Analysis of the uniqueness and persistence of human scent

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Abstract

To date there has been limited research on the chemical components present in human odor, their usefulness in distinguishing between people, and the persistence of human scent in the environment. This research discusses the use of solid phase microextraction gas chromatography-mass spectrometry as a method for extracting, separating, and identifying the volatile components of human scent. The volatile components of human odor have been evaluated and compared to distinguish among individual odor profiles. The persistence of human scent in a controlled environment will also be discussed.

Introduction

The use of canines, Canis lupus var. familiaris, in law enforcement is widely accepted; however, there are few peer-reviewed studies confirming their accuracy and reliability. The use of detector dogs for human-scent lineups has been used in Europe, including Belgium, Denmark, Germany, Hungary, the Netherlands, Poland, and Russia, but has not gained widespread acceptance in the United States, mainly due to the lack of definitive studies demonstrating the reliability of this approach. Published results pertaining to the accuracy of canines used in human-scent lineups will be discussed later in the text.

There is limited scientific data to validate the selectivity and reliability of detector dogs used by law enforcement agents for the detection of drugs, explosives, flammable and ignitable liquid residue, and human scent. Research has recently begun to identify some of the volatile organic compounds present in human scent, but there is still limited knowledge concerning the identity of target-vapor signature and the transport and detection mechanisms associated with a canine alert. There is also limited understanding of how the body produces human scent. This lack of information has resulted in successful legal challenges to using these biological detectors in courts of law.

Human Production of Odor

The human skin serves several functions, including regulating body temperature and excretion. The skin is divided into two layers--the outer layer called the epidermis and the inner layer called the dermis. The dermis layer contains most of the specialized excretory glands and up to five million secretory glands including eccrine, apocrine, and sebaceous glands (Ramotowski 2001).

The human axillary (i.e., armpits and genital areas) regions are the areas of the body where the largest collection of sweat glands in size and number is located. Apocrine, eccrine, and sebaceous glands, which are the major glands responsible for the secretion of sweat, are all present in the axillary region of the body (Van Toller and Dodd 1988).

The apocrine glands are found primarily in the axillary areas. The eccrine glands can be found throughout the body, with the highest densities found in the palms and the soles of the feet. In a normal person, eccrine glands are capable of secreting up to two to four liters of fluid each hour. Eccrine sweat is typically composed of 98 percent water, but it also contains various organic and inorganic components. The sebaceous glands are usually located in body regions where hair is present, including the face and scalp. Sebaceous glands produce secretions called sebum, which consists of glycerides, free fatty acids, wax esters, squalene, and cholesterol. The wide variety of organic compounds found in the sebum can be influenced by a person's diet and genetics. The hydrolysis of human sebum results in the formation of a mixture of fatty acids, and the amount of free fatty acids in sebum can vary but averages between 15 to 25 percent (Ramotowski 2001). Investigations into the biochemical uniqueness of skin lipids have suggested that slight differences in the overall composition of the sebaceous fatty acid mixture can lead to unique individual odors in humans (Nicolaides 1974).

The following factors make the axillary region a good odor-producing area in the human body:

* The contents of the apocrine gland secretions may serve as bacterial substrates.

* Moisture is available from the eccrine glands.

* There is a resident population of bacteria to transform nonodorous to odorous substances.

* The presence of axillary hair may aid in the dispersion of the odor (Van Toller and Dodd 1988).

There is a limited understanding of how the human body creates scent. It is known that the epidermis (outer) layer of the skin constantly sheds epithelial cells into the environment. The surface of the skin contains about two billion cells, and approximately 667 cells are shed each second. The average lifespan of an epithelial cell is approximately 36 hours. Dead cells that are shed from the surface of the skin are referred to as rafts and are approximately 14 microns in size and weigh approximately 0.07 micrograms. A raft is composed of one or more dead cells carrying approximately four microbial bacteria and is catalyzed by body secretions. All three components of the raft are characteristic to a person. Each raft is also said to be surrounded by a minute vapor cloud that results from the bacteria acting upon the cells (Syrotuck 2000).

Studies conducted at the National Institute for Medical Research in London have shown that there is a current of warm air that surrounds the human body (Doyle 1970). The current of warm air is approximately one-third to one half-inch thick, and it travels up and over the body at a rate of 125 feet each minute. Analysis of the air current indicates that it contains four to five times as many germs as the air in the rest of the sampling room. The germs come from the bacteria that are shed with dead skin cells. Larger flakes of skin fall to the ground, but smaller ones are drawn up into the current. These currents can also be visualized through clothing. The warm air currents carry the rafts from the body into the surrounding area allowing for the deposit of human scent in the environment. The idea that human scent is produced through bacterial action on dead skin cells and secretions is the most common depiction of the creation of human odor. Other studies have suggested that odor is formed very quickly, supporting the idea that odor production is due to simple bond cleavage as opposed to a complex bacterial action (Zeng et al. 1991). Comparisons of the extracts of axillary sweat collected from males and females showed qualitative similarities in the volatile organic acids present, suggesting a similar origin and mechanism for odor production in

men and women (Zeng et al. 1996).

Human Scent Evidence Admissibility

Despite the demonstrated usefulness of human scent discrimination by canines, the admissibility of such evidence in United States courts is often challenged. In order for evidence to be considered scientific, it must pass the Frye and Kelly rules. In essence, evidence is scientifically admissible if there is proof the technique is considered reliable in the relevant scientific community, if the evidence is presented by a qualified expert, and if the test is conducted using proper scientific procedures. Currently, dog evidence is admitted as expert witness testimony by the dog's handler.

In Tomlinson versus the State of Florida, dog evidence was admissible because the dog immediately took the track, followed it to the shoes worn by the appellant, and was reinforced by a visible track made by a shoe matching the pair found by the canines. In State of Arizona versus Roscoe, scent evidence was admitted as expert witness testimony after explaining the testing procedures and proving them to be fair, and thus the Frye test was inapplicable. United States versus McNiece held that there was a "lesser potential prejudicial impact" on the jury than was expected and that courts did not need to apply the strict Frye ruling to scent evidence. However, some courts still support the Frye ruling. California versus Ryan Willis held that dog-scent-identification evidence was improperly admitted to the courtroom according to the rules set forth by the Frye and Kelly cases. More scientific research into the uniqueness and stability of human scent is useful in determining the admissibility of human scent evidence in United States courts of law.

Canines and Human Scent

The ability of canines to discriminate human scent was documented as early as 1887. Romanes (1887) contributed many fundamental observations about the ability of dogs to scent discriminate, such as the human body leaves an individual odor that a dog can distinguish, individual odors can be determined at great distances and under different environmental stresses, and canines are not deterred from scent discrimination by fragrances.

There is a difference between canines that are used to track human scent, trail human scent, and identify scent. Tracking canines are trained to use human scent and environmental disturbances to locate the track of a person but are not given an initial scent to follow. Trailing canines are scented on an object and then asked to determine if the scent of the person can be detected in an area (uncontrolled environmental conditions) and followed to the source or until the trail ends. Human-scent-identification canines are presented with a person's scent collected from a crime scene and then asked to match the odor from a selection of scents under semicontrolled environmental conditions.

There are two main methods of collecting human scent for scent identification. The direct method collects the actual object to be presented to the canine. The indirect method collects the odor on an absorber and then presents the absorber to the canine. A scent-collection tool called the Scent Transfer Unit-100 (STU-100) was developed to aid law enforcement in collecting human scent from people and objects using sterile gauze absorbers (Kanable 2003). The STU-100 is a portable vacuum that uses air flow through sterile gauze to trap the scent. The STU-100 can be used for contact (placing the object directly on the gauze) and noncontact scent collection (placing the STU-100 directly over the object). There are many variations to the process of collecting scent on an

absorber ranging from wiping the object or surface, placing the absorber in contact with the object or surface, or using the STU-100.

The purpose of a human-scent lineup is to make an identification based on a canine matching the human scent collected from a crime scene to a possible suspect. The process for conducting a human scent lineup in the Netherlands begins when scent evidence is collected at a crime scene, packaged, and preserved. When a suspect is taken into custody, he or she may be asked to submit to a human-scent lineup. The suspect holds a metal bar in his hands for a period of time, and then this metal bar is collected. This metal bar from the suspect, along with metal bars that have been held by other people and collected at random throughout the population, are set up in a sterile room where the law enforcement-certified canine is exposed to the scent evidence and allowed to work the lineup of metal bars independently. The order of presentation of the metal bars is determined by rolling dice that correspond to differing placement patterns. A scent identification indicates an association between the suspect and the scent evidence.

The experimental design for human-scent identifications differs from country to country. Various experimental designs for human-scent identification have been evaluated and compared (Schoon 1996). The designs were evaluated on the basis of performance and forensic considerations. It was determined that the experimental set-up does significantly affect the outcomes of scent identifications. The implementation of a control trial as a type of calibration for the dogs provided the best results. The performance-check set-up indicates that the odors in the array, including the odor of the suspect, are neutral for the dog and that there is no prior preference of the dog for the odor of the suspect. This control trial indicates that a positive identification is not the result of a particular preference the dog may have, or because the odor of the suspect is very different from the others in the array that should be required when introducing a scent lineup identification as evidence in a court of law. Assessing the reliability of scent identifications using this method has been conducted (Schoon 1998), and it has proven to be a useful forensic tool with a high degree of reliability.

The ability of dogs to match odor collected from different parts of the body has been evaluated by two different groups, and the overall outcome was the same in each. A dog can match odors of the same person taken from different parts of the body. Dutch police dogs were able to match scent collected from the hands to scent collected from the crook of the elbow from the same person. These dogs also matched odor collected from the hands to scent collected from pants pockets of the same person (Schoon and De Bruin 1994). Studies in the United Kingdom have also shown that dogs are able to match scent taken from various places of a body to that of a specific person (Settle et al. 1994).

Limited research has been conducted into the ability of bloodhounds to discriminate the scent of people through trailing (Harvey and Harvey 2003). In one study, scent was sampled from different areas of the body using a STU-100. The bloodhounds were then presented with trails that varied in cross-contamination from incidental human scent and weather conditions. The search areas used in this study included urban and suburban environments to simulate searches commonly undertaken in criminal investigations. The STU-100 was used as a collection device for human scent, and by using this instrument the bloodhounds were able to follow the trails to an effective conclusion for investigative purposes.

Another study conducted by the Federal Bureau of Investigation in conjunction with the Southern

California Bloodhound Handlers Coalition has shown that scent collected from bomb fragments can be a useful tool in explosive device investigations (Stockham 2003). After the explosive device was detonated, scent was collected from the fragments using the STU-100 and stored on gauze pads. The bloodhounds were then presented with the scent and correctly identified matching scent from the device builders 60 to 100 percent of the time with no false positives.

In a recent feasibility study, the Federal Bureau of Investigation and the Southern California Bloodhound Handlers Coalition have shown the ability of bloodhounds to discriminate when scented from objects that were irradiated to remove possible contamination with biological agents (Stockham et al. 2004). In this study the scent samples were irradiated for one hour with average doses of 40.7 kGy and 39.5 kGy, and in six trials the bloodhounds were scented from the irradiated objects and correctly trailed and matched the scent to the target corresponding to the scent pad. Both of these studies attempt to determine the survivability of human scent in real-world situations.

Previous attempts have been made to characterize the human odor, which a dog uses to match scent (Sommerville and Green 1989). Armpit odor was collected over 12 hours using polyester squares, and after collection, the samples were evaluated and fractionated into four sections using a gas chromatograph. The odor of twins was evaluated by presenting the fractions to scent-discrimination canines that were scented from the whole scent. It was shown that although chromatographically fraction three of the twins was similar, the dogs could make a distinction between the twins. When presented with fraction two alone, the dogs could not make the distinction between the twins. The chromatograms for fraction two were also determined to be chromatographically similar. When the twin's samples were presented as a whole; however, the dogs could not distinguish between either of the twins.

Another study confirms the differences in underarm sweat among European and Japanese males and females (Sommerville and Gee 1987). The experiment involved collecting scent by pinning a polyester pad on the inside of a volunteer's t-shirt and then evaluating the sample using a gas chromatograph. The chromatograms produced from the different people with differing ethnic backgrounds were qualitatively different.

Characterization of Human Scent Components

Although the composition of human secretions and fingerprint residue has been evaluated for chemical composition, comparatively little work has been done to determine the compounds present in human odor. Knowing the contents of human sweat may not accurately represent the nature of what compounds are present in the headspace above such samples that would comprise human scent. Human scent is the most abundant of the volatile organic compounds determined to be in the headspace above scent samples; however, other substances may contribute to human odor. The individual body odors of humans are determined by several factors that are either stable over time (genetic factors) or vary with environmental or internal conditions. For this manuscript, the following distinguishing terminology for these factors will be used:

* The primary odor of a person contains constituents that are stable over time regardless of diet or environmental factors.

* Secondary odor contains constituents that are present due to diet and environmental factors.

* Tertiary odor contains constituents that are present because of the influence of outside sources (i.e., lotions, soaps, perfumes).

For an individual identification by human scent, the primary odor must have constituents that are stable over time and diverse across people.

Compounds present in male (Zeng 1991) and female (Zeng 1996) axillary secretion extracts that contained the characteristic odors present in the axillary region have been isolated and identified. These analyses showed the presence of several C6-C10 straight chains, branched, and unsaturated acids, and the major odor-causing compound was determined to be (E)-3-methyl-2-hexenoic acid. Other important odor contributors were terminally unsaturated acids, 2-methyl C6-C10 acids, and 4-ethyl C5-C11 acids. Short-chain fatty acids have also been extracted from sweat samples obtained from feet (Kanda et al. 1990). Olfactory evaluation by humans of 1000 ppm solutions of short-chain acids ([C.sub.2]-[C.sub.9]) showed that each short-chain fatty acid resembled either foot or axillary odor. Short-chain acids that resembled axillary odor tended to be higher in carbon number than those that resembled foot odor.

Investigations into the compounds emitted by humans that attract the yellow-fever mosquito have provided insight into the compounds present in human odor. Samples were collected using glass beads that were rolled between fingers. The beads were then loaded into a gas chromatograph and cryofocused by liquid nitrogen at the head of the column before analysis with gas chromatography-mass spectrometry. The results showed more than 300 observable compounds (Bernier et al. 1999). In a later study, 346 compound peaks were observed (Bernier et al. 2002) and of the compounds detected, 43 were unidentifiable, whereas 303 were identified by standard or identified tentatively by library and spectral interpretation. Of the 303 compounds identified, 26 were confirmed to be of background origin, leaving 277 compounds identified as components of human skin emanations. Through this method, comparisons of the compounds found in different people (Bernier et al. 2002) showed qualitative similarities among the people; however, quantitative differences were observed.

Laundry soiled with human sweat and then washed with a laundry detergent has been analyzed for the residual presence of human odor (Munk et al. 2000). Esters, ketones, and aldehydes were identified as primary odorants in the swatch's postwashing. However, organic acids, which are considered to be the dominant characteristic odorants in human axillary sweat, were not present in the extracts of residual odor.

Research has been done to determine the applicability of pattern recognition in analyzing and interpreting gas chromatograms produced from the analysis of human sweat (Sommerville et al. 1994). This study used a recirculating system to load the sweat head-space into concentrating traps. The samples were then desorbed from the traps and analyzed by gas-liquid chromatography-flame ionization detection. The gas-liquid chromatography-flame ionization detection was interfaced with a pattern-matching program. The alignment coefficients, profile correlations, Euclidian distances, and box-car distances were all determined using the program. The analysis was conducted on two sets of twins who were shown to be identical through DNA profiling. One pair of twins was teenage boys and the other adult women. Sweat samples were collected by pinning squares of cotton fabric to the armpit area of a t-shirt, which was worn for eight hours. The results showed there was a difference between the twin matches and the unrelated matches across all four parameters. The largest difference was found in the profile correlation,

indicating that identity signals may be shown by differences in the concentrations of certain ranges of volatiles. The difference in alignment coefficients indicates that some of the identity signal depends on an absence or presence of certain compounds. The differences in the Euclidian and box-car distances indicate that variation in the amounts of certain compounds present is an important factor in individual scent profiling. This study demonstrated that human identity is determined by qualitative and quantitative differences in sweat volatiles.

Solid phase microextraction in conjunction with gas chromatography-mass spectrometry has been used previously to identify volatile components that are responsible for odor produced from human skin (Ostrovskaya et al. 2002). The sampling was done using a 6 cm glass tube with a septum at one end that was placed over the skin and secured. Several different classes of compounds, including shorter and longer chain hydrocarbons, short-chain aldehydes, and a branched ketone, were identified from human skin in the headspace. Eighty-eight percent of the subjects showed the presence of short-chain aldehydes, such as octanal, nonanal, and decanal. Hydrocarbons of longer chain lengths were found in 96 percent of the subjects, such as tetradecane, pentadecane, and hexadecane. The abundances of these compounds varied among people, and some subjects exhibited specific volatile compounds, such as 6-methyl-5-hepten-2-one, and hydrocarbons of shorter chain lengths including decane.

In this study, headspace solid phase microextraction was combined with gas chromatography-mass spectrometry to identify the signature odors that law enforcement-certified detector dogs alert to when searching for humans and distinguishing among people. Solid phase microextraction gas chromatography-mass spectrometry has demonstrated unique capabilities for extracting volatiles from the headspace of forensic specimens and shows great potential to aid in the investigation and understanding of the complicated process of canine odor detection. The long-term aim of this research is to evaluate the practical operational questions surrounding canine-human-scent identifications, such as collecting and preserving scent and also evaluating the fundamental questions of human odor and its uniqueness to people.

Materials and Methods

Materials

All gauze used in this study were DUKAL brand, sterile, 2X2, 8 ply, gauze sponges (DUKAL Corporation, Syosset, New York). The sterile gauze was not subjected to any additional sterilization processes. Although the gauze is biologically sterile, this does not equate to chemically sterile. (Research is currently being conducted to achieve a chromatographically clean absorber material for the collection of human scent.) The unscented soap used in this study was Dove unscented moisturizing soap (Unilever, Greenwich, Connecticut). The vials used in this study were 10 mL glass, clear, screw-top vials with PTFE /Silicone septa (Supelco, Bellefonte, Pennsylvania). Prior to use, the glass vials and septa were rinsed with acetone and baked at 210[degrees] C for 48 hours to remove volatile compounds initially present in the vials.

Sampling

The sterile gauze was sealed in 10 mL glass vials, extracted, and analyzed to determine which compounds were initially present on the gauze. These compounds were noted prior to use for background purposes. The only contact the researcher had with the sterile gauze was when the

gauze was initially sealed in the glass vials. In order to reduce contamination, powderless latex gloves were worn, and contact between the gloves and the gauze was kept to a minimum. Gloves were changed after each piece of gauze was handled.

Two unrelated, 24-year-old males were evaluated in this study. Subjects were required to use fragrance-free soap and to discontinue using deodorants, lotions, and perfumes for 48 hours before sampling to minimize the influence of tertiary odors. In this study, no attempt was made to control the diet of the subjects being sampled. Each subject exercised outdoors for a period of one hour wearing a tank top to eliminate compounds in clothing. Each subject then sampled themselves, used a 2X2 sterile gauze pad to wipe the armpit area, collected their own sweat, and then resealed the sample in the 10 mL glass vial. All samples were stored in the 10 mL vials at room temperature.

Subjects were sampled on different days and at different times throughout the same day to evaluate the stability and reproducibility of the resulting scent profile. For intraday sampling, the first sample was taken in the morning and the second sample was taken 10 hours later. Interday samplings were all taken prior to 12:00 p.m. The average humidity and temperature for the days' samplings are listed in Table 1.

Extraction and Analysis of Armpit Samples Solid Phase Microextraction Gas Chromatography-Mass Spectrometry

Each sample was analyzed individually as received. The samples were collected from Male 1 and Male 2, allowed to sit for 24 hours, and then extracted using solid phase microextraction. Divinylbenzene/carboxen on polydimethylsiloxane 50/30 [micro]m fibers (Supelco, Bellefonte, Pennsylvlania) were used to extract the volatile organic compounds from the headspace of the vials containing the gauze. The exposure was done at room temperature for 15 hours. The extraction time used was determined to be the best extraction time for the samples, in respect to number of compounds extracted and abundances of the compounds (Curran and Furton 2004). The instrumentation used for separating and analyzing the analytes was an Agilent 6970 gas chromatography/Hewlett Packard 5973 mass selective detector. The column used a Hewlett Packard 5 mass selective detector, 30 meter, 0.25 [micro]m, 0.25 mm with helium as the carrier gas (flow rate: 1.0 mL/min). The gas chromatogram method has been described by Curran et al. (submitted). The mass spectrometer used was a Hewlett Packard 5973 mass selective detector with a quadrapole analyzer in full scan mode (range: 50-550).

Method for Scent Weight Dissipation

Four pieces of DUKAL sterile gauze were weighed on a Metler AE 240 Analytical Balance (Mettler Toledo, Columbus, Ohio).Three pieces of the gauze were given to Female 1, Female 2, and Male 3 to roll in their hand for five minutes. The subjects were asked to wash their hands 15 minutes prior to scenting. After the five minutes had elapsed, the gauze was allowed to sit for 15 minutes to cool, and then weighed again. Mass by difference was used to determine the initial scent weights on the gauze. The scented gauze and the reference gauze were left open to the atmosphere in uncovered plastic containers inside an open cardboard box in an air-conditioned room and weighed for 84 days. The reference gauze was used to account for environmental changes such as humidity, and any weight changes in the reference gauze were subtracted from the weights of the scented gauze. Since the reference gauze pad was stored under the same conditions as the scented gauze pads, the environmental factors affecting the weights of the scented gauze pads equally affected the

reference gauze pad. All changes in weight of the reference gauze pad can be attributed to environmental factors because it was handled with powderless latex gloves while being weighed on a clean analytical balance. Gloves were discarded after each weighing.

Results and Discussion

Intraday Analysis of Male 1

Figure 1 shows the chromatograms produced from intraday sampling and analysis of Male 1. Male 1 was sampled once in the morning (Sampling 1) and then again ten hours later (Sampling 2). Figure 1 is shown with the siloxane peaks removed. These peaks are attributed to the solid phase microextraction fiber coating and the column. Table 2 lists the previously reported compounds that were extracted in both samplings. Sampling 1 produced a higher abundance of compounds than Sampling 2, and cyclotetradecane, hexanal, and nonanoic acid were only seen in Sampling 1. Table 3 shows the relative peak ratios of the common compounds relative to (E)-2-nonenal extracted from the same person at different times on the same day. (E)-2-nonenal was chosen as the compound that the ratios are relative to because it is extracted in all of the samples presented here. The ratios of the common compounds between the same person on the same day appear to be relatively similar, with only minor differences.

Figure 1: Chromatograms Produced from Intraday Analysis, Male 1

Interday Analysis and Individual Comparison: Male 1 and Male 2

Figure 2 shows the chromatograms produced from intraday analysis of the same person. The initial sampling used for intraday analysis is compared to another sampling conducted two weeks earlier (Male 1, W3 and Male 1, W1), and to another person Male 2. Figure 2 is shown with the siloxane peaks removed. These peaks are attributed to the solid phase microextraction fiber coating and the column. Peaks seen at 12.59 and 14.24 minutes correspond to nonanal and decanal, respectively. Nonanal (Bernier 2002; Bernier et al. 1999; Bernier et al. 2000; Ostrovskaya et al. 2002) and decanal (Bernier et al. 1999; Bernier et al. 2000; Ostrovskaya et al. 2002; Ramotowski 2001) have been previously reported as components of human emanations; however, both compounds are present prior to sampling in the sterile gauze and will be counted only for background purposes. The abundance of these two compounds will be disregarded. Figure 2 shows the chromatograms expanded to highlight the main compounds seen, which results in an off-scale nonanal peak. Some common compounds can be seen among the people along with some differing compounds.

Table 4 lists the previously reported common compounds extracted between Week 1 and Week 3 (Sampling 1 and Sampling 2) for Male 1. Table 5 shows the relative peak ratios of the previously reported common compounds among Male 1 (W1, W3 [S1], W3 [S2]) and Male 2 relative to (E)-2-nonenal. Although there is some variation present in the same person (Table 6), the ratio pattern is still distinguishable among people with significantly greater variation in the ratios of components observed among people tested than that seen for one person. Table 7 also lists the compounds between Male1 and Male 2, which are uncommon among people. A combination of the relative ratios of the common compounds among people along with the presence of some differing compounds allows for the chromatographic distinction among people.

Figure 2: Expanded Chromatograms Produced from Different People, Male 2, and Male 1 (W1,

W3S1, W3S2)

Scent-Weight Dissipation Study

The data collected in the weight-dissipation study is shown in Figure 3, scent-mass difference plotted versus time. It is apparent that the scent collected on the gauze decreased exponentially over time and began leveling off as the scent weight approached zero. The initial weights of the scent for Female 1, Female 2, and Male 3 were .69 mg, 2.52 mg, and 3.16 mg, respectively. After 84 days of weighing, there was still weight present on the gauze scented by Male 3 and Female 2. It is expected that the mass of odiferous compounds would decrease over time because these compounds must diffuse into the air to produce a detectable scent; thus, the amount of these compounds on the source object must decrease over time.

Figure 3: Scent Weight Dissipation

Conclusions

The method described in this manuscript has shown to be a viable route for extracting, separating, and analyzing human odor. It appears that human scent is a combination of various compounds differing in ratio from person to person along with some compounds that are unique to certain people. These preliminary studies indicate that the compound ratio patterns produced for a person are reproducible over time. Although there is some variation present in the same person, the ratio pattern is still distinguishable among people with significantly greater variation in the ratios of components observed among people tested than that seen for one person. In addition to the ratio of common chemicals, the presence of different compounds varies among people. A combination of the relative ratios of the common compounds among the people along with the presence of some differing compounds allows for the chromatographic distinction among people for the subjects studied here. Finally, there appears to be a relatively long persistence of the human-scent compounds in a controlled environment with measurable amounts still present nearly three months after being deposited on sterile gauze. Further studies

are underway, including expanding the number of people tested (with different ages, races, gender) as well as optimizing the collection and preservation of scent samples, and improving the quantitative aspects of these comparisons.

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Table 1: Average Humidity and Temperature for Samplings of Male 1 and Male 2

Subject	Date	Average Temperature ([degrees] C)	Average Humidity (%)
Male 1, Week 1	4/07/2004	73	63
Male 1, Week 3	4/18/2004	73	62
Male 2	4/10/2004	80	76

Table 2: Volatile Compounds Extracted Intraday, Male 1

Compound Name	M.W.	Sampling 1	Sampling 2
(E)-2-nonenal (7)	140	X	X
(E)-2-octenal (7)	126	X	X
(E,E)-2,4-nonadienal (1,6,7)	138	X	X
(E,E)-2,4-decadienal (7)	152	X	X
3,7-dimethyl-2,6-octadienal (1)	152	X	X
6,10-dimethyl-5,9-undecadien-2-one (1)	194	X	X
Benzaldehyde (1,6)	106	X	X
Benzyl alcohol (1,4)	108	X	X
Cyclotetradecane (1)	196	X	
Dodecanoic acid (1,3,5,6)	200	X	X
Heptadecane (1,2)	240	X	X
Heptanal (1,5,6)	114	X	X

Hexanal (5,7)	100	X	
Nonanoic acid (1,3,4,8)	158	X	
Octadecane (1)	254	X	X
Toluene (1,6)	92	X	X
Undecanal (5)	170	X	X

(1.) Previously reported as a component in human skin emanation (Bernier et al. 2000).

(2.) Previously reported as a volatile component of the skin (Ostrovskaya et al. 2002).

(3.) Previously reported as a component of armpit odor (Zeng et al. 1991).

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(7.) Previously reported as a component of armpit odor (Munk et al. 2000).

(8.) Previously reported as a component of fingerprint residue (Ramotowski 2001).

Table 3: Relative Ratios of Common Compounds Found Through Sampling 1 (S1) and Sampling 2 (S2), Male 1

Compound	Peak Ratio (S1)	Peak Ratio (S2)
(E)-2-nonenal	1.0000	1.0000
(E)-2-octenal	1.0205	0.6842
(E,E)-2,4-nonadienal	0.9683	0.7200
(E,E)-2,4-decadienal	0.3247	0.2914
3,7-dimethyl-2,6-octadienal	1.6698	2.5324
6,10-dimethyl-5,9-undecadien-2-one	5.1980	6.7795
Benzaldehyde	1.1034	0.4013
Benzyl alcohol	0.4492	0.5847
Dodecanoic acid	2.6417	2.4870
Heptadecane	0.3107	0.3302
Heptanal	0.7935	0.6783

Octadecane	0.1931	0.1891
Toluene	0.0810	0.0850
Undecanal	1.1646	1.5836

Table 4: Volatile Compounds Extracted Interday, Male 1

			S1	S2
Compound Name	M.W.	Wk 1	Wk 3	Wk 3
(E)-2-nonenal (7)	140	X	X	X
(E)-2-octenal (7)	126	X	X	X
(E,E)-2,4-nonadienal (1,6,7)	138		X	X
(E,E)-2,4-decadienal (7)	152		X	X
3,7-dimethyl-2,6-octadienal (1)	152		X	X
6,10-dimethyl-5,9-undecadien-2-one (1)	194	X	X	X
6-methyl-5-hepten-2-one (1,2,6)	126	X		
Benzaldehyde (1,6)	106	X	X	X
Benzyl alcohol (1,4)	108	X	X	X
Cyclotetradecane (1)	196	X	X	
Dodecanoic acid (1,3,5,6)	200	X	X	X
Heptadecane (1,2)	240	X	X	X
Heptanal (1,5,6)	114		X	X
Hexanal (5,7)	100		X	
Nonane (1,6)	128	X		
Nonanoic acid (1,3,4,8)	158	X	X	
Octadecane (1)	254	X	X	X
Phenol (1,3,4)	94	X		
Toluene (1,6)	92		X	X
Undecanal (5)	170	X	X	X

(1.) Previously reported as a component in human skin emanation (Bernier et al. 2000).

(2.) Previously reported as a volatile component of the skin (Ostrovskaya et al. 2002).

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(8.) Previously reported as a component of fingerprint residue (Ramotowski 2001).

Table 5: Volatile Compounds that are Common Between Male 1 (W1, W3S1, W3S2) and Male 2

Compound	Peak Ratio M1 (W1)	Peak Ratio M1 (W3) S1	Peak Ratio M1 (W3) S2	Peak Ratio M2
(E)-2-nonenal	1	1	1	1
6,10-dimethyl-5, 9-undecadien 2-one	4.0209	6.7795	5.198	13.584
Benzyl alcohol	0.6440	0.5847	0.4492	2.1466
Dodecanoic acid	1.3175	2.4870	2.6417	4.9138
Heptadecane	0.3300	0.3302	0.3107	6.4197
Octadecane	0.2574	0.1891	0.1931	0.9252
Undecanal	0.6456	1.5836	1.1646	3.7387

Table 6: Comparison of Volatile Compounds that are Common Between Male 1 (Average) and Male 2

Compound	Average Peak Ratio (M1)	Standard Deviation of Peak Ratio (M1)	Peak Ratio (M2)	M2/M1 Ratio
(E)-2-nonenal	1	0	1	1
6,10-dimethyl-5, 9-undecadien-2 one	5.3328	1.3842	13.584	2.5472
Benzyl alcohol	0.5593	0.0998	2.1466	3.8378
Dodecanoic acid	2.1487	0.7240	4.9138	2.2868
Heptadecane	0.3236	0.0112	6.4197	19.8381
Octadecane	0.2132	0.0383	0.9252	4.3404
Undecanal	1.1312	0.4699	3.7387	3.3049

Table 7: Volatile Compounds Uncommon Between Male 1 (M1) and Male 2 (M2)

Compound Name	M. W.	M1	M2
Alcohols	---	---	---
3,7-dimethyl-6-octen-1-ol (1)	156		X

Phenol (1,3,4)	94		X
Phenylethyl alcohol (6)	122		X
Aldehydes	---	---	---
(E)-2-octenal (6)	126	X	
(E,E)-2,4-decadienal (6)	152	X	
(E,E)-2,4-nonadienal (1,5,6)	138	X	
3,7-dimethyl-2,6-octadienal (1)	152	X	
Benzaldehyde, (1,5)	106	X	
Aliphatics/Aromatics	---	---	---
Cyclotetradecane (1)	196	X	
Octadecane (1)	254	X	
Pentadecane (1,2)	212		X

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