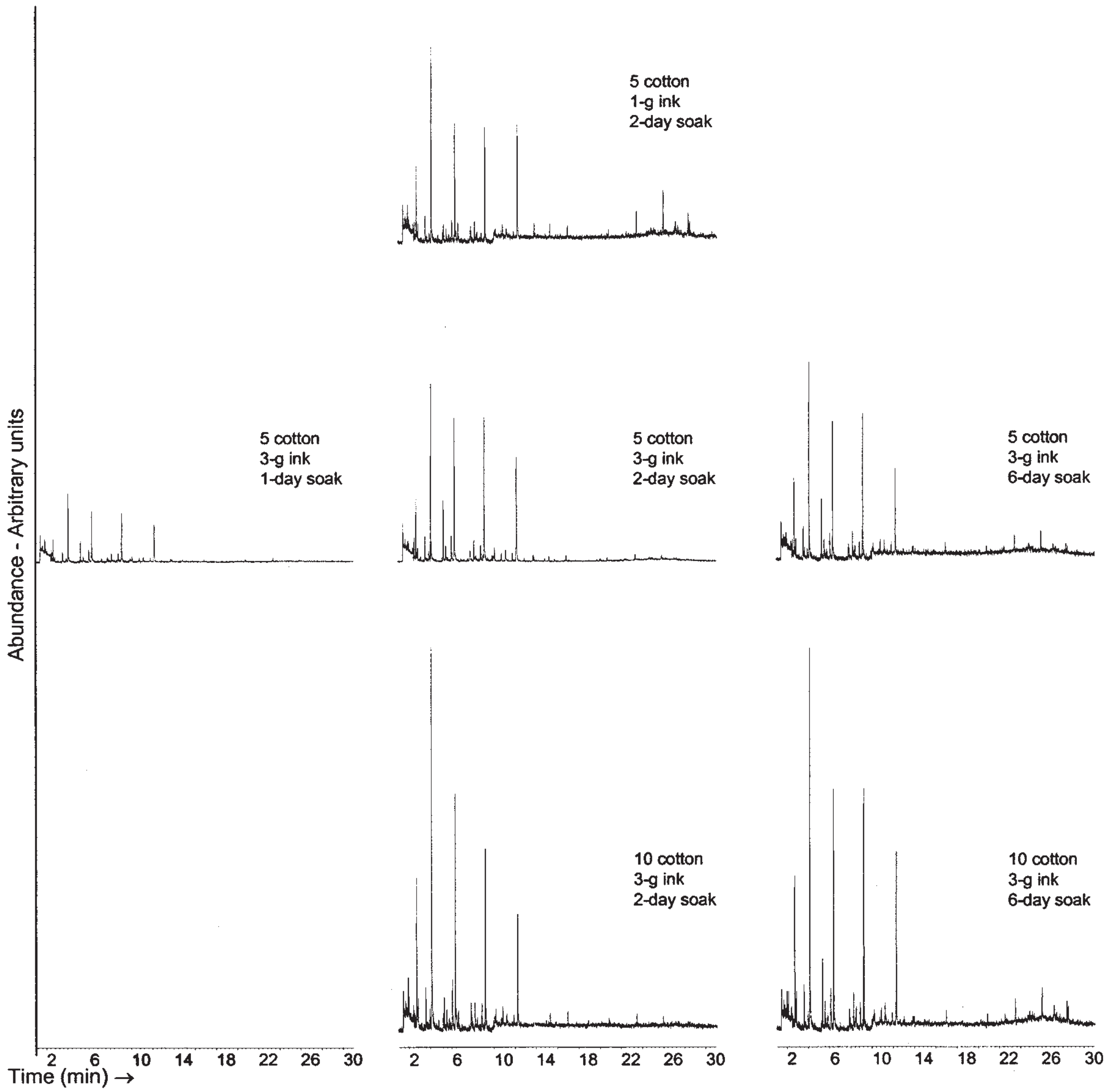

FIG. 9—*Odor level comparison for currency-scented cotton balls. The odor level of 500-US$1 is between those of five and ten cotton balls that have been incubating in a currency ink jar for at least two days. Odor level is not significantly increased with a longer soak time or when using more ink.*

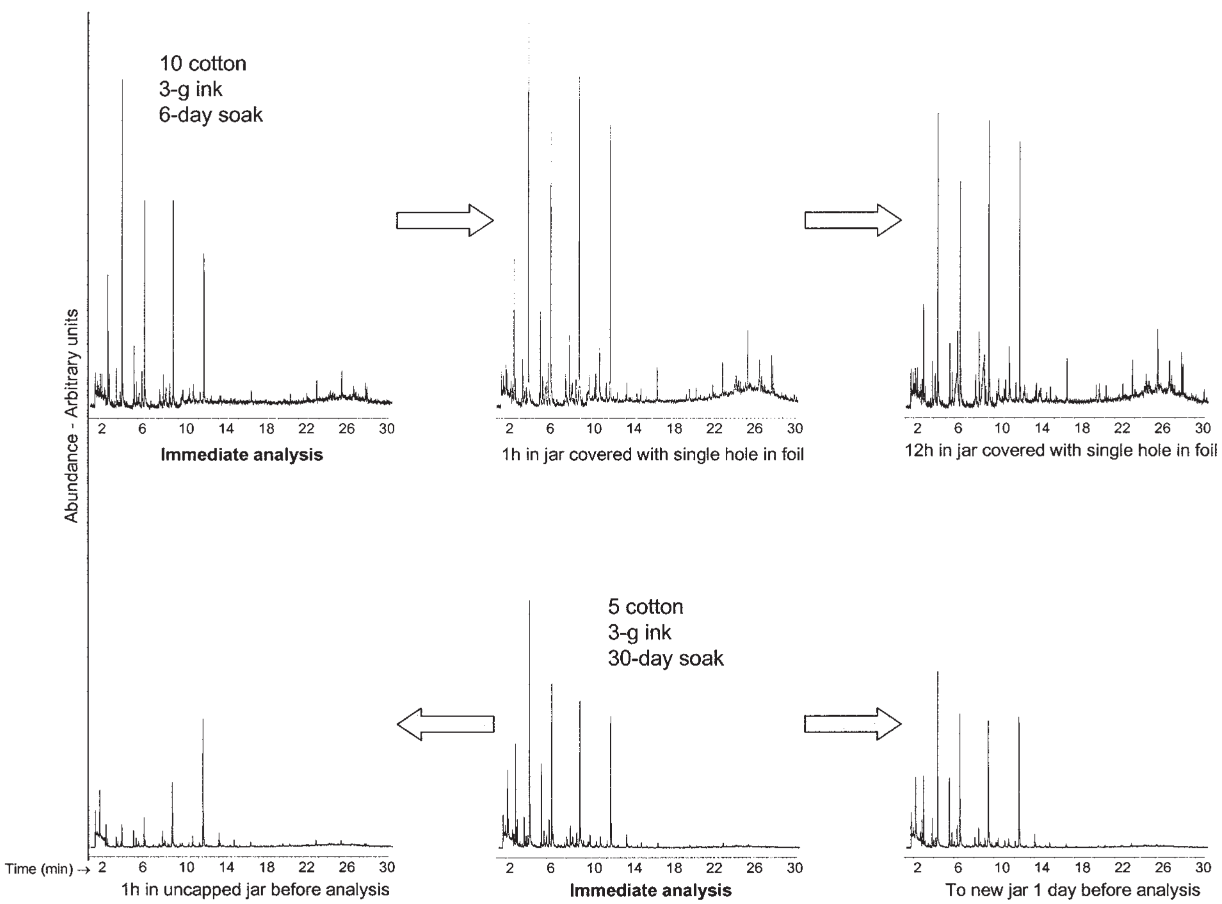

FIG. 10—*Changes in odor level of currency-scented cotton balls upon removal from the incubating ink jars. No significant change is observed when the samples are stored in covered or partly covered containers, but substantial loss of volatile components is observed after only 1 h in an open jar.*

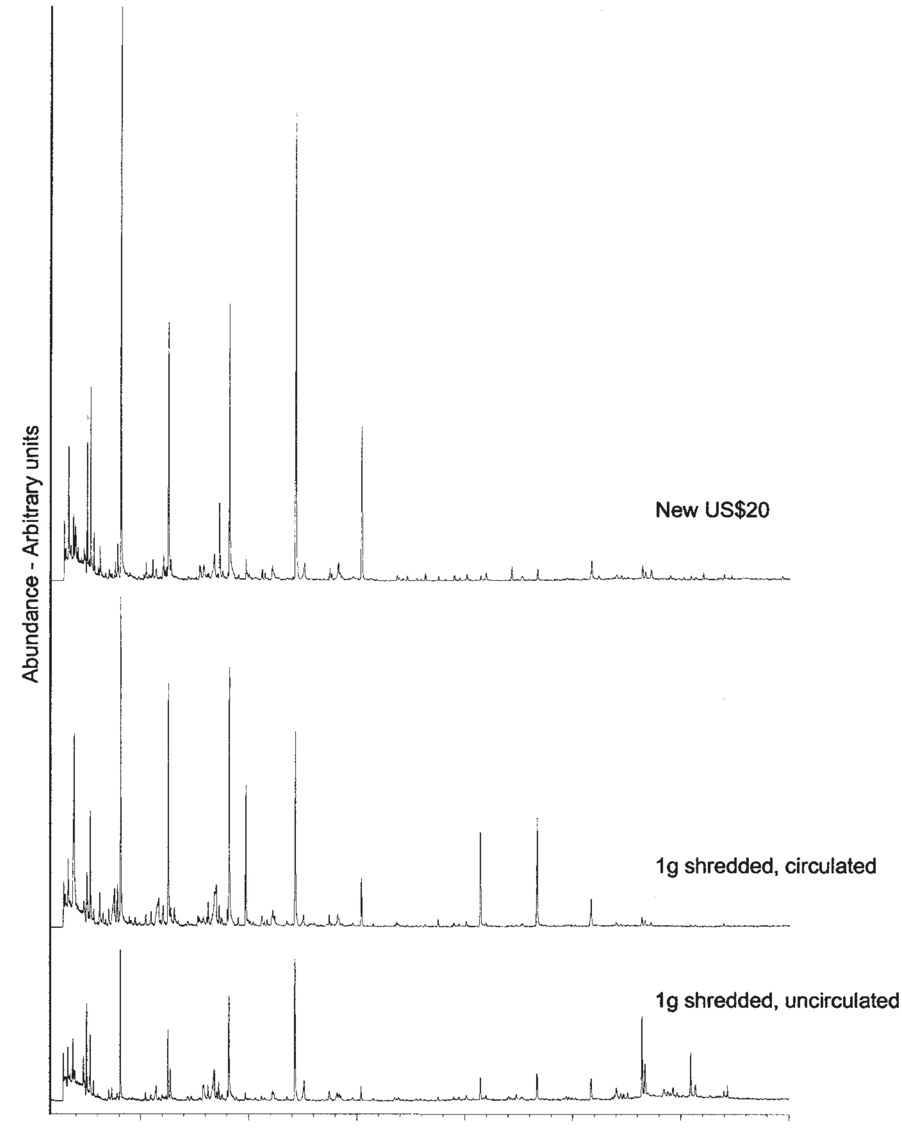

FIG. 11—*Headspace profile comparison for one US$20 with 1 g shredded, circulated and shredded, uncirculated U.S. currency. Analytical conditions are the same as for Fig. 2.*

ness compared to authentic currency notes. A 480-g shredded currency aid (equivalent to 480 bills) completely filled a gallon jar, whereas 1200 currency notes filled less than two thirds of the same jar (Fig. 1*a*). Compressed currency bricks, on the other hand, are much more compact than authentic currency notes, a 1-kg brick having roughly the same volume as 400 bills, and odor levels are lower than expected for 1000 bills because of the reduced surface area.

Conclusions

Based on work done with Canadian currency, it is clear that the ink curing products play a critical role in canine detection of currency, although which specific compounds or class of compounds are key remain unknown. Currency inks, currency-scented cotton balls, and shredded currency provide useful, supplemental training aids for currency detector canines. Under certain conditions, each type of training aid presents a headspace profile closely approximating that of authentic, circulating U.S. Federal Reserve Notes. The main drawback of each type is the lack of consistent correlation between the odor levels of the training aids and authentic currency. Currency-scented cotton balls have the additional problems of irreversible loss of odors and the greater need for discrimination training on blank cotton balls, and its use has been discontinued in the U.S. Customs' currency canine program. Authentic currency remains the best available training aid, provided that the notes are frequently exchanged so that contamination from handling is random and the only consistent odor picture is that arising from the inks themselves.

Acknowledgments

The author wishes to acknowledge Ms. Julie Evans of the BEP for providing invaluable background data on currency inks and the currency production process; Special Agent Mike Evans of the U.S. Secret Service for providing currency from the Federal Reserve Bank of Richmond; Mr. Jim Roberts, CCRA, for providing

Canadian currency; Mr. Dave Hoglund of the U.S. Customs Service for providing currency inks through Ms. Evans; and various U.S. Customs Canine Enforcement Officers who provided insight based on their field experience handling currency canines.

References

1. Treasury task force wages financial warfare against terrorists (2001 Dec 18) at http://www.govexec.com/dailyfed/1201/121801h1.htm
2. Operation Powerplay at http://www.customs.gov/custoday/nov2000/powerpl2.htm.
3. $650,000 found in bag at O'Hare. Chicago Tribune 2002 Jan 26.
4. Traffickers use U.S. businesses, cash smuggling to hide billions in profit. Seattle Times 2001 Nov 19.
5. Reports on exporting and importing monetary instruments, 31 U.S.C. 5316.
6. Search and forfeiture of monetary instruments, 31 U.S.C. 5317.
7. http://www.customs.gov/xp/cgov/enforcement/investigative_priorities/canines/canine.xml.
8. See for example, United States v. Carr, 25 F.3d 1194, 1216–17 (3rd Circuit 1994) and United States v. Buchanan, 207 F.3d 344 (6th Circuit 2000).
9. Vu DT. SPME/GC-MS characterization of volatiles associated with methamphetamine: toward the development of a pseudomethamphetamine training material. J Forensic Sci 2001;46(5):3–13.
10. In an internally issued, unpublished report (1998), a dog trained on blank (not printed) currency paper did not alert to circulating currency or currency inks, indicating that the paper contributed negligibly to the scent picture required for canine detection of currency.
11. http://www.bep.treas.gov/document.cfm/18/106.
12. Lentini JJ, Dolan JA, Cherry C. The petroleum-laced background. J Forensic Sci 2000;45(5):968–89.
13. Buchbauer G, Nikiforov A, Remberg B. Headspace constituents of opium. Planta Med 1994;60:181–3.
14. Aldrich flavors and fragrances catalog (2000). A more extensive list of odor descriptions can be found in: Arctander S. Perfume and Flavor Chemicals, Vols. I and II. Carol Stream: Allured Publishing Corporation, 1994.

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