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Nature, source, and behavior of a human characteristic vulnerable to intelligence exploitation.

HUMAN SCENT AND ITS DETECTION

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The olfactory sensibilities of dogs have made them a useful adjunct of intelligence and security services for as long as such services have existed. In World War II the German and currently several East European counterintelligence organizations have made notably regular use of them for tracking and identifying suspects, fugitives, and subjects of surveillance. It is curious that this anachronistic animate operational aid has simply been accepted into the age of science and technology without much effort to discover whether it could be replaced or improved upon, to define its precise capabilities with a view to countermeasures, or even to determine how it really works. The very familiarity of the fact that a dog can detect a man's odor from a considerable distance and can also distinguish one person from another by odor alone may explain why there has been little serious consideration of the parameters of the dog's capabilities or what it is about a human being that he smells.

Just what is the odor that a dog identifies as human scent? This is the first question that must be answered in a systematic inquiry into the phenomenon. Knowledge of the nature of this odor would open the way to a definition of the abilities of the dog. It would make possible experimental studies to determine the effects of weather, terrain, and other factors on the persistence and spread of the scent. It would provide a base point in the search for techniques to neutralize human odor or otherwise counteract the effectiveness of dogs. Since every person appears to have a different odor, it could also lead to a technique for identifying individuals. A more visionary but still potential outcome of the study of human odor could be the development of a "mechanical dog," a device that would automatically detect the presence of an individual by his scent.

These eventual applications of value to intelligence cannot be approached, however, until the basic questions are answered. This paper summarizes the results of current research in this field.

Characteristics of the Scent

In 1924 L. Löhner, of the Physiological Institute of the University of Graz, published a paper comparing human and canine perception of human odor.[1] In an experiment devised to determine if humans could differentiate between individuals by odor, he had used a group of males between 20 and 40 years old, racially similar agrarian people from the Bavarian Alps. All were given the same diet during the testing period and they bathed before each test. Then they took sun baths with test cloths on various parts of their bodies—armpits, pubic region, the hair on the head, and, for a hairless region, the upper back or the palm of the hand. With practice, the men could distinguish among cloths which had been on different parts of the body, but they could not distinguish one individual from another. Löhner apparently didn't get dogs to sniff these cloths, but he pointed out that trailing dogs can take a scent from clothing off any part of the body, and he concluded that whereas humans differentiate among odors from different regions of the body, dogs recognize some common component which identifies the individual.

In another paper, published in 1926, Löhner reported some experiments with a female Doberman pinscher and blocks of wood which had been held by various individuals.[2] He said the dog could identify a block which had been touched by only one finger for a period of one or two seconds. Furthermore, the human odor was not masked when odorous substances such as bergamot, oil of cloves, or wild marjaram oil were applied to the test blocks. Trying to determine how long a block retained the hand scent, he found that it was lost faster in warm weather than in cold, and most slowly if the block was kept in a closed jar. It was not removed by soaking for two minutes in warm water, but could be eradicated

[1] Löhner, L., Pflüger's Archiv für die Gesamte Physiologie des Menschen und die Tiere, *202*, 25–45, (1924).

[2] Löhner, L., Pflüger's Archiv für die Gesamte Physiologie des Menschen und die Tiere, *212*, 84–94, (1926).

by placing the block in a hot air dryer at about 150° C. for five to ten minutes or in boiling water for ten minutes.

It is possible to draw several conclusions about the nature of human scent from these experiments and from other evidence.

First, the odorous substance must be somewhat volatile, since it could be removed by hot air. There are other considerations that support this conclusion. For instance, it is difficult to imagine how a dog could detect a person from a distance if the odorous material were not volatile. In one series of our own experiments, portions of trails were laid by rowing a boat along the shore of a lake, and it was found that a dog, trailing on shore, could determine which way his human quarry had gone without its having set foot on the ground. The shore line must therefore have been marked for him by vaporized scented matter.

Second, its volatility can nevertheless not be very high under ordinary conditions. Since it remains on sticks and clothing for a considerable length of time, it must have a fairly low vapor pressure.

Third, it must be rather persistent (in the chemical warfare sense), hence chemically stable and relatively dense with respect to air. Dogs can follow a trail hours after it was laid, and their actions indicate that pockets of scent collect and persist in particular places under the proper conditions.

Fourth, since warm water did not remove the scent from Löhner's test blocks, it is not readily soluble in water. There is evidence that a dog can identify an individual by scent, although apparently with more than usual difficulty, even after a number of successive baths. Either it is very difficult to wash the scent off even with soap, or else it is replaced rapidly after a bath.

Some of our own experiments lead to further conclusions. In these a male Laborador retriever named Skimmer, after sniffing the hand of one individual, would select a stick he had handled from among three or four handled by other persons. The experimental variations of this basic test procedure were each repeated at least three times, a different set of sticks being placed in different order on a different section of a wooden floor at each repetition. In practice the tests were not necessarily consecutive: it was found the dog would lose interest after a few hours of work on any single day.

In one set of tests, although Skimmer was still given the individual's scent by holding a hand over his nose, he selected the right stick just as well if, instead of having been held in the hand, it had been placed only under the arm or had only been rubbed through the hair. A female miniature poodle named Onyx, given the hand scent of an individual, also readily selected a stick which had only had contact with his hair. This essentially was a continuation of Löhner's experiment, demonstrating that the hand, armpit, and hair all contain some common element by which a dog identifies a person.

In another series of tests, however, the sticks were not handled, but urine samples from the four test individuals applied to them; and Skimmer could not identify these sticks.

Then an attempt was made to extract the odorous material from samples of hair. Hair cuttings from the four test individuals were treated with a fat solvent, carbon tetrachloride or perchloroethylene. When the solvent was removed by evaporation at room temperature, there remained a small amount of very pale yellow fatty material which had a slight and not unpleasant odor. It was solid at room temperature, liquid under body heat. These extract samples were tested on Skimmer as follows.

Three individuals each handled a stick, but the fourth's was marked only by a small amount of the material extracted from his hair sample. Skimmer, given a hand scent by the fourth individual, readily picked the correct stick. The test was repeated, using a different person's extract each time, always with success. It was also reversed, all four sticks being handled but the dog given the scent from one of the bottles of extract. Again he could equate the extract with the hand scent on the stick. The experiment was repeated on Onyx, the miniature poodle, with the same results. But when a stick was rubbed with the hair which remained after the extraction process, Skimmer could not identify it.

Thus it is possible to obtain from human hair an extract which contains the odor identifying the individual. Moreover, since several weeks or even some months elapsed between the cutting of the hair and the tests with Skimmer, the experiments also indicate that an individual's characteristic odor does not change over quite a period of time. It could be that a person's scent is a permanent individual characteristic.

The additional conclusions one can draw from these experiments may be summarized as follows.

Fifth, dogs appear to find some common individual scent produced by different parts of the human body, whereas to a human the different parts of the body have different odors. Urine, however, does not contain the individual's scent.

Sixth, the substance of human scent, although not very soluble in water, is susceptible to fat solvents and can be extracted from hair by the use of these.

Seventh, the characteristic scent does not change from day to day.

Source of the Scent

If we assume, as we have, that what a dog identifies as the characteristic scent of an individual is the property of some very specific material, and if we further assume, as seems reasonable, that this specific and characteristic material would have a unique source, the next step would be to look about for the most probable source for it. Since it is transferred to an object by contact with the skin or hair, the scent is apparently present on the skin; and a logical source for it might therefore be one of the various secretions normal to the human skin.[3]

The skin is normally covered with a part aqueous, part oily film made up of the secretions of several different types of glands. Some of these glands are found all over the body, others only in certain parts. The most familiar of them is that which produces the eccrine sweat whose evaporation serves to control body temperature. It is about 99% water, and the materials that make up the remaining 1% are very similar to those of urine. The glands are all over the body, the rate at which they operate depending on temperature, exercise, and emotional factors. Eccrine sweat probably has

[3] The information on skin secretions in this section is derived from Rothman, Stephan, *Physiology and Biochemistry of the Skin* (University of Chicago Press, 1954).

some odor, one which becomes more noticeable with bacterial decomposition.

Another type of gland produces a kind of sweat known as apocrine, which contains fatty as well as water-soluble ingredients. There are apocrine sweat glands in all the hairier parts of the body (armpits, perimammillary regions, mid-line of the abdomen, pubic and anal regions) except on the head, where they are found only in the external ear canal and the nasal vestibule, not in the scalp or on the face. Apocrine sweat contains odorous materials, and the odor becomes more pronounced with bacterial decomposition; it is probably the main source of so-called "body odor." These glands do not respond to temperature changes, but they are readily activated by mental stimuli. In animals, at least, they appear to be related to sexual attraction. Beyond that, not much is known as to why they exist.

A third set of glands secretes a fatty material that serves to lubricate and protect the skin. These are called sebaceous glands, and their secretion sebum. There are sebaceous glands over the entire body except for some parts of the feet, the palms of the hands, the palm sides of the fingers, and between the fingers. But sebum is found on all parts of the skin, including those where there are no glands, because it flows over the skin very rapidly. It is said to be very difficult to get even a small portion of the palm free from sebum, and it is estimated that it flows over wet skin at the rate of some 1.3 inches per second.

Sebum is liquid at body temperature, a solid at ordinary room temperature. Chemically, it is a very complex mixture of free and combined fatty acids, wax alcohols, sterols, terpenoids, and hydrocarbons, with compounds of relatively high molecular weight predominating. Many of the compounds do not occur anywhere else in the body. If it is removed from the skin, the glands operate very rapidly to replace it, but when the sebum layer reaches a certain thickness they slow down and stop until it needs renewal again.

In order to complete the catalog of organic materials found on the skin, it should be mentioned that a small amount of fatty material is released by skin cells that are in process of being discarded. This process is quite slow.

If we now examine each of these skin secretions in the light of what we know about human scent, we should be able to decide which of them is the most likely source of the scent, or whether several are equally possible sources.

Of eccrine sweat, the 1% that isn't water is water-soluble. But Löhner's experiments indicated that human scent is not readily soluble in water, and we found that an individual's scent can be extracted from a hair sample by using a fat solvent. Moreover, eccrine sweat contains materials similar to those found in urine, which we concluded does not carry the characteristic odor of the individual. So eccrine sweat does not appear to be a good candidate.

Apocrine sweat, since it is the main cause of the familiar "body odor," might be supposed to be the source of the individual's characteristic scent. But we saw that dogs can as readily take a scent from a person's hand or the hair on his head as from his armpit, the only one of these three areas equipped with apocrine glands. So if we stick to our assumption of a single unique source for human scent, apocrine sweat is also a poor candidate.

The fatty material from the decomposition of skin cells is produced so slowly that it could not be replaced promptly after having been removed by a good bath. Yet a dog can detect the human scent even after a series of baths. We can therefore probably ignore skin cells as a source.

This elimination leaves sebum the only remaining candidate. It seems reasonable that such a fatty substance containing heavy alcohols and hydrocarbons and having a point of fusion between room and body temperatures would have the limited volatility, the persistence, and the solubility characteristics we have attributed to human scent. The rapid replacement of sebum removed from the skin would explain why the most thorough bath or series of baths does not eliminate the individual scent. Sebum, like the hair extracts by which Skimmer identified our test individuals, is soluble in fat solvents; in fact, these extracts were prepared in the same way many investigators of sebum have obtained their samples. There does not seem to be any reason why sebum could *not* be the source of individual scent, and we may therefore make the working hypothesis that it is, although it cannot be said we have proved that it is the unique source or that other skin secretions do not also contain the scent.

From this hypothesis it would not follow that sebum is the only thing about an individual the dog can smell. There are, in fact, observations indicating that dogs do use other human odors as cues. Those who work with police dogs have observed that they sometimes seem to be drawn to a person for no other reason than that he has done something which he fears will be detected. The cue here could be a copious amount of one of the emotionally controlled secretions, say apocrine sweat. If sebum provides an ever-present identification of the individual, the variable intensity of apocrine and perhaps eccrine sweat odor may give an indication of his emotional state.

Individuality of the Scent

In 1955 H. Kalmus, of University College, London, published a paper on the ability of dogs to discriminate between identical twins.[4] In a series of experiments with trailing dogs and retrievers he found that they could distinguish between identical twins when confronted simultaneously with both scents, but that if they were presented only one scent at a time they would confuse one with the other. No other pairs of individuals, even blood relatives, were so confused. Kalmus concluded that there is more similarity between the scents of identical twins than between those of other individuals and inferred that individual scent is probably genetically controlled.

If it is true that scent is genetically controlled, and if the source is sebum, there should be a marked difference in the composition of the sebum of different species. There is. Rothman says,[5] "It seems that the chemical composition of sebaceous gland and other skin products shows more striking species differences among mammals than that of any other organ or organ product." For instance, human sebum contains a good deal of squalene (a compound structurally related to cholesterol), which is replaced in sheep sebum (wool fat, lanolin) by a structurally similar terpenoid called lanosterol. Such differences in composition could produce major

[4] Kalmus, H., British Journal of Animal Behavior, 3, 25–31, (1955).

[5] See footnote 3.

species differences in scent, if one grants that the components are odorous to the dog.

It is not so easy, however, to account for the fact that each individual appears to have his own characteristic scent. It would be absurd to suppose that each individual's sebum contains some unique chemical compound to produce his individual scent. But the complexity of sebum and the possibility of structural variations within its many compounds makes another hypothesis possible. Of the fatty acid series, all the normal straight-chain monobasic acids from seven to twenty-two carbons (both odd and even) have been identified in human sebum. These include both saturated and unsaturated chains with one, two, and three double bonds. The wax alcohols present an equally large array of related compounds, this time with both straight and branched chains present. If one postulates individual variations in the comparative quantity of even a few of these components, there could be a large number of possible combinations. Only five individual compounds each present in any one of ten possible proportions would give more than 600,000 combinations.

Thus it could be surmised that human scent, as a species, is the property of a major component (or set of components) characteristic of human sebum (say squalene), but that each individual has a unique mixture of various minor ingredients (say certain fatty acids or long-chain alcohols). Individual scent would be a blend, the major scent modified by various additives, like a series of different perfumes compounded on the same basic theme. Such chemical individuality is not without precedent, and it may even turn out to be the rule that the chemistry of living organisms displays individual variations around some central theme. In blood groupings, which have been studied rather extensively, it has been found that each individual appears to have his own characteristic pattern of blood types and sub-types, while genetically related individuals (racial groups) show characteristically similar patterns. It is possible, by determining the presence or absence of a comparatively few factors, not only to identify blood as human, but also to obtain information about the donor's genetic background and, potentially at least, to identify the individual.

Parameters of Detection

If one is willing to make a number of simplifying assumptions, it is possible to estimate the approximate amount of human odor a dog would have available at a given distance from a man. The calculation is rather crude, but at least it gives a quantitative idea of the order of magnitude of the dog's ability.

Take a man standing in a field with a wind blowing across his body and a dog 100 yards down wind. Scent is transferred from the man's body to the air and is carried down wind to the dog. We will assume the man and dog have maintained their positions long enough that a continuous cloud of scent is present between them. As it goes down wind, the cross section of the cloud will grow larger and the concentration of the scent in the air smaller in rough proportion to the square of the distance. The concentration at any particular point will vary, however, not only with the rate of emanation of the scent, wind speed, and distance, but also with corrective factors expressing the effects of weather and terrain on the width and height of the cloud, the earth's drag on the part of the cloud near the ground, and the tendency of the concentration to decrease with altitude.

Having noted the apparent similarities in limited volatility, density, and persistence between human scent and chemical warfare agents, we shall adopt the values for these corrective factors that have been worked out for the travel of clouds of chemical warfare agents. Prentiss[6] gives values for conditions which he lists as "favorable," "average," and "unfavorable" for a chemical gas attack. These conditions equally well describe good, average and poor working conditions for a dog.

For the rate of transfer of the scent from man to air we can make an estimate on the following basis. Rothman[7] estimates that an adult produces an average of at least 200 micrograms of sebum per minute. We have noted that the sebum layer on the skin tends to maintain equilibrium, being replen-

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[6] Prentiss, Augustin M., *Chemicals in Warfare* (McGraw-Hill, New York, 1937).

[7] See footnote 3.

ished as fast as it is lost. So we can use this average rate of sebum production to represent the average rate at which it is transferred to the air. But presumably not all the many ingredients of sebum are odorous to the dog, and we shall therefore arbitrarily take ten percent of this rate, or 20 micrograms per minute (2×10^{-2} mg/min) as the rate of transfer of the scent from man to air.

Taking this expression as the rate of scent transfer, a distance of 100 yards, a wind speed of 6 miles per hour, and the values of corrective factors for "average" conditions, we get a concentration of scent available to the dog of approximately 10^{-12} milligrams per milliliter of air. For "favorable" conditions, using a wind speed of 2 mph, the concentration would be about 10^{-11} mg/ml, and for "unfavorable" conditions, with a wind speed of 12 mph, it would be about 10^{-13} mg/ml. It is possible, to judge from practical experience, that under "unfavorable" conditions 100 yards would be a little beyond the dog's effective range.

The spread between the concentrations available to the dog under favorable and under unfavorable conditions is about two orders of magnitude (10^{-11} to 10^{-13}mg/ml). Since scent concentration varies inversely with the square of the distance when everything else is constant, a variation in the distance by a factor of 10 would give this concentration change of two orders of magnitude. It jibes well that a practical rule of thumb for the effective range of a sentry dog's detection by scent is 50 to 500 yards, depending on conditions, a minimum and maximum distance separated by our factor of 10.

The concentration of scent available to the dog is exceedingly small. The value obtained for "average" conditions (10^{-12} mg/ml) represents only one millionth of a microgram of odorous material in a liter of air, a microgram being a millionth of a gram. By weight, since a liter of air weighs somewhat over one gram, this means that the air 100 yards down wind contains one ten thousandth of a millionth of one percent of the odorous material.

Although these results seem at first sight incredible, man in his own sense realm can also detect by smell exceedingly small amounts of odorous materials in air; and there are several substances which he can recognize in concentrations similar to those just calculated. Some minimum concentrations detectable by humans are the following: [8]

vanillin	10^{-13}mg/ml
synthetic musk	10^{-13}mg/ml
mercaptan	10^{-11}mg/ml
skatol	10^{-13}mg/ml

In the light of these data, our fantastically small figures for the concentrations a dog can detect are not particularly unreasonable. It is only necessary to make the obvious postulate that some things which have little or no odor to a human must be quite odorous to a dog.

Toward Intelligence Applications

These tentative findings should provide a beachhead for scientific study of the detection of human scent and its present and potential applications in intelligence work. With respect to the current use of dogs for security patrol and tracking and to the converse problem of evading them, the parameters of the dog's ability and the influence thereon of weather, terrain, and other factors can be defined more precisely in laboratory and field experiments when controlled by measured quantities of sebum in refinement of the uncertain emanations of an individual. If the constant odorous component of human sebum, which we have suggested above may be associated with squalene, can be identified and isolated, chemical experimentation should in time turn up a counteracting agent. Potentially, at least, physical or chemical analysis of the variant minor components appears also to offer an alternate means of positive individual identification.

The more universally important senses, because they are more important, have in the past century been supplemented with inorganic aids which make them much more capable than the animal originals. We have long been accustomed to seeing and hearing much more by means of instruments than with our natural powers, and to recording sights and sounds by mechanical artifact. Once we have identified the medium of human scent analogous to the light and air vibration which stimulate sight and sound, it seems reasonable to

[8] Moncrieff, *The Chemical Senses* (John Wiley and Sons, New York, 1946).

suppose that we shall also find mechanical means to improve upon animal olfactory capabilities and not only to detect but to record the otherwise unknown presence of an individual. Our mechanical dog, when he is born, should be much more unobtrusive than his natural ancestor, should be able to tell us just whom he has smelled, and should maintain a reliable permanent record of his visitors.