HOW DO I SMELL? THE POTENTIAL OF BODY ODOR IN HUMAN PERSONAL IDENTIFICATION

Jovana Vesović, MSc
Anja Zlatanović

Smilja Teodorović, PhD[1]
University of Criminal Investigation and Police Studies, Belgrade, Serbia

Abstract: The ability of canines to discriminate among individuals lead scientists to believe, a long time ago, that every human has a unique scent. Development of physicochemical analytical techniques enabled testing and further researching these expectations. Sensitive and reliable SPME-GC/MS method allows detection and identification of volatile organic compounds comprising individual scent, whose presence in odor is constant and can, therefore, be used for personal authentication. Ongoing studies further demonstrate the efficiency of chemical sensors, such as the E-nose, in real-time personal recognition. In this paper, factors defining human scent, as well as the possibility of utilizing body odor as a novel biometric identifier, were presented. The advantages and limitations of mentioned techniques, as well as future directions for experimental studies, were also considered. Finally, the possibility of utilizing body odor in police work for locating human remains and sniffing out the wrongdoers was given.

Keywords: human scent, volatile organic compounds, SPME-GC/MS

INTRODUCTION

In practical police work dogs are used for scent detection since the beginning of the twentieth century. Beside the possibility to train dogs to find substances like explosives or narcotics, canines are being used to follow the trail of missing humans or even to find buried human remains. Today canines are used in police stations around the world to connect the smell from an object found on criminal site with one of the scented objects from the row for identification in scent line-up technique (Prada, Curran & Furton, 2015). High rates of successful canine identifications lead scientists to wonder what it is in human odor that a

1 smilja.teodorovic@kpu.edu.rs

canine detects in order to match two samples of odor left by the same individual. The possibility of using the existing techniques to differentiate humans based on their odor signatures, which could then be regarded as a biometric characteristic, was therefore considered (Rodriguez-Lujan, Bailador, Sanchez-Avila, Herrero & Vidal-de-Miguel, 2013).

The first step in ascertaining the possibility of human scent as a biometric characteristic is determining the frequency of occurrence of compounds from scent across a population and possibility of acquiring human scent profiles that vary among individuals. Technology development in the last few decades brought several methods that can be utilized for this task. A solid-phase microextraction followed by gas chromatography-mass spectrometry analysis (SPME-GC/MS) proved to be adequate technique for characterization of human smell compounds. The aim of this paper is to present feasibility of this method and results obtained over the years, as well to introduce new approaches based on the electronic nose (E-nose).

BODY ODOR AND FACTORS THAT DEFINE IT

There are numerous sources that contribute to a person's odor signature. Volatile organic compounds (VOCs) released from the body result from individual's genetics, gender and age, but also skin microbiota, together with various environmental factors. All these aspects combined define the ultimate odorant mixture characteristic of an individual (Prada et al., 2015).

Human skin and scent transfer

Skin is a protective barrier of a human body responsible for its thermal regulation. It is equipped with secretion glands that aid in this function. These glands govern the production of volatile organic compounds of scent; therefore distinct odors are emitted from different body parts depending on the gland types present, as well as their concentration on the skin surface (Dormont, Bessière & Cohuet, 2013).

Eccrine sweat glands have long, thin ducts that open directly onto the skin surface. They excrete perspiration responsible for reducing the body temperature and are widely distributed over the body, but are especially concentrated in the palms of the hands, the soles of the feet and forehead. There are approximately 3-4 million eccrine glands in one person's skin which can excrete up to 3 liters of sweat per hour. Composition of eccrine sweat depends on the body region. It is a clear, acidic fluid containing up to 99% water, while remaining components include electrolytes, glycoproteins, lactic acid, sugars and amino acids.

Apocrine sweat glands have ducts that exit towards the surface via hair follicles. They are, hence, restricted to hairy body areas (mostly pubic area, armpits

and breast areola) and their activity starts at puberty. They too excrete colorless, slightly acidic fluid, which consist of water and higher concentrations of fatty acids, triglycerides, ammonia and sugars.

Sebaceous glands can primarily be found on the face and scalp but are distributed all over the skin surface, and excrete sebum via hair follicles. Sebum is a complex, yellowish, viscous fluid that contains fatty acids, triglycerides, wax esters and free sterols. Its excretion is a slow process, as approximately 0.3 mg of sebum is excreted per 10 cm^3 per hour (Rodriguez-Lujan at al., 2013; Prada et al., 2015).

Secretions of sweat and sebum glands are odorless, however metabolic activity of skin bacteria transforms them into odorous components. Human skin is inhabited by a diverse bacterial flora, including but not limited to *Corynebacterium*, *Staphylococcus*, *Propionibacterium*, *Streptococcus*, *Pseudomonas*, *Brevibacterium*, *Acinetobacter*, *Bacillus* and *Micrococcus* species (Wood & Kelly, 2010). Type and density of present bacteria are determined by numerous factors, such as anatomic location, sweat production, host's hormonal status and environmental conditions. Bacterial degradation of sweat components leads to the production of many VOCs present in human smell. For example, sulphur compounds present in human scent are metabolic products of several bacterial species, such as *Corynebacterium tuberculostearicum*, *Corynebacterium minutissimum*, *Staphylococcus epidermidis*, *Bacillus licheniformis* and *Staphylococcus haemolyticus* (Fredricks, 2001); many fatty acids, aldehydes and alcohols result from sebaceous triglycerides decomposition by the lipases produced by *Staphylococcus capitis*, *Propionibacterium*, *Corynebacterium* and other *Staphylococcus* species (Chiller, Selkin & Murakawa, 2001).

There are approximately two billion cells which make the outer layer of skin, more than 600 of which are shed per second into the environment during the natural process called desquamation. These rafts of dead skin contain one or more dead epithelial cells, skin microflora and body secretions, which all contribute to the individual's odor. Rafts are approximately 14 μm in size with mass of 0.07 μg.

Since the air around the skin is usually of lower temperature than that of a human body, thermal convection process constantly transfers body heat to the surrounding area, carrying with it the skin rafts. Lighter rafts then drift away while the heavier ones fall close to the person, leaving scent in their wake. Once transmitted into the environment, stability of human scent is dependent of various environmental conditions, such as temperature, moisture or wind (Li, 2009; Prada et al., 2015).

Body odors can be classified into three categories. Primary odor is a result of the components that are stable over time regardless of external factors. Secondary odor contains components that are present in a scent due to diet, drugs, diseases, mood swings and other internal factors. Tertiary odor is comprised of external components, such as the ones resulting from the use of perfumes and other cosmetic products (Rodriguez-Lujan at al., 2013; Prada et al., 2015).

Clearly, detection and analysis of primary odor components has been the focus of research attempting to utilize odor signature as a unique human identifier.

METHODS OF SCENT COLLECTION AND CHARACTERIZATION

For investigative purposes, human scent can be collected either directly or indirectly. Direct methods include collecting the object that has been in contact with a person whose smell is being analysed, or collecting the sample from an individual with a collecting medium such as gauze pads. Indirect methods include the use of absorber placed in contact with or in the vicinity of an object from which the scent is collected (Curran, Prada, Schoon, Almirall & Furton, 2005).

Nowadays, methods for collecting smell usually imply passive collection, or headspace absorption. One such method, designed specifically for human scent collection, utilizes the Scent Transfer Unit device (STU-100), a portable vacuum instrument which draws the air through the sterile pads, which than traps VOCs from scent. This method allows noncontact collection without contamination of the object of interest (Prada et al., 2015).

SPME-GC/MS

SPME-GC/MS is a method that has been successfully used for the extraction and characterization of volatile compounds of explosives and drugs and has, therefore, been proposed for use in the human scent VOCs analysis (Curran et al., 2005a). SPME is a simple, sensitive, solvent-free technique which allows extraction and pre-concentration of analytes from headspace of samples on adsorbent-coated fibres (Curran, Ramirez, Schoon & Furton, 2007), as well as their desorption directly into GC injectors. GC is used for separating components of the sample, while MS is used as a detector for individual analytes (Li, 2009). Many studies employed this technique over the years.

Most commonly tested body parts were armpits (Curran et al., 2005a; Curran, Rabin, Prada & Furton, 2005; Penn et al., 2007) and hands (Curran et al., 2005b, 2007; Curran, Prada & Furton, 2010), but smell had been sampled from the upper back and forearms as well (Gallagher et al., 2008). In order to minimize the presence of tertiary odor components in scent samples, various skin treatment procedures were implemented prior to the odor collection in different studies. Some protocols required participants to discontinue the use of deodorants and perfumes (Curran et al., 2005a, 2005b; Penn et al., 2007; Gallagher et al., 2008), while others urged them to use fragrance-free liquid soaps (Penn et al., 2007; Gallagher et al., 2008) several days before the odor sampling. In cases when washing of the sampling area occurred, it was done with olive oil (Curran et al., 2005b, 2007, 2010) or glycerine-based (Curran et al., 2005a) soaps and air-dried. Vol-

unteers were sometimes asked to do some exercise in order to accumulate larger amounts of sweat (Curran et al., 2005a, 2005b; Gallagher et al., 2008).

Odor samples were collected on adsorbent materials, such as cotton swabs (Kusano, 2011) or gauze pads (Curran et al., 2005a, 2005b, 2007, 2010) and stored in controlled environmental conditions before the extraction; alternatively, SPME was used to collect the VOCs directly from the headspace above the participants' skin (Gallagher et al., 2008).

Obtained profiles were analysed, present compounds identified by spectral library and their quantitative presence in samples estimated. Close to one hundred chemical compounds were detected in scent samples, including only a few families of compounds, namely carboxylic acids and derivative esters, but also aldehydes, alkanes, alcohols and ketones. Table 1 shows fifteen most often reported compounds in these studies.

Table 1: *Most often reported VOCs of human smell with references*

Compound	Reference
phenol	Curran et al., 2005a, 2005b, 2007, 2010; Penn et al., 2007; Gallagher et al., 2008; Kusano, 2011
nonanal	Curran et al., 2005a, 2005b, 2007, 2010; Gallagher et al., 2008; Kusano, 2011
decanal	Curran et al., 2005a, 2005b, 2007, 2010; Gallagher et al., 2008; Kusano, 2011
undecanal	Curran et al., 2005a, 2005b, 2007, 2010; Penn et al., 2007;
dodecane	Curran et al., 2005a, 2005b, 2007, 2010; Kusano, 2011
tetradecane	Curran et al., 2005a, 2005b, 2007, 2010; Kusano, 2011
2-furancarboxaldehyde	Curran et al., 2005a, 2005b, 2007, 2010
2-furanmethanol	Curran et al., 2005a, 2005b, 2007, 2010
hexanedioic acid, dimethyl ester	Curran et al., 2005a, 2005b, 2007, 2010
propanedioic acid, dimethyl ester	Curran et al., 2005a, 2005b, 2007, 2010
octanoic acid, methyl ester	Curran et al., 2005a, 2005b, 2007, 2010
6,10-dimethyl-5,9-undecadiene-2-one	Curran et al., 2005a, 2005b, 2007, 2010

benzyl alcohol	Curran et al., 2005a, 2007, 2010; Kusano, 2011
toluene	Curran et al., 2005a, 2005b, 2007; Kusano, 2011
octanal	Curran et al., 2005a, 2007; Gallagher et al., 2008

Obtained profiles of VOCs differ significantly among individuals. Although some studies reported a lack of significant differences in compounds detected in male and female samples (Gallagher et al., 2008), others reported the presence of 'gender-specific' signatures (Penn et al., 2007). Specifically, even though unique individual markers to discriminate the sexes were not discovered, multivariate distribution of several marker compounds was used to successfully predict volunteer's gender. Further, specific compounds were found to be present only in particular age groups (Gallagher et al., 2008).

Despite variations in smell composition on different body parts due to the presence of distinct gland types, two samples from the same individual share a considerable number of compounds and their ratio pattern is constant for one person and varies significantly from other tested subjects (Curran et al, 2005a; Gallagher et al., 2008).

Reproducibility of the results was also tested. It was noted that samples taken on different occasions show differences in component concentrations, but similarities in ratio patterns of the peaks remain constant (Curran et al, 2005b).

Only those compounds found in all scent samples of one individual are considered their primary odor components. Curran et al. (2010) tested 10 subjects, where three samples were collected from each individual during a 12 hour period. The analysis resulted in 24 compounds deemed to constitute primary odor. When correlation tests were used to determine relationships between acquired samples, individuals were correctly discriminated and identified in over 99.5% of the cases, even using high correlation threshold.

The possibility of matching person's odor profiles from a human scent database library was evaluated. Successful identification rates were inconsistent and unsatisfying even with low correlation threshold, which implies that 24 compounds determined to be primary odor components were not sufficient markers for identification when larger population was considered. This further implies that determination of human odor baseline on an individual basis is critical in determining which VOCs are significant for determining identity.

Even though SPME-GC/MS proved to be a sensitive and reliable method for detecting sweat compounds present even in small concentrations, the exact origin of individual VOCs from human odor is still unknown. Current studies were unable to determine whether discriminating potential of scent compounds lies in the relative ratio of VOCs between individuals, the presence of highly variable VOCs, or whether the coherence of both factors is required.

Therefore, the use of human scent for personal identification in large populations is currently impossible, however it demonstrates satisfying results for authentication purposes.

E-nose

Even though conventional instruments such as GC and MS allow identification of all VOCs present in smell samples, those analytical procedures are time consuming and too expensive for routine identifications (Li, 2009). The goal is, thus, to develop technology which allows their real-time efficient automated detection and classification. One such system is E-nose, a combination of sensing and classification units, which is already being successfully used for quality control of food and beverages, as well as the detection of air pollutants (Wongchoosuk, Lutz & Kerdcharoen, 2009). Since such instrument does not provide information about types of VOCs present in the sample, but a system generates data based on the change of sensors' signals when they come in contact with any volatile, it was considered as a biometric technique that could recognize odor signature for personal authentication (Iskandarani, 2010).

A number of various E-noses have been developed, some of them shown in Figure 1.

Figure 1. E-nose systems: HERACLES Neo (Alpha MOS)[2] and Cyranose (Sensigent)[3]

The sensing system represents an array of chemical sensors whose role is to acquire odor components, where each detected odorant produces a signature of characteristic pattern. Odor molecules are being detected based on their reaction with the target sensing materials on the sensor surface (Li, 2009). A number of chemical sensors have been developed, and based on their detection mechanisms, they can be classified into several categories. Most commonly used are conductivity, piezoelectric, optical fibre and spectrometry-based sensors; clearly,

2 Taken from www.alpha-mos.com
3 Taken from www.sensigent.com

each sensor type has its advantages and flaws (Korotkaya, 2003; Oyeleye, Fagbola, Babatunde & Adigun, 2012).

Pattern recognition system is designed to classify detected odorants through automated identification. It includes several approaches, statistical techniques for reducing amount of analysed data and pattern classifying algorithms such as Principal Component Analysis (PCA) or Artificial Neural Networks, which performs clustering of the acquired data into groups based on measured attributes (Korotkaya, 2003; Oyeleye et al., 2012).

Considering it is a device designed to analyze volatile components, E-nose is a gas sensor that is, like most gas sensors, sensitive to humidity. That means that if two odor samples from one person are analyzed in different humidity conditions, obtained results could differ significantly. Correction of humidity effect is therefore crucial for ensuring that sensor responds only to odor components. In their studies, Wongchoosuk at al. (2009) proposed and simultaneously used two methods for this task. The first solution was a hardware-based approach where the carrier gas was directed through water container immersed in a heath bath with controlled temperature, ensuring the constant humidity background. The second was a software-based method, where a mathematical model describing the resistance of every used gas sensor at different humidity level was developed. Model calibration ensured that humidity signal could be subtracted from the total signal.

In this study commercially available gas sensors of varying detection ranges for different types of gases were used. Utilized sensors were fabricated by deposition of a metal oxide semiconductive material on device electrodes. Catalytic reaction between gas molecules and metal oxide surface resulted in a change of resistance between the electrodes, which was then measured and converted into a signal.

Since the armpit is a body part known to have large number of glands where skin bacteria produce strong odor, it was chosen as a region of interest. Samples were taken from two male subjects twice a day for five consecutive days. During this period volunteers were forbidden to consume alcohol and engage in sexual activities, as to lessen the effects of secondary odor in scent samples. In order to test the impact of hygiene products on scent signature, subjects were instructed to use deodorant after showering on one arm only. Cotton pads were used for collecting the samples, which were then presented to E-nose for analysis.

PCA was used for pattern analysis of the smell samples, and the results showed that even though obtained signals varied among samples taken from an individual, PCA was able to successfully group the data of each volunteer regardless of the deodorant use. It was, therefore, demonstrated that each person had distinguishable odor pattern that could be used for their authentication.

A subsequent study (Wongchoosuk et al., 2011) broadened this research by testing four volunteers, without controlling their everyday activities. The applied

system was able to successfully differentiate the odor signals of individuals with 95% accuracy.

Initial studies demonstrated that E-nose represents a promising approach for authentication of individuals based on their scent. However, they were performed on a negligible number of subjects and experiments on extensive population need to be conducted.

POSSIBLE APPLICATIONS OF HUMAN IDENTIFICATION BASED ON BODY ODOR

Human scent is a trait whose composition is dependent on many factors, such as diet, medical conditions and the use of personal hygiene products. Despite challenges, scientists continue attempting to determine primary odor constituents given their promising potential in practical work. Given that presence of those components is dictated by genetic factors, as a well as accompanying microbiota that are highly diverse between individuals (Gao, Tseng, Pei & Blaser, 2007), odor profile is an individual trait that could be exploited for unambiguous personal identification. Thus, underlying factors defining body odor make intentional change of scent signature virtually impossible. Biometric sensors, such as E-nose, that could be built for discrimination among individuals based on their scent are, therefore, less likely to be circumvented, which is crucial for real-life applications.

Canines have been used for locating missing persons and identifying suspects based on their scent for decades. They are also utilized for locating human remains in various stages of decay. It is therefore only logical to assume that decomposing human body releases characteristic VOCs in the environment, and many experiments were conducted to discover them. DeGreeff and Furton (2011) collected samples from the headspace of human and animal remains, as well as from the headspace of living humans and animals with the STU-100. Utilizing the SPME-GC/MS, they detected 13 VOCs present only in human remains samples. Despite some shared compounds, complete odor profiles of living humans and human remains samples differed significantly. VOCs detected in animal and human samples differed even more. This demonstrates the promising potential of the technique for differentiation between living and deceased humans scent trails left on crime scenes, as well as for uncovering the origin of indistinguishable body parts and tissues.

For the last several years there has been a great interest in olfactory sensors development, which could be used for smelling potential threat at a distance. The idea is based on the detection of fear pheromones in human body odor. It is speculated that bodies of stressed individuals release unique compounds in the environment (Randerson, The Guardian; 2008, December 3). The identification and detection of these components could be used for devising the sensors that would

be able to sniff out the wrongdoers at the distance based on their scent alone. That could lead to the detection of people with bad intentions, terrorists, drug dealers and fugitives at strategic locations, such as control gates on airports and customs at state borders, leading to their arrest before they have a chance to act on their intentions or leave the country.

CONCLUSION

An increasing body of work in recent years has attempted to ascertain whether human scent is a sufficiently distinguishing characteristic among people and whether it can be used as a biometric characteristic for individual authentication. Analytical methods, such as SPME-GC/MS, proved to be effective tools for obtaining characteristic odor profiles, but, at the same time, too expensive and time-consuming for routine authentications. On the other hand, E-noses have shown great potential as uncostly, real-time biometric sensors, but their proficiency has yet to be demonstrated in experiments conducted on larger populations.

In order to investigate the utilization of scent as a biometric trait, the feasibility of human identification must be examined. Extensive research needs to be conducted, in order to determine the primary odor components and identify specific compounds responsible for the unique scent signatures. That would include long-term sampling of large population groups, where influence of secondary factors such as diet, medicament consummation and health conditions would need to be excluded. In addition, strict protocols would need to be developed in order to minimize the effects of varying experimental conditions.

Other than personal identification in civil applications, human body odor is an emerging biometric characteristic with respect to forensic evidence. With the use of functional detectors, scent trails left on crime scenes could be used for identifying criminals, as it is being done with fingerprints and DNA traces. Knowing which components to seek, selective E-noses could be designed to help find buried human remains. That could lead to the exclusion of dogs on site and the use of reliable devices. Finally, advances in detection of alert signals from human scent at the distance would contribute to efforts in preventing terrorist attacks worldwide.

REFERENCES

1. Chiller, K., Selkin, B. A. & Murakawa, G. J. (2001). Skin Microflora and Bacterial Infections of the Skin. *Journal of Investigative Dermatology Symposium Proceedings*, 6(3), 170-174. doi:10.1046/j.0022-202x.2001.00043.x.
2. Curran, A. M., Prada, P. A., Schoon, A. A., Almirall, J. R. & Furton, K. G. (2005). Human Scent as a Biometric Measurement. *Biometric Technology for Human Identification II*, 5779, 398-408. doi:10.1117/12.603820.
3. Curran, A. M., Rabin, S. I., Prada, P. A. & Furton, K. G. (2005). Comparison of the Volatile Organic Compounds Present in Human Odor Using SPME-GC/MS. *Journal of Chemical Ecology*, 31(7), 1607-1619. doi:10.1007/s10886-005-5801-4.
4. Curran, A. M., Ramirez, C. F., Schoon, A. A. & Furton, K. G. (2007). The frequency of occurrence and discriminatory power of compounds found in human scent across a population determined by SPME-GC/MS. *Journal of Chromatography B*, 846(1-2), 86-97. doi:10.1016/j.jchromb.2006.08.039.
5. Curran, A. M., Prada, P. A. & Furton, K. G. (2010). The Differentiation of the Volatile Organic Signatures of Individuals Through SPME-GC/MS of Characteristic Human Scent Compounds. *Journal of Forensic Sciences*, 55(1), 50-57. doi:10.1111/j.1556-4029.2009.01236.x.
6. DeGreeff, L. E. & Furton, K. G. (2011). Collection and identification of human remains volatiles by non-contact, dynamic airflow sampling and SPME-GC/MS using various sorbent materials. *Analytical and Bioanalytical Chemistry*, 401(4), 1295-1307. doi:10.1007/s00216-011-5167-0.
7. Dormont, L., Bessière, J. M. & Cohuet, A. (2013). Human Skin Volatiles: A Review. *Journal of Chemical Ecology*, 39(5), 569-578. doi:10.1007/s10886-013-0286-z.
8. Fredricks, D. N. (2001). Microbial Ecology of Human Skin in Health and Disease. *Journal of Investigative Dermatology Symposium Proceedings*, 6(3), 167-169. doi:10.1046/j.0022-202x.2001.00039.x.
9. Gallagher, M., Wysocki, C. J., Leyden, J. J., Spielman, A. I., Sun, X. & Preti, G. (2008). Analyses of volatile organic compounds from human skin. *British Journal of Dermatology*, 159(4), 780-791. doi:10.1111/j.1365-2133.2008.08748.x.
10. Gao, Z., Tseng, C., Pei, Z. & Blaser, M. J. (2007). Molecular analysis of human forearm superficial skin bacterial biota. *Proceedings of the National Academy of Sciences*, 104(8), 2927-2932. doi:10.1073/pnas.0607077104.
11. Iskandarani, M. Z. (2010). A Novel Odor Key Technique for Security Applications Using Electronic Nose System. *American Journal of Applied Sciences*, 7(8), 1118-1122. doi:10.3844/ajassp.2010.1118.1122.
12. Korotkaya, Z. (2003). Biometric Person Authentication: Odor. Downloaded May 28, 2019. http://www.it.lut.fi/kurssit/03-04/010970000/seminars/Korotkaya.pdf.

13. Kusano, M., Mendez, E. & Furton, K. G. (2011). Development of headspace SPME method for analysis of volatile organic compounds present in human biological specimens. *Analytical and Bioanalytical Chemistry*, 400(7), 1817-1826. doi:10.1007/s00216-011-4950-2.
14. Li, S. (2009). Overview of Odor Detection Instrumentation and the Potential for Human Odor Detection in Air Matrices. Downloaded May 28, 2019.
15. http://www.mitre.org/sites/default/files/pdf/09_4536.pdf.
16. Oyeleye, C. A., Fagbola, T. M., Babatunde, R. S. & Adigun, A. A. (2012). An Exploratory Study Of Odor Biometrics Modality For Human Recognition. *International Journal of Engineering Research & Technology*, 1(9), 1-9.
17. Penn, D. J., Oberzaucher, E., Grammer, K., Fischer, G., Soini, H. A., Wiesler, D., Novotny, M. V., Dixon, S. J., Xu, Y. & Brereton, R. G. (2007). Individual and gender fingerprints in human body odour. *Journal of The Royal Society Interface*, 4(13), 331-340. doi:10.1098/rsif.2006.0182.
18. Prada, P. A., Curran, A. M. & Furton, K. G. (2015). *Human Scent Evidence*. Boca Raton, FL: CRC Press.
19. Randerson, J. (2008, December 3). The smell of fear is real, say scientists. *The Guardian*. Accessed on March 19, 2019.
20. https://www.theguardian.com/science/2008/dec/03/fear-smell-pheromone
21. Rodriguez-Lujan, I., Bailador, G., Sanchez-Avila, C., Herrero, A. & Vidal-de-Miguel, G. (2013). Analysis of pattern recognition and dimensionality reduction techniques for odor biometrics. *Knowledge-Based Systems*, 52, 279-289. doi:10.1016/j.knosys.2013.08.002.
22. Wongchoosuk, C., Lutz, M. & Kerdcharoen, T. (2009). Detection and Classification of Human Body Odor Using an Electronic Nose. *Sensors*, 9(9), 7234-7249. doi:10.3390/s90907234.
23. Wongchoosuk, C., Youngrod, T., Phetmung, H., Lutz, M., Puntheeranurak, T. & Kerdcharoen, T. (2011). Identification of People from Armpit Odor Region using Networked Electronic Nose. *Defense Science Research Conference and Expo (DSR)*, proceedings book (1-4), Singapore: IEEE. doi:10.1109/dsr.2011.6026826.
24. Wood, A. P. & Kelly D. P. (2010). Skin Microbiology, Body Odor, and Methylotrophic Bacteria. *Handbook of Hydrocarbon and Lipid Microbiology*. Berlin, Heidelberg: Springer. doi:10.1007/978-3-540-77587-4_243.