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Chemical Communication In Humans

Abstract

Olfactory cues are important for communication and recognition in a wide variety of animals. Humans have a number of structures which when seen in other mammals are recognized as being part of a chemical communication system, but which have traditionally been described as vestigial or non-functional. Recently, several reports have appeared which demonstrate that some form of olfactory communication exists in humans as well. This paper reviews some of the existing literature on human olfactory communication and discusses a series of experiments which demonstrate that humans use olfactory signals for scent-marking, synchronization of hormonal states, sexual recognition, and parent-infant identification.

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Chemical Communication In Humans

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> "He and his school were provided with noses, which smelt their way into sources of knowledge."
>
> T. Mitchell
> The Clouds of Aristophis 1838

Introduction

Chemical communication was the first form of informational interaction to develop between organisms. Indeed, it must have originated the first time two cells began to cooperate in their efforts to consume or reproduce in the primordial milieu from which they originated. From this ancient origin two types of chemical communication have developed: one regulates the coordination of systems within an organism and the other carries signals outside an organism. Olfaction is the primary sensory pathway for this second system of chemical communication in most higher animals.

Olfactory communication among organisms has resulted in the specialized production of certain chemicals or blends of chemicals termed "pheromones" which have highly specific effects on the recipient. Some pheromones can induce changes in the recipient which lead to prompt behavioral responses: these substances are designated as "signaling pheromones." Other chemical signals can induce physiological changes which have a long-term influence on the recipient; these substances are referred to as "priming pheromones".

There is also a more general class of odors which do not elicit specific responses, but which are unique to an individual organism and help to identify that organism. These odors are termed "signature odors" (or "informational odors"), because they serve to identify a specific individual.

The concept of pheromonal communication originated with work on insects (Karlson and Luscher, 1959), and the process was defined as an "airborne hormone" (i.e. Pheromone). When Hilda Bruce discovered that pregnancy could be blocked in newly mated mice by exposure to odors from strange males (Bruce, 1959; and Parks and Bruce, 1961) and Wesley Whitten found that estrus, in a group of mice, could be suppressed by odors (Whitten, 1956a, b; Whitten et al., 1968) the concept was extended to mammals. These findings stimulated a great deal of work on mammals which demonstrated a number of different effects (See Vandenbergh, 1983 for a recent review), but these findings were not immediately considered relevant to primates and particularly not to humans. This lack of concern existed largely because the effects of odors on reproduction had not been recognized in primates, animals who were generally considered to be microsomatic with a poor olfactory sense (Gleeson, and Reynierse, 1969). The suggestion that humans might use some form of chemical communication began to emerge when Martha McClintock (1971) demonstrated that women who lived together tended to have synchronous menstrual cycles, and Alex Comfort (1971) asserted that "Humans have a complete set of organs which are traditionally described as non-functional, but which, if seen in any other mammal, would be recognized as part of a pheromonal system." This led the present investigator to a direct search for functional human odors which might have effects similar to those demonstrated in animals. Such an inquiry requires some background review of the existing literature on human organs which have potential as possible receiving and transmitting organs, and-the completion of a series of experiments designed to determine if humans are using olfactory communication in a fashion similar to that seen in animals.

The Receiving Organs

The mammalian chemosensory system includes four to six known organs which have separate, but sometimes related functions: 1) the main olfactory organ 2) the vomeronasal system or Jacobson's organ, 3) the septal organ, 4) the trigeminal nerve 5) the nervous terminalis, 5) and the taste system. Our level of knowledge of these organs in humans is uneven and in some instances sparse, but a general review is helpful in understanding some of the possibilities for human communication.

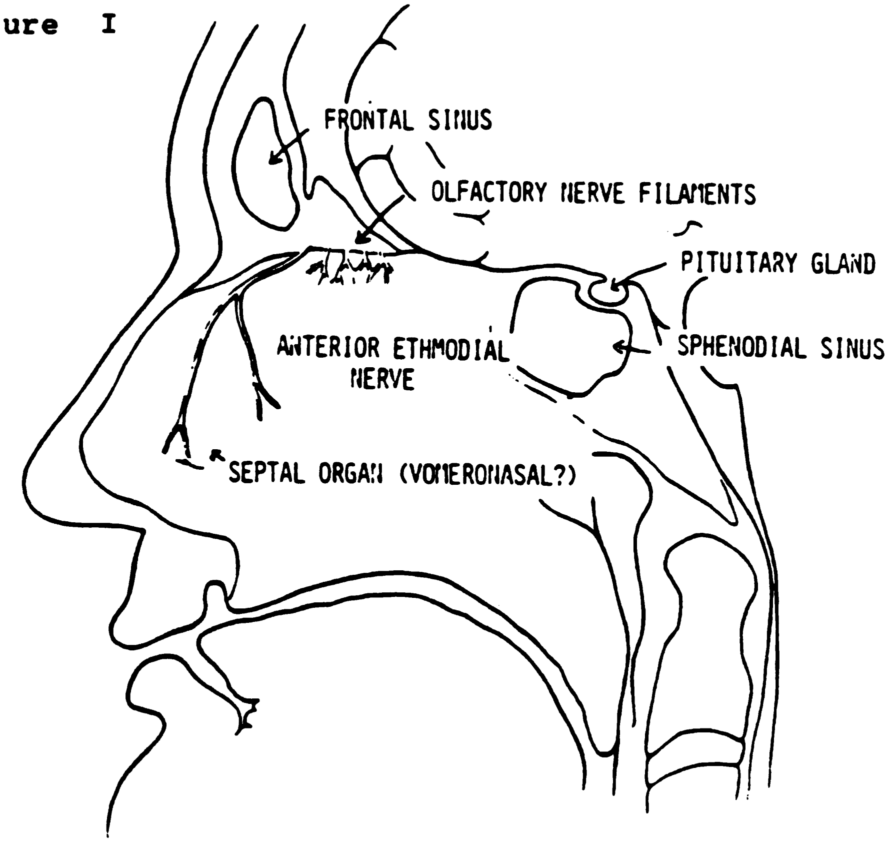
The Main Olfactory Organ

In man, the main olfactory organ is a small patch (see figure I) of olfactory receptors which lie in the uppermost portion of the nasal cavity under the cribriform plate. These receptors are neurons with their apices in the mucous overlying the olfactory epithelium and with axons that pass directly into the olfactory bulb. This organ is primarily responsible for our ability to discriminate the multitude of odors we recognize.

There have been several theories developed in an effort to explain how this organ is able to recognize such a large number of volatile compounds. The present consensus seems to be that although there are some specific receptor types (Amoore, 1977), neural messages characteristic of particular odors are determined by the spatial pattern of activity across the olfactory mucosa (Moulton, 1976; Mackay-Sim et al., 1982) in a fashion similar to that found in a gas chromatograph. The responses of this organ to biologically important odors have not been extensively investigated, but the current

Nasal Organs

Figure I



evidence suggests that it exhibits no obvious specificity to potential pheromone-containing materials in either man or animals (Paff and Gregory, 1971; Macrides, 1976; Skeen, 1977).

The main olfactory organ has not been shown to play a significant role in the organism's response to pheromones. It is almost certain, however, that this is the organ which would be essential for recognition of a signature odor. Recognition of a signature odor may be important in mediating an individual's response to a pheromone acting on one of the other chemosensory organs.

The Trigeminal Nerve

The trigeminal is a somatic sensory nerve with distributions to the epithelium inside the nasal cavity, the outer skin of the head, and the cornea of the eye. Both the intranasal and corneal fibers of the trigeminal system are sensitive to airborne chemicals. The intranasal terminations are free nerve endings situated between the cells of the olfactory and respiratory epithelia (Graziadei and Gagne, 1973). This system appears to be primarily responsible for the detection of irritating chemicals. It stimulates changes in respiration, heart rate, and mucosal secretion, activities which modulate access of stimuli to the various parts of the nasal cavity. Additionally, there is evidence that the trigeminal may have other functions as well. Cain and Murphy (1980) have shown that it is sensitive to carbon dioxide, a substance generally thought to be odorless, but which is given off by all air-breathing animals. What function this sensitivity may have is not known. However, the trigeminal system is able to modify the sensitivity of the main olfactory, gustatory, and perhaps other chemosensory systems

(Silver and Maruniak, 1982), and this may be significant in its responsiveness to carbon dioxide. The trigeminal system is a possible pathway for both signature and pheromonal odors.

The Vomeronasal Organ

The vomeronasal organ (also called Jacobson's organ) is very poorly understood in humans, with many current head and neck atlases even failing to list it. In ungulates and certain other mammals it is an elaborate structure with special glands and a vascular pump. In these animals the organ is associated with sexual behavior, particularly the lip curl, or "flehmen" behavior, which some animals use to test urine (Ladewig and Hart, 1980) or gland secretions for the approach of estrus (Meredith, 1980; Ladewig et al., 1980). It is especially designed to pick up heavy non-volatile compounds which might be secreted on the ground or other objects, and which have biological significance for the animal. The vomeronasal organ is clearly involved with the pheromonal communications of a wide variety of animals (rat [Wysocki, 1982]; cat [Meredith, 1982]; reptiles [Burghardt, 1979]; guinea pig [Beauchamp, et al., 1980).

The human vomeronasal organ is much simpler in appearance than that found in animals. It first develops in the fetus on both sides of the ventral surface of the nasal septum. It then appears to atrophy at the time of birth as ontogeny replicates phylogeny suggesting that the vomeronasal organ may be vestigial organ in man. This simple explanation is, however, confounded by the fact that a similar appearing patch of tissue develops in approximately the same location in some adults (McMinn, et al., 1981) (see Figure I). This patch (receptor?) is innervated by a branch of the ethmoidal nerve, suggesting that the vomeronasal organ may become active again in adulthood.

The secondary development of this organ suggests several possibilities:

1) Since the receptive cells of the vomeronasal system are uncilliated neurons (Graziabei, 1977) which would be difficult to identify without their accessory structures it may be that what appears to atrophy at birth does not really do so.

2) Since there has not been an extensive investigation of this structure across even moderate numbers of autopsy specimens it may be that the few adult samples investigated by McMinn, et. al (1981) are anomalous individuals whose organ did not atrophy but

rather persisted to adulthood.

3) It could also be that the patch of tissue is not the same organ at all, but an entirely different organ which has been recently recognized to exist in several small mammals (Bojsen-Moller, 1975). This newly recognized organ called, the "septal organ" (also called the "organ of Masera"), was first recognized by Masera (1943) to appear in fetal opossums, and is now known to be an accessory olfactory organ in adult mammals (Meredith, 1983). It could easily be mistaken for a simplified vomeronasal organ, because it also appears on the anterior ventral surface of the nasal septum in animals. The sensitivity, selectivity and central projections of the septal organ are not known in humans or other animals.

Not enough is known about the vomeronasal organ in humans to make definitive statements. Indeed, its very existence as an organ is open to question, but, given the significant role it plays in animal communication, it deserves further investigation. It should be an area for future research and should be considered as a potential pheromonal receptor.

The Nervus Terminalis

The nervus terminalis is present and well developed in man (although it, too, does not appear in many atlases) The nerve consists of a network of cells and unmyelinated nerve fibers strung out between the anterior-ventral end of the forebrain between the hemispheres (the laminal terminalis) and the anterior end of the nasal cavity. Not much is known about the function of this system in animals, and even less in humans, but Jennes and Stumpf (1980) have shown that the nervus terminalis fibers contain luteinizing-hormone-releasing-hormone (LHRH) and are probably secretory. LHRH is involved in the secretion of estrogen, the timing of ovulation, and the production of testicular androgen (Turner and Bandura, 1971). These actions in turn affect the timing of ovulation in females and sexual excitement in males thus making the Nervus Terminalis a probable candidate for a pheromonal receptor in humans.

Taste

Taste is frequently overlooked as a possible pathway for intraspecies communication, but many mammals lick the secretions of other individuals as well as sniff them as a means of communication (pigs [Signoret et al., 1975], sheep [Pheffer, 1967], goats [Gubernick, 1980], cats [Freeman and Rosenblatt, 1978a]). Further, Beidler (1977) has shown that the human taste system is sensitive to both proteins and peptides, suggesting that the range of chemicals which could be involved is much greater than the traditional bitter, sweet, sour and salt. It is also possible that substances ingested through the mouth might pass into the system and act directly on some internal target as has been demonstrated to occur in other mammals (Lee & Moltz, 1984). Considering the prevalence of kissing and other oral activities in human social behavior, it would be premature to eliminate this system from consideration as a channel for chemosensory signals.

Summary: Receiving Organs

In sum, humans have a number of receiving organs that appear to be non-functional or of unknown function, but which are recognized as being involved in the detection of chemical signals in animals. Some of these structures are sensitive to compounds which are neither odorous nor volatile, and cannot properly be considered odors, but which may be used as chemical signals in communication. It has also been demonstrated that at least some of the accessory olfactory organs are capable of detecting compounds without our conscious awareness (Cain and Murphy, 1980).

The Transmitting Organs

For chemical communication to exist in humans it is necessary that we have transmitting organs as well as receiving ones. Humans have a number of potential emitting organs which have traditionally been viewed as non-functional. These organs include: apocrine glands, sebaceous glands, eccrine glands, saliva, and hair tufts.

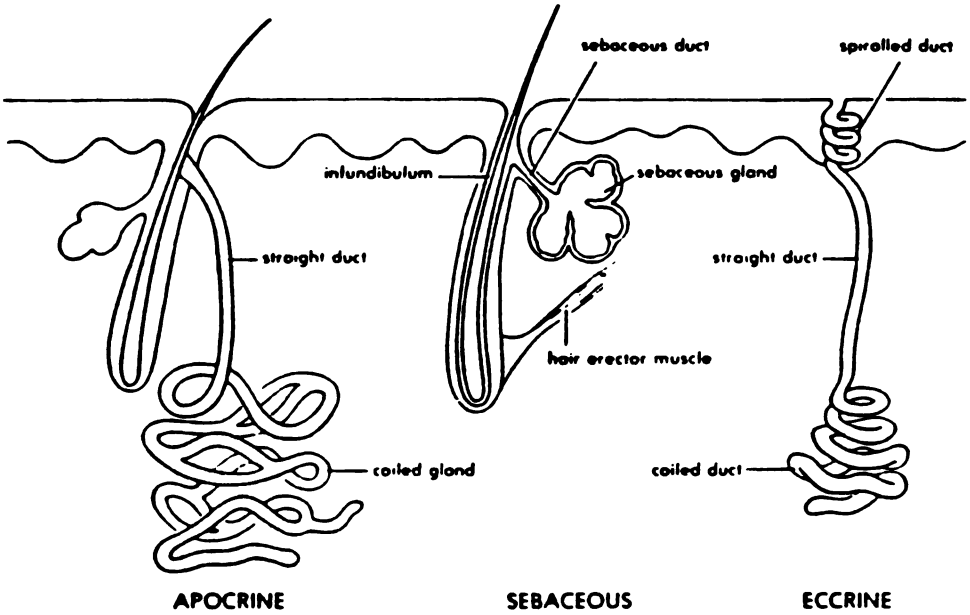
The Apocrine Glands

In other mammals, such as dogs, monkeys, and apes, apocrine glands are either distributed over the entire surface of the skin or localized into specialized scent-signaling structures that are used for scent-marking. In humans they are coiled tubular glands found in and/or around the: axilla, areolae, mons pubis, labia minora, prepuce, scrotum, periumbilical, circumanal, external ear (ceruminous glands) and on the eyelids (Moll's glands). The apocrine glands are active before birth, and then regress and remain small until early puberty when they enlarge and begin to secrete again (Ackerman, 1975).

There are two aspects to the production of apocrine sweat: secretion and excretion. After puberty secretion appears to be continuous. Excretion occurs when an accumulated reservoir of apocrine secretion is propelled upward by the myoepithelial cell sheath (Ackerman, 1975). Excretion appears to be under adrenergic sympathetic control, and is known to occur when the subject is experiencing fear, anger or sexual orgasm (Hurley and Shelley, 1960).

Figure II

The Skin Glands



Fresh apocrine secretion is odorless (Montagna, 1962), but when the material reaches the skin surface it is acted on by bacteria which give it an odor which is characteristic of the individual from which it comes. The underarm area where these glands are most numerous is also a dark moist area of the body which appears to be well suited for the production of such bacteria. It may be that bacterial actions are symbiotic to the functions of these glands.

The fact that these glands and their associated bacteria are an integral part of the chemical signaling systems of most species of mammals makes them a prime candidate as part of a transmitting system for chemical communication in humans.

The Sebaceous Glands

Sebaceous glands are distributed over the entire surface of the body except for the palms, soles and dorsa of the feet. They are most numerous and most productive on the face and scalp. They are generally associated (See Figure II) with a hair follicle and vary inversely with the size of the follicle. The exceptions to this rule are the large sebaceous glands that are associated with the beard and scalp (Montanga, et al., 1963). In a few locations sebaceous glands are not associated with hair follicles: the buccal mucosa and vermillion border of the lip (Fordyce's spots), the female areola (Montgomery's tubercles), prepuce (Tyson's glands) and the eyelids (Meibomian glands).

The sebaceous glands develop in the fourth month of fetal life and are primarily responsible for the vernix caseosa, a pasty lipid covering that protects the skin of the fetus and helps to lubricate it for travel through the birth canal. After birth the glands involute and remain small and inactive until the age of 8-10 years when they redevelop as an early manifestation of puberty (Pochi and Straus, 1974). Sebaceous maturation continues into adolescence and remains unchanged until it decreases with menopause in women and after the seventh decade in men. The production of sebum is an androgen-dependent process (Porchi and Straus, 1974), and generally more active in men than in women. The sebaceous glands do not appear to be innervated and are not responsive to the administration of norepinephrine or acetylcholine (Shuster and Thody, 1974), suggesting that they are not under nervous control.

Several functions have been suggested for the sebaceous glands of the skin including: barrier protection, antimicrobial protection, and a vitamin D precursor. However, the evidence for these is not convincing (Kligman, 1963). The fact that the sebaceous glands have an activity pattern which is coincident with sexual maturation, and that they are androgen dependent target organs makes them possible candidates for a chemical signaling system relating to sexual pheromones.

The Eccrine Glands

The eccrine sweat glands are most highly concentrated on the palms, soles, axilla and forehead. The existence of eccrine sweat glands in other animal species is an uncommon, but not unique phenomenon. Eccrine sweating is observable in horses and some species of primates. The eccrine sweat glands are present and functional at birth, and their function in the control of body temperature is well established. The prime stimulus for the eccrine sweat gland is heat. The control center for the gland is the hypothalamus which controls the glands through cholinergic fibers of the sympathetic nervous system. The glands are also able to respond to regional heating, probably due to direct thermal action on the eccrine sweat apparatus. It is clear that any possible signalling function is secondary to the control of body temperature.

The possibility of chemical signaling cannot be dismissed even with these glands, however. Despite the fact that heat is the prime activator, eccrine sweat glands respond to other physiologic stimuli which generally produce localized sweat responses. Sweating stimulated by emotional stress such as tension, fear or anger is a common experience. The palms, soles, axilla, and forehead are the most frequently reported areas. Although, the palms and soles are poor responders to heat (Ackerman, 1975), they are very sensitive to emotional stimuli.

Saliva

Saliva is a very complex mixture of compounds primarily involved in the preparation of food for digestion, but a number of animals also use it for scent-marking various objects, including other individuals (Gubernick et al., 1979; Rosenblatt, 1972). In man, saliva is mostly produced by the parotid, submaxillary and sublingual glands. Additionally, there are a number of secondary glands that contribute, including: the lingual mucous glands, lingual serous (Ebner's) glands and numerous small mucous glands in the membranes covering the oral surfaces of the cheeks, hard and soft palates, and the walls of the pharynx.

Although, a great deal is known about the general function and biochemistry of these glands in digestion and oral hygiene (see Arglebe, 1981 for a review) their possible role in human scent-marking has not been explored. They do have a significant role in the scent-marking behavior of a number of other animals, however. Several species of mammals use saliva for marking of mothers and infants during early development (Rosenblatt, 1972; Gubernick, et al., 1979; Gubernick, 1980, 1981).

Hair Tufts

Hair tufts, which appear at puberty and are associated with odor producing glands in animals, are generally considered to be part of a chemical signaling system. In humans, these tufts occur in the pubic region, the axillary region, and on the faces of males. Mature body hair has been classified into six morphological types (Garn, 1951): head hair, eyebrow and eyelash hair, beard and moustache hair, body hair, pubic hair and axillary hair. The hair of the beard, underarm and pubic regions is different from other body hair in both structure and development. These hairs are generally coarser and have more scales that appear to be better suited for the capture and holding of oil and bacteria. The significance of these differences is difficult to assess without a firm idea of what the function of the hair tufts is in the first place. Certainly in some areas, such as the beard, they serve as visual cues to mark maturity, but the difficulty of seeing the hair tufts in the axillary region suggest this is only a partial explanation of their function.

The dark and humid environments these hair tufts create are well suited for the growth and development of bacteria. Although, the number of bacteria in these regions is high, the type and variation is relatively limited (see Noble and Somerville, 1974 for a discussion of the types and distribution). It is possible that the function of these tufts is simply to support the bacteria which provide the individual with a major portion of his body odor as an identifiable olfactory "signature" of the individual, or that they help to disperse some volatile compound given off by the apocrine or sebacious glands associated with these tufts.

Summary: Structures

In sum, each of the various skin glands and hair tufts have potential as transmitting organs in humans. Some of them have functions other than chemical signaling, but when seen in combination they suggest chemical transmitting organs that are supportive of the receiving structures discussed earlier. Both the receiving and emitting organs described in the preceding pages appear to be overly elaborate to be entirely vestigial. Yet, we have little or no conscious awareness of a functioning chemical signaling system, and no demonstrable behavior which is comparable to the incessant sniffing and scent-marking observed in many animals. The following discussion and experiments will attempt to determine what types of chemical signals might be functional in humans.

Animal Models

The mere existence of transmitters and receivers does not provide evidence of the types or even existance of messages being communicated. One source of clues to possible human chemical communication are the patterns of behavior which have been established to be chemically mediated in animals. The chemically mediated animal behaviors include: sexual attraction, individual identification, sexual recognition, hormonal synchronization, mother-infant attachment, and scent-marking. Each of these areas of animal behavior will be examined for potential human chemical messages in the following sections.

Sexual Attraction

One of the more obvious pheromonal responses in animals is sexual attraction. This area of animal olfaction has been well investigated in a number of species (See Doty, 1976; Stoddard, 1980 for reviews). In mammals there is a general pattern of the male being attracted to a pheromone given off by the female during the female's fertile period. The type and source of odorant varies considerably between species, but the general pattern of response is consistent (Stoddard, 1980). The female is not usually attractive except when she is sexually receptive. When receptive, she emits a specific pheromone from a specialized signaling gland. Frequently the emission of the sexually attracting odor is accompanied by the presentation of visual and auditory cues which also have powerful attracting properties to males.

One of the more striking aspects of human sexuality is our apparent lack of specific sexually attracting signals and our concealment of fertility periods. Women do not have the obvious changes in behavior or coloration related to sexual receptivity seen in other animals. Women are, essentially, continually sexually receptive.

The absence of visual, auditory or behavior signals of sexual receptivity suggests that we do not have a sexually attracting pheromone. This logic, however, appears to be in conflict with the numerous and persistant anecdotal reports of odors being important for human sexual attraction, and the existence of a large and profitable perfume industry.

Sexual attraction is by far the oldest and most continuing area of interest in human olfactory communication. The search for an effective aphrodisiac goes at least back to the early biblical period when, in the book of Genesis, Leah uses the Mandrake plant to seduce Jacob (Genesis ,30.16).

> "And Jacob came out of the field in the evening, and Leah went to meet him, and said, Thou must come in unto me; for surely I have hired thee with my son's mandrakes. And he lay with her that night."

While the odor of mandrakes was popular among the early Heberews, many other substances have been used in other cultures. The list of aromatic substances which have been tried as aphrodisiacs in various cultures is extensive (see Walton, 1958 for a colorful review of the history). The substances advocated as aphrodisiacs includes things as varied as garlic cloves and rhinocerous horn. The variety itself argues against the likelihood of a sexually attracting pheromone, however, as the list is too varied to suggest a commonality. Additionally, none of the many substances tested have stood up to scientific verification of their effectiveness (Rogel, 1978).

A possible explanation of this apparent discrepancy between scientific evidence and anecdotal reports comes from a recent series of studies done on rhesus monkeys.

Responding to a series of experiments by R. P. Michael and his associates (Michael and Keverne, 1970; Michael, et al., 1971; Michael and Bonsall, 1971) in which they asserted that a group of aliphatic acids present in the vaginal secretions of the female rhesus monkey (called "copulins") were acting as pheromonal sexual attractants for the male, Goldfoot, et al., (1976) did a series of investigations in which aliphatic acids were tested for their attractant properties. They showed that the males would only use these as cues if their presence was repeatedly paired with successful coital encounters, and that they would not use these odors if they did not experience such pairings. Goldfoot, et al. suggested that associative learning and classical conditioning could more easily account for the earlier reported positive effects of aliphatic acids, and pointed out that their animals would also respond to other odors in a similar fashion when the odors had been paired with coital behavior. It appears that learning is more important to the types of olfactory cues used for sexual attraction than a spcific pheromonal attractant, thus helping to explain the wide variety of substances which various individuals and cultures have considered effective as aphrodisiacs.

Another possibility is that humans have adapted to continuous sexual receptivity by constantly giving off an odor which is an attractant for the opposite sex. Cowley et al. (1977) have tested this hypothesis directly with two compounds thought to have attractant properties for animals: androstenol (the Boar attractant which is also present in small amounts in human perspiration) and copulin. In this study, subjects were asked to evaluate the qualities of other individuals while wearing masks which had been treated with one of the odorous compounds. The subjects did not know the purpose of the study or that they were being exposed to the odors. The women tended to judge the males more highly when androstenol was present, but there were no changes in the males' responses. In a follow-up study Kirk-Smith et al. (1978) also used treated masks to examine the influence of the odor of androstenol on subjects' judgments of photographs. In contrast to the results of Cowley et al., both male and female subjects rated photographs of women as "more attractive" and or "better" in the presence of androstenol. In a third study of the effects of androstenol, McCollough et al. (1981) had subjects read an erotic passage while being exposed to either androstenol or rose water and found no change in emotional responsiveness in either men or women as measured by the Differential-Emotions-Scale questionnaire.

While these findings cannot be compared directly because of the differences in techniques, it appears that there are enough discrepancies in the results to make any general conclusions about the attractant properties of androstenol tentative at best. Even if the positive results of Crowley et al. are confirmed, it will not be sufficient evidence to demonstrate a pheromonal response, as it is quite possible that if a preference exists it is learned. Androstenol is present in male axillary sweat (Brooksband et al., 1974; Sastry et al., 1980), and it is quite possible that the subjects have simply learned that it is characteristic of human male odors.

The existing anecdotal reports of human attractant odors can be explained through associative learning. While it is very difficult to prove that a particular phenomenon does not exist, the fact that the search for a human sexual attractant (or aphrodisiac) has been pursued for at least two thousand years without success indicates that further investigation is not warranted.

Gender Identification

Gender identification is another aspect of animal sexual behavior which is often modulated by olfactory cues in animals. That humans can determine sexual identity from sexually specific sources such as vaginal odors, seminal fluid, etc., is generally accepted (Doty, 1976). It is not as intuitively obvious, however, that humans have the ability to make sexual discriminations on the basis of odors from organs common to both sexes. To determine whether humans could make this discrimination a group of college students were tested by the present investigator (Russell, 1976 also Appendix A).

Experiment I

In this experiment the subjects were 29 college students, 16 male and 13 female, all recruited from an introductory psychology class at the College of Marin. The subjects were asked not to use any soap, perfume or deodorant for 24 hours before the experiment and to wash only with tap water during this period. Then they were each given a plain white, appropriately sized T-shirt of

50% polyester and 50% cotton, and asked to wear the shirt as an undergarment for 24 hours. The subjects were asked to don the shirts after class and remove them before class the next day. They were provided with new identical sealable plastic bags in which to place their shirts. The shirts were then collected, removed from the bags, and put in wax-coated cardboard ice buckets in which a one-inch triangular hole had been cut (to allow the subjects to sniff the contents). The ice buckets were then placed on waxed paper with the shirts arranged so that the under-arm portion was closest to the hole. Each subject was tested individually in a testing room. The placement of containers was randomized and counterbalanced for each of the subjects.

The test was a two choice, forced discrimination, consisting of an unfamiliar male's and an unfamiliar female's T-shirt. The subject was brought into the room and asked "sniff each bucket three times and indicate which one was worn by a male. Take as much time as you wish and sniff as many additional times as you wish." Generally, each subject sniffed each bucket once in succession and then repeated the process. (see Appendix A for more detail).

Results

Thirteen of the sixteen males and nine of the thirteen females answered correctly. This provided a P < 0.005 level of significance when a binomial expansion was used on the 29 students. Although males had a higher number of correct selections there was no statitically significant sex difference in the preformance of the test. These results indicate that we are capable of making discriminations of odors from underarm secretions, and sexual identification can be made on the basis of olfactory cues.

A subsequent replicating study by Hold and Schleidt (1976) using axillary odors found similar results. Wallace (1977) found sexual identification could also be made on the basis of hand odors.

In each of these studies the intensity of the odor varied considerably, and it was not clear what the subjects were using as cues for discrimination. McBurney et al. (1977) and Doty (1977) found that when odors were equated for intensity by a magnitude estimation procedure, the discrimination was more difficult. Strong odors are usually classified as male and less intense odors classified as female. This appears to reflect the fact that women have, on the average, smaller apocrine glands and produce less intense general body odor than men (Hurley and Shelley, 1960). Thus, gender identification can occur, but it appears to be based more on odor intensity then on the presence or absence of some specific volatile compound.

Sexual Selection

Another hypothesis is that body odors may not be used for general sexual selection, but rather specific selection. In this hypothesis, the partner's odor is considered to be neutral or undesirable unless the odor is empowered with positive attributes by previous social conditioning or learning. Stoddard (1980, p. 103) has suggested that in some animal species females are able to "discriminate between less desirable and more desirable males by their noses. When deprived of this ability, they accept all comers." This view is supported by the observation that sexual receptivity is enhanced by the removal of the olfactory bulbs of females of some species (Satli and Aron, 1976).

The bulk of the evidence in humans shows that body odors are indeed aversive rather than attractive. Many of our personal hygiene practices are activities which either reduce the intensity of natural body odor, or attempt to eliminate personal odors altogether and replace them with some type of perfume or deodorant.

Studies of odor preferences in our culture demonstrate that male body odors collected on T-shirts are viewed by both males and females as unpleasant (Hold and Schleidt, 1976; Schleidt, et al., 1981). Since the current evidence suggests that the major discriminable difference between male and female odors is the greater intensity of male odors, and these odors can be identified as belonging to specific individuals (see below) it may be that males are using odors as a means of signaling their physical presence or signature rather than as a sexual attractant. If this is the case, and a learned attraction to the signature odor of a specific individual is based on previous sexual experience, it could lead to a situation were the odor of a particular partner is attractive and that of other individuals is not. This hypothesis is supported by a study of married couples (Schleidt, 1980) which looked at the ratings of pleasantness of partners' odors and strangers' odors. This study found that partners' odors collected on T-shirts were generally rated positively by both sexes more frequently than strangers' odors.

Summary: Sexual Attraction

It is not likely that there is a sexually attracting pheromone for humans. While such a substance may have been given off by our ancestors at some earlier time in evolutionary history it was probably lost as we evolved and concealed our periods of fertility. We do have the capacity to detect messages for gender identity, however. Messages such as "I am a man" or "I am a woman" or "I am a specific individual" appear to be more in keeping with the types of olfactory messages available to the human olfactory system. When these messages are reinforced through positive sexual or other experience they may take on attracting properties, but, in contrast to animals sexual attraction does not appear to be an intrinsic property of any specific chemical signal used by humans.

Reproductive Sychronization

Another aspect of mammalian sexual activity which has been demonstrated to be olfactorally mediated is the control of reproductive synchrony (See McClintock, 1983 for review). In humans, menstrual synchrony has been demonstrated between women who live in close proximity (McClintock, 1971) and acceleration of menstrual cycles which occurs when women come into contact with men (Veith, et al., 1983). Since both of these phenomena have been shown to be pheromonally controlled in animals (Bronson and Macmillan, 1983), it seemed reasonable to hypothesize a similar process in humans. The following experiment was devised to determine if the timing of human menstrual cycles could be influenced by olfactory cues (Russell, et al., 1980 also Appendix B).

Experiment II

Sixteen women were recruited to act as subjects. None of these women were taking oral contraceptives, none were accepted who were having sexual relations with other women, and none were living together. Their mean age was 28.5 years (range 19-39). The purpose of the experiment was explained to each subject. They were then asked to allow the experimenters to place an odor on their upper lip, just below the nose three times a week for a period of four months. The odor for each presentation was collected from the axillary region of a female donor subject.

The donor was selected according to a number of criteria: she had a history of a very regular menstrual cycle of 28 days, and no significant history of menstrual problems. She had reported a previous experience of "driving" another woman's menstrual cycle on three separate occasions, over three consecutive years, i.e. a friend had become synchronous with her when they roomed together in summer and dissynchronous when they moved apart in the fall. She did not use underarm deodorants nor shave under her arms. During the experiment she was not allowed to use a deodorizing or perfumed soap, and was not allowed to wash under the arms during the odor collection period.

The odorants were collected by having the donor wear square 4 x 4 in. cotton pads under each arm for a period of twenty-four hours. The pads were then removed and each was cut up into four equal pieces, and four drops of 70% alcohol were placed on each piece. The pieces of pad were then put into individual glass vials and frozen with dry ice. When the subject arrived, her sample was taken from the dry ice, allowed to thaw for two minutes, and then rubbed on her upper lip. The subjects were then allowed to go about their normal business, but asked not to wash their faces for the next six hours.

The subjects in the control group received the same treatment, but did not receive the odor. Because of subject attrition the final number of subjects was eleven, with five in the experimental group and six in the control group. The study ran for a total of five months, with a one-month pretreatment period and a four-month treatment period. The subjects did not know in which group they had been placed. The date of the subject's menstrual onset was determined by questioning her when she came to the laboratory.

Results

The individual results from this experiment are shown in Figure III. The mean difference in days from

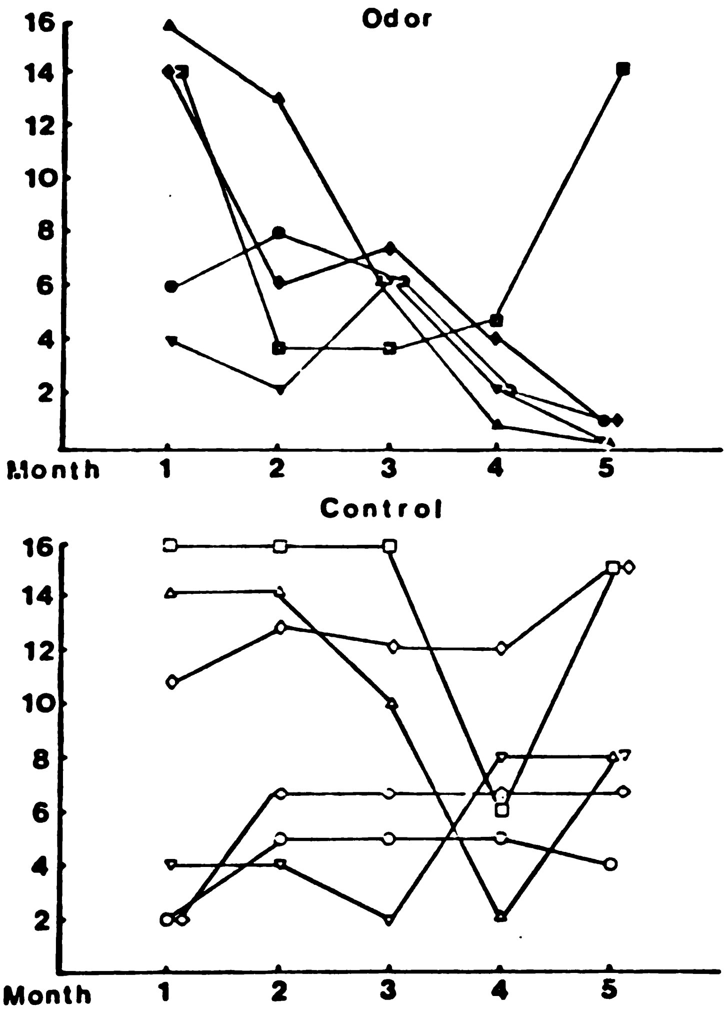


Fig. III Individual results from treatment and control groups. Scores are differences in days from donor subject.

onset of the menstrual cycle of the subjects from the donor was 9.3 days in the pre-treatment month and 3.4 days post treatment for the experimental, group and 8.0 days for the pre-treatment month and 9.2 days post treatment in the control group. Analysis of variance for repeated measures showed statistical significance of $P < 0.01$. Four subjects synchronized to within one day of the donor's onset.

These data indicate that chemical signals from one woman may influence the menstrual cycle of another, and that these signals can be collected from the underarm area, stored as frozen samples, and placed on another woman. Further, the experiment supports the theory that odor is a communicative element in human menstrual synchrony, and that a pheromonal system exists in humans. This system is not vestigial and is capable of bringing about hormonal changes in women.

The significance of these changes is difficult to determine on the basis of a single experiment done on a small sample of women. It seems likely that the function is not the coordination of menses, however, but rather the synchronization of the reproductive cycle. If humans are coordinating their reproductive cycles it suggests that many of the pheromonal effects which have been shown in animals may also be occurring in humans.

Phenomena which have been demonstrated in animals, such as the acceleration of ovulation, suppression of ovulation, and blocking of pregnancy should be tested for in humans.

A more recent study (Veith, et al., 1983), used a similar technique to demonstrate that acceleration of menstrual cycles can be caused by the presentation of male odors. In this study women were tested who had been isolated from males. When male underarm odor was placed on their upper lip their cycles were significantly shorter. This demonstration that the acceleration of the menstrual cycle (and probably ovulation) can occur in response to chemical cues suggests that both sexes are involved in some form of olfactory communication which affects the timing of the sexual cycle. Neither the extent of this communication nor its exact influence on the reproductive system is known, but it should certainly be an area of further research.

Summary: Reproductive Synchronization

Some form of chemical signalling occurs which modifies the menstrual cycle in humans. The signals involved in this synchronization appear to be active without the subject's awareness, affecting the hormonal cycle, and probably the timing of ovulation within that cycle. This response should certainly be considered to be pheromonal in nature.

Individual Identification

Recognition of an individual is a primary component of communication, and discrimination of self from non-self is a basic level of individual recognition. We take it for granted that we are able to recognize an individual's features by sight or sound, but it is less intuitively obvious that we are also able to recognize an individual's odors. Several tests have been done to determine whether individuals are able to make these discriminations (Porter, et al., 1983; Schleidt, 1980; Russell, 1976 also Appendix A). In the present experiments we wished to determine if adults could recognize their own odor from that of others when both were presented on a piece of clothing (Russell, 1976 also Appendix A).

Experiment III

The procedure in this experiment was identical to that used in the earlier experiment with sexual discrimination except that a three-choice discrimination was required. The choices consisted of: (1) the subject's own T-shirt (2) a strange male's T-shirt and (3) a strange female's T-shirt. Each subject was directed to the testing room and was asked "to sniff each bucket three times and indicate which one is yours. Take as much time as you wish and sniff as many additional times as you wish". Most subjects sniffed each bucket once in succession and then repeated the process. Each odor sample was changed between trials.

Results

As in the earlier test thirteen of the sixteen males and nine of the thirteen females answered correctly. Since this was a three-choice condition it provided a $P < 0.001$ when a binomial expansion was used as a statistical measure. Although the males made more correct choices there was no statistical difference between the males and females on this test.

The results of this experiment indicate that adults are able to make this preliminary level of discrimination of their own clothing versus that of a stranger from olfactory cues. Further, they made these discriminations without any prior training or control for such factors as intensity or individual sensitivity to odors.

Infants' Recognition of Mother

Since it had been established that an individual could recognize his/her own odor, the next step was to determine whether an individual could also identify the odor of close family members. A second experiment was designed to determine whether an infant could recognize its mother's odor and if the odor was capable of eliciting a behavioral response (Russell, 1976 also Appendix A).

Experiment IV

In this experiment the subjects were recruited by asking mothers in the delivery ward of the University of California Moffitt Hospital to volunteer. The subjects were 10 healthy, full-term breast-feeding mothers (both multiparas and primiparas) and their infants. The tests were conducted on the second day, during the second week, and during the sixth week after birth. The olfactory stimulus for these tests was obtained by asking each mother to place a breast pads (white cotton sponges) inside her bra for 3 hours before testing. The mothers were also asked not to feed their babies during this period so that the infants would be somewhat hungry, but not distressed, during testing.

The test consisted of the experimenter holding a folded breast pad with thumb and index finger under the infant's nose at a distance of 1-2cm for approximately 30 sec without touching the infant. During each test the infants were exposed to: (1) a clean moist pad, (2) their own mother's pad, and (3) a strange mother's pad. The sequence of presentation was randomized for each infant. During the six-week test the infants were also tested with a pad that had been moistened with raw cow's milk, as an additional control.

The test on day two was conducted in the hospital at the mother's bedside, and the 2- and 6-week tests were conducted in the home of the subject with the mother present. Each test was conducted in either a standard hospital bassinet, or the infant's crib at home. All breast pads were collected just before testing, except when it was necessary to travel between homes, and then the pad from the strange mother was stored in a plastic bag. The order of presentation of pads was random.

Infants were tested while sleeping whenever possible and not tested when distressed or crying. Pilot work had indicated this was an effective method of testing the infants independent of visual and auditory cues. When an infant was aroused by the stimulus, time was allowed between presentations for the infant to return to its original behavioral state.

Results

On day two, only one of the ten infants responded to any of the stimuli presented. The responding infant made a sucking response to both the strange and familiar odors.

At two weeks, three infants showed a "differential" response between their own mother and the strange mother. A differential response occurred when the infant responded only to his/her own mother's pad and not to the strange mother's pad. At six weeks one responded to both mothers, and seven responded only to their mothers' pad. The most common response observed (in five of the infants) was a sucking orienting response to their own mothers' pad and no response to the strange mothers' pad. A sixth infant who was hungry and sleeping when the test began did not respond at all to the presentation of the strange mothers' pad, but awoke and began to cry when its own mothers' pad was presented.

In each of the 6-week tests the responses to the raw cow's milk were the same as to the strange mothers' pads.

Discussion: Infants' Recognition of Mother

This experiment tested the infants' abilities to identify their mothers by odors left on breast pads at 2 days, 2 weeks, and 6 weeks after birth. At 2 days there was no response. At 2 weeks the infants showed general arousal and minimal if any, discrimination. Then, at 6 weeks of age, infants responded to their own mothers' odors with a pattern of orienting and sucking that was markedly different from their response to both the strange mothers' odor and the odor of cow's milk. Furthermore, at least six of the infants showed a positive attraction to their own mothers' odor and only one infant responded at all to the strange odor. This was a negative response, with a head jerk and cry which appeared more as a startled avoidance than attraction.

It might be argued that this response could have been due to a diminition in the attractiveness of the samples of the strange mothers' odors which were frozen during transport. This does not seem to have been the case, however, as Porter and Moore (1983) have recently demonstrated similar findings with nursery school subjects where it was not necessary to freeze the samples.

The existence of olfactory maternal identification indicates that humans are able to make individual discriminations at a very early age. Since the infants were not able to make the discrimination in the first tests, but did so by six weeks, suggests that the discrimination is learned and that the learning occurs after parturition, not in the womb as in some species of animals (Leon, 1983).

Studies by Schaal et al. (1980) and Macfarlane, (1975) found similar results in studies which also examined the abilities of infants to discriminate their own mothers' odors from unfamiliar mothers' odors.

Young children are also able to identify their siblings by olfactory cues. Porter and Moore (1981) tested infants from 36 to 49 months in a two-choice discrimination test to determine if they could identify T-shirts which had been worn by siblings. They found that most of the children could make the discrimination easily, with 13 of the 16 girls and 6 of the 8 boys tested making a correct choice.

Parents' Identification of Infants

Olfaction plays an important role in maintaining the parenting behavior of a number of species of animals (Goats [Gubernick 1980,1981], rabbits [Mykyotowycz, 1968], rats [Leon, 1974], gerbils [Wallace et al., 1973], and monkeys [Kaplan and Russell, 1974 also

Appendix C]).

The preceding experiments demonstrated that infants respond preferentially to odors of their own nursing mothers, and that adults can make discriminations between themselves and other individuals. To determine if mothers are also able to recognize their infants from olfactory cues, and to determine what amount of exposure to the infant is necessary for recognition, the following experiment was done (Russell, et al., 1983 also Appendix D).

Experiment V

Twenty-six mothers were recruited from the "well baby" nursery of the University of California San Francisco Medical Center. All were full-term pregnancies vaginally delivered without remarkable complications. Half of the mothers were tested at 6 hours post-partum and the other half at 48 hours post-partum.

The test consisted of the presentation to each mother of three babies, the mothers' own and two unfamiliar babies. All the babies were similarly washed, clothed and placed in standard hospital bassinets. The mother was blindfolded and asked to smell each infant, and guess which was her own. The test was repeated three times in succession with the order of presentation randomized between tests. The babies generally slept throughout the procedure. When and if an infant vocalized during the test, the bassinets were rearranged and the test repeated. The mothers were also questioned to determine if they could detect any vocal cues. In all cases the infant's body was covered with a blanket and the mother was directed to the infant's head. The sex of the infants was mixed. Mothers were not given feedback as to their accuracy during the experiment.

In other respects the mothers were treated according to standard hospital practice. At the well baby nursery this included mothers being allowed to hold and be with their infants for half an hour immediately after birth. The infant was then separated from its mother for approximately 6 hours while the infant was given a physical examination and the mother allowed to rest. During this separation the mothers were recruited for testing. For the six hour test, the mothers were tested immediately upon the infant's return prior to the mother's having any further contact with her baby. At this time after delivery the mothers were generally experiencing fatigue, but were alert enough to be tested. A second group of mothers was tested at 48 hours post-partum. In addition to the brief experience immediately after birth, these mothers had been allowed as much additional exposure to their infants as they wished after the six hours of separation which was imposed upon them by the hospital. The amount of time spent together varied considerably dependent upon the mother.

Results

At six hours post-partum 61% of the mothers identified their infants correctly, compared to 33% which would be expected by chance. The data achieved a statistical level of $P < 0.01$ using the Kolmogrov-Smirnov test (Conover, 1971). This test was selected rather than the binomial expansion as a conservative strategy.

At 48 hours post-partum, mothers were again able to identify their infants with a total of 58% correct guesses and a $P = <0.01$. This does not differ significantly from the 61% obtained at 6 hours. There did not appear to be any significant relationship between the number of children the mother had previously borne and the mother's ability to identify her infant, but the sample size was too small to make any strong conclusions.

Experiment V(a)

In addition to the mothers tested, ten fathers were asked to perform the same test. The fathers had variable amounts of experience with their offspring, and were tested anywhere from 24 to 48 hours after the birth of their child. This was done as an adjunct to the above experiment with mothers when it was discovered that the mothers were able to make the discriminations as early as six hours post-partum.

Results

The fathers correctly identified their own children only 37% of the time, which is not significantly different from the 33% which would be expected by chance.

Discussion

A possible explanation for these findings is that the mothers are recognizing that odor which is most similar to their own. The mothers and infants might have an odor similarity, because they have shared nutrition during gestation, and they have similar genetic makeups. The mother could be discriminating between the infants by simply recognizing that odor which is most similar to her own. This is not a likely explanation, however, because the fathers are not able to make the same discrimination. Fathers share an identical portion of the infant's genetic makeup and presumably have a similar although not identical diet to the mothers.

It could also be argued that these results might be due to a difference in the overall olfactory sensitivity of men and women. This would not seem to be the case as a number of studies comparing the olfactory sensitivity of men and women found that they are essentially the same with the exception of some slight differences with certain musky odors (LeMagnen, 1952; Doty et al., 1981). The differences found would not appear to be sufficient to account for the mens' inability to identify their infants. Further, previous studies have shown that husbands can recognize their wives' odor, and their children's odors by the time the child is three years old (Porter and Moore, 1981). It would seem that there is a genuine difference between mothers and fathers in the development of olfactory recognition with the mothers being able to make the discrimination earlier than the fathers.

Summary: Individual Recognition

Humans clearly are able to recognize each other through olfactory cues. Infants can recognize parents, parents infants and siblings each other. Taken together these data suggest that we are at least capable of recognizing a variety of individuals from olfactory cues. But the most interesting aspect of this is the discrepancy between the ability of fathers to identify their infants and that of mothers. Mothers seem able to make the discrimination earlier than fathers, and further research should be done to determine if there is a sensitive period for early mother-infant recognition.

Human Scent-marking

Scent-marking, or the placing of a body odor on an object or individual for later use is a common practice among mammals. Scent-marking takes advantage of the time delay property of olfactory cues. Unlike signals given off by the visual or auditory systems, odors can persist on an object long after the individual which deposits them has gone. The same individual or a different one can then return to that place or object later and receive the signal placed there earlier. For many animals it is the only method by which they can leave a long lasting message in their environment.

Although scent marking is widespread among animals our understanding of the significance of these marks is limited. Several investigators (Kleimen, 1966; Ewer, 1968; Ralls, 1971; and Muller-Schwarz, 1982) have proposed that scent-marking originated as a means of familiarizing the animal with its environment and providing the individual with a feeling of security as well as a means of communicating with others. The effect of one's own odor could be to provide familiarization with a strange area or object and give reassurance. When placed on a conspecific, the odor may be a marker which provides a social transition between the unfamiliar and the secure, making the individual feel more at ease in its home environment. In effect the individual is marking the conspecific with the message "you're mine, I have no need to worry." The hypothesis is that animals are more at ease with an object or individual which it has scent-marked than with one it has not.

Scent-marking has not been considered part of the human behavioral repertoire, but it may be a common occurrence. Young children frequently carry a blanket or cloth toy around with them and use the object as a source of contact comfort. The child will suck on the object and/or rub it about the face, suggesting the mouth and/or face as possible sources of scent-marking odor. These "security blankets" are then used by the infant when tired or stressed for what appears to be tension reduction.

The public observation of this putative form of human "scent-marking" is common, and it has even been the subject of a popular cartoon character (Schultz, 1984). Despite the frequency of this public observation, scent-marking has been ignored in the scientific literature on human olfaction. Scent-marking by infant animals has been well investigated, however. The research suggests that it can have profound effects on the mother-infant relationship, effects that are critical for infant survival.

Several species of animals use scent-marking as a means of identifying their mother or nesting area (cat [Freeman and Rosenblatt 1978], rat [Teicher and Blass, 1976], hamster [Devor and Schneider, 1974], and monkeys [Kaplan and Russell, 1974 also Appendix C]). Odors from both the mother and the infants are used for marking the home area. In rats it has been found that washing disrupts nipple attachment by pups from their first opportunity (Thicher and Blass, 1977) through 30 days postpartum (Bruno et al., 1980). Teicher and Blass (1976) were able to reinstate nipple attachment to previously cleaned nipples by painting the nipples either with an extract taken from the fluid previously used to clean the rat's breast area or with saliva from the rat pups themselves (Teicher and Blass, 1976). A variety of other odorants including rat milk were ineffective in restoring nipple attachment. The rat mother's saliva and amniotic fluid have also been shown to be effective (Thecher and Blass,1976), but not saliva from virgin rats. Further, infant rats will orient to the bedding or whole body odor of their mothers (Leon, 1983). It appears that both the rat infant and the mother are capable of providing odors for infant attachment and sucking.

The odors infant animals use for attachment have three components. One is the infant's signature odor which it places on the mother. This is an odor which is manufactured by the infant and identifies a spot as belonging to a particular individual. The second component is the mother's signature odor which identifies her to the infant. The third component is an actual attractant odor which the infant will approach independently of the signature odors (see Leon, 1983 for review). These odors are somewhat different from some other forms of scent-marking in that the animals place them on each other while engaged in other activities.

There is none of the active or overt marking which an animal uses when it sprays a scent on a tree or other object in its environment. Instead the marking appears to be an inadvertent part of some other process. The infant places its saliva on the mother when it is nursing, and the mother places her odors on the infant when she is cleaning it or simply moving about the nest. Although the presence of the scent is often critical for the mother-infant relationship and thus, indirectly for the survival of the infant, the placement of the scent is integrated into other behaviors such as nursing cleaning and nest building and thus may not be obvious to the casual observer. Our previous experiments suggest that this might also be the case for humans.

Experiment VI: Source of Maternal Odor

In experiment IV (Infants' Recognition of Mother) it was shown that human infants will respond to odors from their mother's breasts. The following experiments attempt to determine the source of that odor. It may be that the infants are responding to the mother's odors, or that they had scent-marked the breast during earlier feedings and were simply responding to their own odor in a fashion similar to that seen in various animal species.

The following experiment will attempt to answer the questions: 1) Does the infant respond to its mother's breast odor? 2) Does the infant scent-mark the mother with saliva?

Subjects

The subjects were 14 breastfed infants and their mothers recruited from Berkeley Pediatric Clinic. They were all healthy full term infants without reported birth complications. There were 8 boys and 6 girls between 6 - 8 weeks of age.

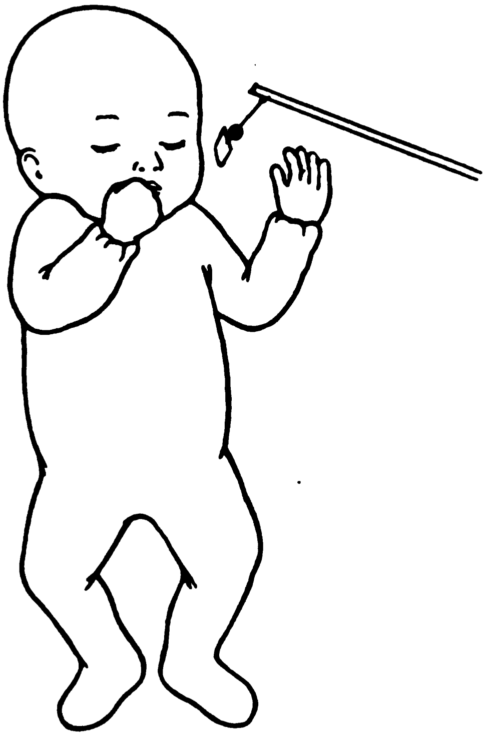


Figure IV

Methods

The tests were a series of two-choice discrimi-nations between odor samples placed approximately 3-6cm from the infant's nose. Samples were suspended from a 50cm dowel with a 20cm nylon string attached to one end (See figure). The dowel was used to hold the samples so that it was possible to position the samples without touching the samples or the baby. In addition there was a colored ball attached to the dowel string so that it was possible to visually identify a sample code. The test intervals consisted of a one minute pre-test baseline period, a one minute testing period, a one minute inter-stimulus interval, a second one minute test period, and a one minute post-test period. This provided a total of five minutes of testing for each infant.

All of the tests were conducted in the infant's home in the infant's crib or bed. The testing was done while the infant was asleep and two to four hours after its last feeding. Test sessions were video taped in ambient lighting conditions for later scoring. The feeding schedule was determined by interviewing the mothers. Previous experiments (Porter and Moore, 1981; Porter et al., 1983; Russell, 1976 also Appendix A; Russell et al., 1983 also Appendix D) have demonstrated that testing the infants while sleeping is an effective means of controlling for low level auditory and visual cues. Strong lights and noises are capable of eliciting responses from sleeping infants, however, and when such stimuli were detected the procedure was stopped, the odors repositioned, and the testing repeated. If the infant awoke during the test session the test was rescheduled.

Sample Collection

Test VI(A): Infant's Saliva

The saliva sample collection procedure was adapted from a method developed by Rosenblatt for use on kittens (Rosenblatt, 1972; Freeman and Rosenblatt, 1978). It consisted of having the infant suck on a pacifier which had been modified for saliva collection. The pacifier had a sponge attached to the base of the nipple. The sponge was situated in a manner which allowed for the collection of the infant's saliva without interfering with the infant's ability to suck. The sponge was attached by simply cutting a small hole in its center (approx 1cm diameter) and then slipping it over the nipple of the pacifier and pressing it against the pacifier base.

In some instances the pacifier was initially rejected by the infant. When this occurred the pacifier was returned to the infant until the infant began to suck and the sponge became moist. These moistened sponges then served as the test samples in the infant's saliva test sample. Identical sponges moistened with four drops of cow's milk served as the control samples.

Test VI(B): Mother's Breast Odor

The second set of samples was collected by asking the mothers to wash their breasts with a fresh bar of unscented soap and rinse with tap water. The mothers wore a breast pad (5 cm. square gauze sponge) inside their bras for a four hour period. A pad which had received four drops of cow's milk served as the control sample.

The purpose of the breast washing was to remove any saliva from the breast which might have been placed there earlier by the infant when nursing. Animal studies investigators (Pederson and Blass, 1979, 1982) have used various organic solvents (acetone and toluene) to clean the breast area. Because of the human subjects concerns about using such solvents with nursing infants and mothers, plain soap and water were substituted. Work with both primates (Kaplan and Russell, 1974 also Appendix C) and dogs (Beach and Gilmore, 1949) have shown that washing with soap and water is sufficient to remove scent-marks even in animals with a high level of olfactory sensitivity.

Sample Handling

All samples were handled in an identical fashion. Each mother was given two odor free air tight vials for storage of the samples. These vials were clearly labeled to prevent confusion in storage. The mothers were instructed to keep the samples refrigerated to prevent any possible deterioration which might occur between the time of collection and the time that the experimenter arrived at the home. The samples were then collected from the mother immediately prior to testing. Previous studies by this investigator and others (Macfarlane, 1975; Russell, 1976 also Appendix A; Porter and Moore, 1981) have shown that refrigeration is effective in maintaining the attractant properties of such samples. The samples were taken out of cold storage and warmed to room temperature for five minutes before testing as a means of assuring uniform sample temperature. Additionally, two control samples stored in identical vials, which had been moistened with four drops of cow's milk were brought to the testing session by the investigator.

To prevent investigator bias during testing, the mother, following instructions given to her in a sealed envlope prepared by a confederate placed the samples into additional coded vials so that the investigator was "blind" to the sample identity. The instructions inside of the envelope stated: "Please be sure that the number on this sheet is the same as the number in the outside of the envelope. Please place the white or black sticker beside the words, 'Your pad' (or 'Your infants pad') on the top of the bottle that holds your pad, and the other sticker on the bottle that holds cow's milk. Do not tell the researcher which is which. The vials were labeled and a coded key log was kept of the sample identity. The key was maintained separately from the record of the infants' responses. The key was not opened until all of the test scoring was completed.

Test Controls

There are a number of potential sources of error in doing olfactory experiments with young infants in their homes. These suggest a number of counter measures such as: controlling for auditory and visual cues; determining the infant's sensory capability; limiting background odors; and determining the infant's state of arousal or sleep. Each of these issues will be addressed in the following section.

Each test was done while the infant was sleeping. Additionally, the mother was telephoned on the day of the test to ensure that the infant was in a suitable condition for testing (no signs of colds, colic, fever, etc.). When the infants were not found to be in a suitable condition or were not sleeping the test was rescheduled. Many of the tests required repeated scheduling to obtain a proper sleeping condition of the infant.

Sound and Light

If a light or sound occurred which disturbed the infant during testing the samples were repositioned and the test redone or rescheduled.

Background Odors

No attempt was made to control for household odors during testing. While it is likely that there were some household odors present during the test period, these were considered part of the general background "noise" present in the infants' environment. In no case were household odors detected which appeared strong enough to distract the infant. This may be because the mothers knew the nature of the experiment and took precautions. They were not asked to do so, however.

The mothers were asked not to wear any perfume and not to perfume their infants during any of the testing or collecting periods. While it might be argued that this could be the normal environment for an individual infant or even part of the mothers' signature odor, it was felt that perfumes would simply be confounding to the experiment and we asked the mothers not to use them.

Olfactory Sensitivity

Ideally, one might wish to have a measure of the infants' olfactory sensitivity before testing to eliminate those infants who had a poor sense of smell and thereby reduce the variance among the responders. Unfortunately there are at least 36 known types of specific anosmia (Amoore, 1977) in humans, and the presence or absence of one type of odor blindness does not correlate with having another (Amoore, 1971). This means that simply testing for the known types of anosmia would require testing at least 36 individual compounds, and testing for hyposmia would require a much larger number. Tests for olfactory sensitivity of infants have proven to be of questionable reliability (Engen, 1982). The procedure, generally used for such testing, is to present a novel odorant to a sleeping infant and observe whether or not the infant shows a startle response to the novel odorant by moving or changing respiration. Repeating the stimulation after a 30 or 60 second interval allows the experimenter to judge the infant's response to a variety of odorants at various concentrations. Unfortunately, these procedures are particularly susceptible to sensory adaptation and habituation (Engen and Lippset 1965, Engen et al., 1963). The results of these sensitivity tests are generally considered to be unreliable even by those who use the procedures (Engen, 1982 p. 62).

These tests are also dependent on the assumption that the odors tested are unfamiliar or novel to the infant and will produce a startle response. Testing an infant for components of its own odor, or of its mother's odor would violate this basic assumption. Additionally, we do not know which specific odorants are important for the infant's recognition of or attraction to its mother, so that it would be difficult to test. Finally, it appears that the previous exposure to a number of odors may reduce the responsiveness of the infant to subsequent ones (Engen, 1982 p. 63), and interfere with the results of the later test.

Because of these concerns and our lack of knowledge concerning the specific properties of infant scent-marks no measures of infant olfactory sensitivity were taken.

Sleep State

In previous experiments assessing olfactory discriminations in infants (Engen, 1982; Porter and

Moore, 1983; Macfarlane, 1976), no attempt has been made to determine the infant's sleep state, because it was felt that the stage of sleep would not affect the infant's choice. The stage of sleep is not likely to affect the infant's choice in the present tests either, but it could determine whether or not the infant will respond to any mild stimulus. Because of the equipment necessary and the difficulty of accurately determining sleep stages in the infant's home environment, no assessment of sleep stage was attempted in this study. If the infant was motionless with its eyes closed it was assumed to be asleep.

Informed Consent

The exact nature of the test was explained to each mother and her consent obtained before testing. When fathers were available their informed consent was also obtained (see Appendix F for sample human subjects consent form).

Reliability and Scoring

The order of presentation of the test and control (cow's milk) stimuli was randomized using a table of random numbers. The confederate prepared the instruction envelopes. Each envelope was marked with a number which was held before the video camera at the time of testing to permit decoding at the time of scoring. The testing sessions were recorded with a portable video camera/recorder (Panasonic VHS) and all scoring was done from these tapes. Two raters who did not know sample identity scored the tapes. The scoring was done independently by each rater. The raters were asked to score each test and determine from the infant's responses which sample contained the test odor. When both raters agreed on the infant's responce the infant was given score of "2". When the raters did not agree the raters then independently viewed the tapes again, rescored the infants responses and then compared their notes. These responses were then given a rater confidence level of score of "1". In the single case where the raters did not agree on the infants response the trial was dropped from analysis. Where both reviews said there was no response a "0" was assigned.

Only when all of the scoring and data comparisons were completed was the key to the sample identity opened.

Results Test VI

Test VI(A): Infant's Saliva

The raters scored seven of the infants as having a response to their own saliva sample with a confidence level of "2", one infant received confidence rating of "1" in response to a control odor, one was scored as responding to the control odor with a level of "2" and four infants were scored as having no response to either odor (see Table I).

Since the data were recorded on a limited ordinal scale (i. e. 0, 1, or 2) a non-parametric test was chosen for analysis. The data were from related samples so the Wilcoxon Matched Pairs Signed-Ranks test was used to determine significance. This resulted in a $P < .025$, and a rejection of the null hypothesis suggesting that the babies did respond to the saliva samples.

Test VI(B): Mother's Breast Odor

In this test ten of the infants were scored as responding to the mother's odor (eight with scores of "2" and two with scores of "1"), none responded to the control sample, and four were scored as not responding to either. The Wilcoxon Matched Pairs Signed-Ranks was used again and it resulted in a $P = < 0.005$, and a rejection of the null hypothesis. Thus the data suggest that the babies also respond to their mother's breast odor.

Table I

Individual Test Results

Infant #	Saliva	Control	Breast	Control
1	2	0	0	0
2	2	0	1	0
3	2	0	2	0
4	2	0	2	0
5	2	0	0	0
6	2	0	0	0
7	2	0	2	0
8	X	X	0	0
9	0	2	0	0
10	2	0	2	0
11	0	0	2	0
12	0	0	1	0
13	0	1	2	0
14	0	0	2	0

Responses of individual infants to odor samples

Qualitiative Aspects of Infants' Responses

There were significant qualitative differences in the infants' responses between the two tests which were not anticipated from the earlier experiments. The responses to the mother's odor included a wide range of activities which varied from simple movements of the mouth and a rooting response to an actual grimace and turning away from the stimulus. While the overall affect of the infants in most cases appeared positive, both raters felt that for one infant the mother's breast odor seemed to be aversive to the infant. The infant turned away from the stimulus and seemed to display an avoidance reaction to the stimulus.

The responses to the infants' saliva odor were much more subtle and consistent. They were slight mouthing movements, eye twitching or changes in facial expressions. There was no rooting and none of the infants turned away from the stimulus. One infant awoke in what appeared to be a response to the stimulus and had to be retested a second time. Although, we had no objective measure of arousal and it is impossible to say for sure, the infants seemed to respond in a manner which would be consistent with a slight change in arousal.

All of the responses began to occur in a period of from five to twenty seconds after the stimulus was presented. When the infant samples were presented, responding infants stopped reacting after thirty seconds. When the mothers' breast samples were presented several of the infants continued to respond until the sample was removed or even after.

Discussion Experiment VI

Both the mother and the infant contribute to the odor given off by the mother. One portion of the odor originates from the mother's breast and another comes from the infant's saliva, placed there during earlier feedings. When the odor sources were separated and tested, the infants responded to both stimuli, but the subjective observation of the reviewers was that the responses were qualitatively different. It is likely that the odors are from two distinctive sets of compounds with each odor bringing separate and distinct properties to a combined smell which is then received by the infant. The presence of two odors (or more) which presumably combine and act together in the more natural circumstances of infant-mother interactions, suggests a level of complexity not anticipated in our earlier discussions. Implicit in our design was the assumption that the infants would respond to one or the other of the sets of stimuli. Instead we found that the infants responded to both stimuli, but in distinctly differing manners.

That infants responded to their saliva odor is evidence that infants are capable of some form of scent-marking, and that these marks are probably an active part of the mother's normal breast odor. The baby's odor mixes with the fraction of the odor which originates from the mother to form a combined smell that the infant normally responds to.

This investigator has observed on several occasions that many mothers with newborn infants initially have difficulty in getting their babies to suck from the breast. Experienced maternity nurses sometimes recommend to these mothers that they put saliva on their breast to get the infant started.

The fact that the infant's portion of the odor is missing during the first feeding of the infant's life may help to explain why some mothers have difficulty in getting their infants to begin nursing. Mothers who continue to have difficulty in getting their infant to nurse from the breast could be missing some fraction of these odors which the infant would normally find attracting or may be present and the infant unable to detect it.

Olfaction has not generally been considered at all in understanding human infant-mother interactions, and scent-marking had been thought to be limited to animals. Olfaction should now be considered along with the other sensory modalities when developing theories of attachment, bonding or simple individual recognition.

Most mothers, hospitals, and health professionals consider washing, cleaning and deodorizing to be an important part of good mothering, but we have no idea what we may be washing away with the bath water.

Perhaps the best evidence that olfaction is related to bonding in humans comes from observations of children playing with cloth toys and depositing odors on them. Young children will place saliva on familiar objects such as cloth toys and blankets (Russell, 1982 also Appendix F) and then carry the marked object around with them. These "security blankets" appear to provide contact comfort when the child is stressed and generally assist in reducing tension. Experimental evidence was reported by Shaal et al. (1980) who reported that infants spend more time in contact with T-shirts previously worn by their own mothers than with identical T-shirts worn by other mothers.

Possible human scent-marking behavior has been discussed in the context of "contact comfort" rather than scent-marking (Hong and Townes, 1976; Passman and Weisberg, 1975). Hong and Townes (1976) have looked at this behavior cross-culturally and found that "an infant's attachment to inanimate objects is lower in a culture or social group in which infants receive a greater amount of physical contact, including a higher rate of breast feeding, and in which the mother is more physically involved and available when the infants go to sleep." Hong and Townes (1976) carefully controlled study demonstrated that infants who sleep with their parents and breast feed are much less likely to attach themselves to a cloth blanket or teddy bear than those who do not. This suggests that objects may help the infant by providing it with some sense of security and reducing mild levels of stress. In scent-marking a toy or blanket, the infant may be using its odor mark as a substitute for the mother's odor when she is not available. Unfortunately, this research was done in the context of contact comfort and not odor as would be desirablee in light of the current findings.

As pointed out earlier, the animal data demonstrates that in a number of species, including primates, (Kaplan and Russell, 1974 also Appendix C) scent-marking has a significant impact on infants' attachment to their mothers. Further research will have to be done to confirm that scent-marking acts as an attractant for human infants.

Future research should also attempt to identify the active portions of the compounds involved, and gain a more specific understanding of their interactions. Another challenge in doing future research will be to find ways of identifying less obvious reactions to biologically significant odors in the sleeping infants. One approach might be to use EEG, heart rate or other psychophysiological measures to define more clearly the infant's resting state. An even greater challenge would be to find means of determining the effects of these odors on the awake and moving infant (where most normal activity could be expected) while still controlling for the effects of visual and auditory cues.

Summary: Human Scent-Marking.

The results of experiment VI(A) suggest that human infants do have an odor in their saliva which could be used for scent-marking their mother's breast when nursing. The results of experiment VI(B) indicate that there is also an odor which originates with the mother's breast, and which has a different and more variable effect on the infant. Whether the mother's odor is a simple signature odor (i.e. one that simply identifies the mother) or an odor which has active attractant or arousal properties has not been determined. It does appear, however, that the infant uses aspects of both the mother's odor and its own salivary scent-mark as part of a combined breast odor.

Conclusions

This series of experiments began with the question of whether or not odors had some of the pheromonal effects on humans which have been observed in animal populations. Taken together the data suggest that there is a system for human chemical communications. While we do not have the olfactory sensitivity of many other species we do have an active system of chemical communication.

The research in this dissertation has been concentrated on those areas which have been shown to be important in animal communication. Particularly, we have examined the possible role that olfactory communication plays in: 1) individual recognition, 2) gender identification, 3) reproductive synchrony 4) mother-infant attachment and 5) infant scent-marking. In each case the experiments have demonstrated that humans do have the capacity to use olfactory signals for communication in a manner similar to that found in other animals. Individuals are able to recognize each other from the odors left on garments. Men and women are able to discriminate male and female odors from underarm and hand odors. Pheromones do play a role in the synchronization of reproductive cycles. Mothers are able to recognize their infants by olfactory cues and conversely infants are able to recognize their mothers. Finally, infants may scent-mark their mothers with saliva when nursing.

Taken together the evidence indicates that olfactory cues are important for human communication and social interactions, and that they act in a fashion similar to that found in many animal species.

Chemical communication is also fundamentally different from auditory and visual communication. Unlike auditory or visual communication, olfactory signals tend to act on the hormonal system and frequently have effects that escape our awarness. Chemical signals are likely to be transmitted without intention, and are usually beyond the control of those individuals involved.

Although olfactory communication can be unconscious it still has major influences on our behavior. Determining the exact nature of that communication and its influence an the human condition will be a fertile area of research for some time to come.

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Appendix A

Human Olfactory Communication
Nature, V. 269 pp. 520-522, 1976.

(Reprinted from Nature, Vol. 260, No. 5551, pp. 520–522, April 8, 1976)

Human olfactory communication

It has long been known that animals use their olfactory senses to communicate information, including sexual status, individual identification and maternal attraction[1-3]. Olfactory communication has been demonstrated throughout the Mammalia, including the primates[4,5], and there has been speculation as to whether or not it exists in some form in man[6,7]. Substances are know to exist on man that serve an olfactory function in other animals[8] and there are many apocrine and sebaceous glands on the human body that produce such secretions. We have done two experiments, the first to determine whether adults can identify an individual and determine his or her sex by the odour of an article of clothing, and the second to examine whether an infant can identify its mother's odour by a behavioural response.

In the first experiment the subjects were 29 freshmen college students, 16 male and 13 female, all recruited by announcing the nature of the experiment in class and asking for volunteers. The subjects were asked not to use any soap, perfume or deodorant for 24 h before the experiment and to wash only with clear water during this period. Then they were each given a plain white, appropriately sized, T shirt of 50% polyester and 50% cotton, and asked to wear the shirt as an undergarment for 24 h. The subjects were asked to don the shirts after class and remove them before class the next day. They were provided with new identical sealable plastic bags in which to place their shirts. The shirts were then collected, removed from the bags, and put in wax-coated cardboard ice buckets in which a one-inch triangular hole had been cut (to allow the subjects to sniff the contents). The ice buckets were then placed on waxed paper with the shirts arranged so that the under-arm portion was closest to the hole. Each subject was tested individually in a testing room. The placement of containers was randomised for each subject.

The first test was a three-choice discrimination consisting of: (1) the subject's own T shirt; (2) a strange male's T shirt, and (3) a strange female's T shirt. After each subject entered the testing room and was seated, he was asked to "sniff each bucket three times and indicate which one is yours—take as much time as you wish, and sniff as many additional times as you wish". Generally, each subject sniffed each bucket once in succession and then repeated this process.

The second test always followed the first and was the same except that it was a two-choice discrimination between the same strange male and the same strange female T shirt as used in the first test, and the subject was asked to discriminate the sex of the wearer by indicating which was male. Test 2 followed test 1, within a few minutes.

In each test, thirteen of the sixteen males and nine of the thirteen females answered correctly. This provided a highly significant result of $P=<0.001$ for test 1 and $P=<0.005$ for test 2 when a binomial expansion was used as a statistical measure.

While the number of correct responses was the same in each test, the individuals who answered correctly were not always the same. Several of the students remarked that they felt they would have been able to make the discrimination at a lower concentration of odour, but none of them mentioned finding either the strength or types of odour objectionable.

There was considerable variation in the concentration of the odour samples and no attempt was made to control diet, sexual cycles, or drug variations within the subjects or donors, yet most subjects could select the correct odour easily. During informal questioning after the test the male odours were usually characterised as musky and the female odours as sweet.

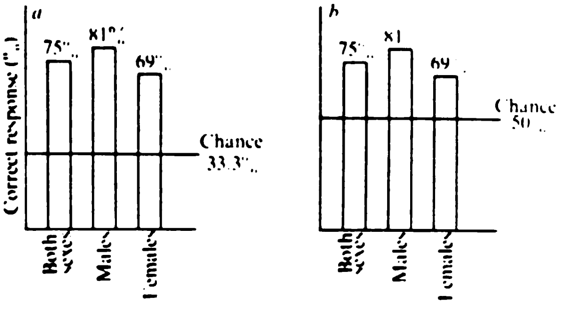

Fig. 1 Experiment 1. *a*, Test 1 shows the percentage of correct responses in identifying subjects' own odour in a three-choice discrimination. *b*, Test 2 shows the percentage of correct responses in identifying male odour in a two-choice condition.

These tests show that at least the rudimentary communications of sexual discrimination and individual identification can be made on the basis of olfactory cues.

In the second experiment we investigated whether a similar type of ability could be demonstrated in an infant and, further, if olfactory discrimination would elicit a behavioural response. Several authors, including Darwin[9], have provided anecdotal reports that children may use odour to identify their mothers at an early age. Pratt *et al.*[10] reported that Pryer, Canestrini and Peterson Rainey in separate experiments obtained preliminary but conflicting evidence that infants may be attracted to the odour of their mothers' milk when nursing.

The subjects were recruited by asking mothers in the delivery ward of the University of California Moffitt Hospital to volunteer for the experiment. The subjects were 14 healthy full-term breast-feeding mothers (both multiparas and primiparas) and their infants. Tests were conducted on the second day, during the second week, and during the sixth week after birth. The olfactory stimulus used for these tests was obtained by asking each mother to place a breast pad (white cotton sponges) inside her bra for 3 h before testing. The mothers were also asked not to feed their babies during this period so that the infants would be somewhat hungry, but not distressed, during testing.

The test consisted of the experimenter holding a folded breast pad with thumb and index finger under the infant's nose at a distance of 1–2 cm for approximately 30 s while being careful not to touch the infant. During each test the infants were exposed to: (1) a clean moist pad; (2) a familiar (own) mother's pad, and (3) a strange mother's pad. For each infant the sequence of presentation was random. During the 6-week test the infants were also tested with a pad that had been moistened with raw cow's milk. Each test was conducted in either a standard hospital bassinet, or the infant's crib at home.

The test on day two was conducted in the hospital at the mother's bedside, and the 2- and 6-week tests were conducted in the home of the subject with the mother present. All breast pads were collected just before testing, except when it was necessary to travel between homes and then the pad from the strange mother was stored in a plastic bag. The order of presentation of pads was random.

Infants were tested while sleeping whenever possible and not tested when distressed or crying. Pilot work had indicated that this was the only time that the infants could be tested independently of visual and auditory cues. When an infant was aroused by the stimulus, time was allowed between presentations for the infant to return to its original behavioural state.

As Fig. 2 shows, during the rest on day two, only one of the 10 responded to any of the stimuli presented. That infant made a sucking response to both the strange and familiar odour.

At 2 weeks, eight of the 10 infants responded to the odour of the strange mother, seven responded to their own mother, and three infants showed a differential response between the two. A differential response occurred when the infant responded only to his/her own mother's pad and not to the strange mother's pad. In the case of the 2-week test nine infants responded, six similarly to both odours, two just to the strange odour, one just to the strange odour and one just to the familiar odour. At no time did any infant respond to the clean moist pad.

At 6 weeks only one of the infants responded to the strange mother, seven responded to the mother's pad and six showed a differential response. The most common response observed (in five of the infants) was a sucking orienting response to the mother's pad and no response at all to the strange mother's pad. A sixth infant who was hungry and sleeping when the test began did not respond at all to the presentation of the strange mother's pad, but awoke and began to cry when its own mother's pad was presented.

In each of the 6-week tests the responses to the raw cow's milk were the same as to the strange mother's pads.

Experiment two tested the infants' abilities to identify their mothers by odours left on breast pads at 2 d, 2 weeks, and 6 weeks after birth. At 2 d there was no response. At 2 weeks the infants showed general arousal and minimal, if any, discrimination. Then at 6 weeks six of the 10 infants tested could identify their own mother's odour from that of a strange mother's odour. At 6 weeks of age infants responded to their own mother's odours with a pattern of orienting and sucking that was markedly different from their response to both the strange mother's odour and the odour of raw cow's milk, which was added as an additional control. Furthermore, at least six of the infants showed a positive attraction to the mother and only one infant responded at all to the strange odour. This was a negative response, with a head jerk and a cry. The existence of olfactory maternal attraction suggests that humans have a pheromonal system and that it operates at a very early age. Since doing this work I have become aware of a strikingly similar experiment by Macfarlane[11] in which he was able to show a differential response at 6 d of age.

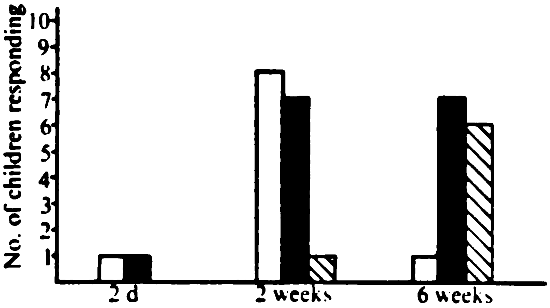

Fig. 2 Experiment 2. The responses of the 10 infants at 2 d, 2 weeks and 6 weeks to the strange mother's odour (open bars) and their own mother's odour (black bars). The hatched bar represents the number of children responding to their own mother and not to the strange mother.

The initial identification of the mother may not be due to a response to her odours but rather to odours placed on her by the infant during earlier contacts, as demonstrated in other primates[12]. Furthermore, the possibility of this maternal scent marking in humans is supported by the common observation by parents of children who reject a favourite teddy bear or blanket after it has been washed because of the loss of odour acquired from earlier contacts.

Although the source of these odours has not been clearly demonstrated, olfactory cues seem to generate behavioural responses in infants, and sexual and individual identification seems to occur in adults.

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Appendix B
Olfactory Recognition in the Infant Squirrel Monkey

Developmental Psychobiology, V. 7 pp. 15-19 1974.

Olfactory Recognition in the Infant Squirrel Monkey

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Infant squirrel monkeys were reared with surrogates and tested at 4, 8, and 12 weeks of age on their preferences for odors and colors of the surrogates. Surrogates in the rearing color that contained an infant's own odor were preferred to clean ones of the same color. Surrogates in the rearing color that did not contain an animal's scent were generally not preferred to different colored surrogates that were also clean. The results suggest that olfaction plays an important role in the development of social attachment in the young squirrel monkey and is more effective than at least one source of visual information.

The importance of mammalian olfaction in regulating certain aspects of social behavior, such as sex and aggression, is now generally recognized (Cheal & Sprott, 1971; Mykytowycz, 1970). Although most of the research in this area has concentrated on nonprimates, odorous stimuli have recently been demonstrated to affect these behaviors in certain primates as well (Epple, 1970; Jolly, 1972; Michael & Keverne, 1968). The response to odors is not limited to adults, however. Kittens and nestling rabbits use odors to recognize their mother and home area, even before they are able to see (Mykytowycz, 1970; Rosenblatt, 1972). Young primates, not yet studied in experiments of this kind, can also be expected to use odor as a means of identifying familiar stimuli. Because different stimulus properties can be controlled and examined more easily in surrogate-reared compared with mother-reared animals, this approach was used in the present experiment to determine the relative significance of olfactory and visual cues in squirrel monkeys during the first 3 months of life.

Method

Surrogate-Rearing and Test Conditions

Twelve infant squirrel monkeys (*Saimiri sciureus*) were taken from their mothers at approximately 1 week of age and housed separately with a surrogate made of a plastic

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cylinder (5 cm diameter x 25 cm long) covered with an acrylic fur material. The cylinder also contained a 30-ml bottle, with an exposed nipple to permit ad lib nursing, and a heat source for keeping the infant warm (Kaplan, 1974; Kaplan & Russell, 1973). The material covers were replaced with laundered ones every 3 or 4 days, and different colors were used to provide a distinct visual cue. Groups of 3 animals each were reared on either green-, red-, or black-covered surrogates, while a 4th group received 1 of the 3 colors—on a rotated basis—each time the covers were changed. Four, 8, and 12 weeks after an infant had been living with a surrogate, its preference for its own odor and color was measured. All tests were conducted in an enclosed apparatus with .76 m high metal walls that contained 4 alleys and a central intersection (Kaplan & Schusterman, 1972). The surrogates used in the preference tests were identical to those in the home cage except for the specific stimulus characteristics of the covers that were being compared.

Odor Preference

Odor preferences were determined by giving the infants a choice between a surrogate they had been living with for the past 3 days and clean ones of the same color. On one day, a clean surrogate and the odorous one were presented side-by-side at the rear of one alley so that the animals could compare the 2 directly. Two 5-min trials were given, the trial beginning with the release of an infant in the opposite alley, 1.2 m away from the 2 surrogates. In the 2nd trial, the position of the surrogates was reversed. The time spent on each surrogate, expressed as a percentage of the total time spent on both, was used to indicate an infant's preference. On the following day, 2 clean surrogates and the odorous one were each presented in 3 different alleys, and the amount of time spent in each of the alleys in a 12-min period was used to measure preference.

All the infants were tested in each of these 2 conditions at the 3 age periods, and the alley positions for the surrogates were randomly alternated across subjects and for the same subject at each age. A few infants were given an additional 2-choice test on the 1st day, in which their own odorous cover was paired with an odorous cover belonging to another animal.

Color Preference

Color preferences were measured on 2 consecutive days following the odor tests and were determined by the infants' responses to the different colored surrogates. Clean covers were always used in these tests to eliminate the possibility of the animals responding on the basis of odor. On one day, the 3 colored surrogates were placed inside the apparatus in different alleys so that they could be contacted. On the next day, they were placed in separate cages behind Plexiglas windows at the end of the alleys so that they could be seen, but not touched. Preferences were measured in both of these conditions by the amount of time spent in each alley over a 12-min period. In addition, a 2-choice test, similar to the odor test, was included at the 12-week session on a separate day, so that the infants could choose between their rearing surrogate and a different colored surrogate, situated next to each other in the same alley. Alley locations for the different colored surrogates were randomized across infants and changed for each infant at each of the test ages.

Results

Odor Preference

The different odor tests clearly indicated that the infants preferred odors associated with their own surrogate, and their behavior when the 2 surrogates were presented next to each other was often very dramatic. For example, many of the infants would approach the 2 surrogates and choose their own only after carefully smelling both. The infants' own odorous surrogates were preferred to clean ones in this situation at each of the ages examined (Fig. 1: $p<.01$, $<.05$, and $<.02$ for the 4-, 8-, and 12-week tests, respectively). For statistical purposes, the percentage of time infants spent on their own surrogate in the 2-choice tests was measured against 50% (*t*-tests), which would be expected if the animals showed no preference. This procedure was

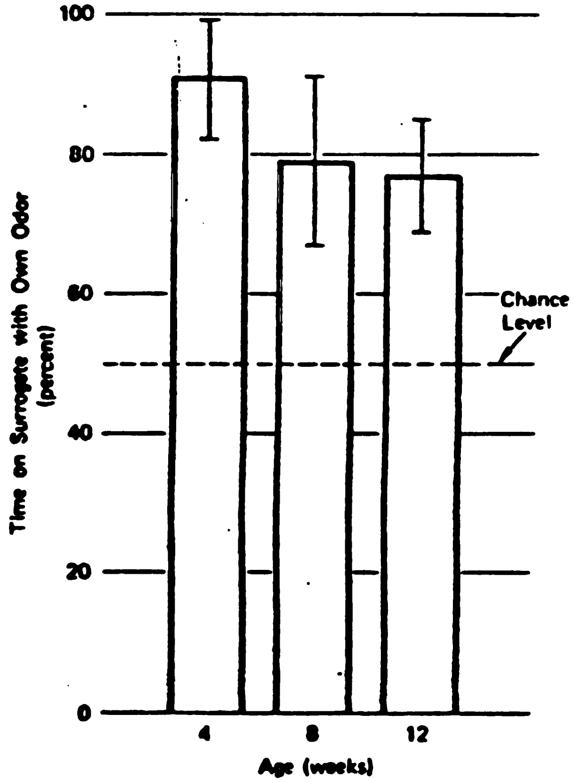

Fig. 1. Mean ± S. E. percentages of time spent on own odorous surrogate in 2-choice tests with a clean surrogate of the same color. Scores represent the percentage of the total time spent on both surrogates in two 5-min trials at each age.

used because the amount of time on the 2 surrogates is reciprocally related, and a direct comparison of the 2 scores would yield spuriously high differences.

The results from the condition where the surrogates were presented in different alleys were similar to those obtained in the 2-choice test, with the infants averaging over 80% of their time in the alley containing their own surrogate at each of the 3 ages. In both conditions, infants typically vocalized in a distressful manner before climbing on an odorous surrogate, after which they were immediately silent.

Two infants were tested at 4 weeks to see if they could distinguish their own odorous surrogate from that of another animal, and both chose their own on each trial and spent their entire time on it. One of these subjects continued to show a strong preference for its own odor at 8 and 12 weeks of age, but the other's response diminished (80% preference at 8 weeks and 60% at 12 weeks). One of 2 additional animals tested at 12 weeks for such specificity also preferred its own odor, spending over 90% of its time on that surrogate. The other infant, however, showed no preference.

Color Preference

The infants' response to the color they were reared with varied considerably from one session to the next. When the surrogates were located behind the alley windows the infants typically ran from alley to alley, vocalizing continuously. When the surrogates were presented inside the apparatus, the infants generally climbed on a surrogate or went from one to the other, without any particular color preference. Vocalizations generally subsided after an infant climbed on a clean-covered surrogate, but these did not appear to stop as abruptly or completely as was typical in the odor conditions.

Discussion

The present results indicate that the infant squirrel monkey makes significant use of odor at a very early age and is less responsive to certain visual stimuli. The infant recognizes and prefers an object that contains a familiar scent, and seems to be able to distinguish its own odor from that of another animal. Normally, this ability would appear to be of great value to the infant in identifying its mother. In the early stages of life, the infant squirrel monkey spends most of its time clinging tightly to its mother's back. This position not only places the infant's nose in close contact with the mother's body, but also prevents it from seeing her face, which might interfere with its learning to recognize her on the basis of sight. A greater dependence on olfaction as a means of identifying the mother may therefore have evolved as a result of these circumstances. Before such a conclusion can be made, however, the infants must be shown to discriminate preferentially odors associated with their natural mother.

Although the infants in the present experiment did not show a consistent preference for their rearing color, the effectiveness of visual stimuli early in development cannot be ruled out. For example, qualitatively different stimuli, such as those that are more naturalistic or more complex (Fantz, 1965), might have a greater impact on the infant. Also, our odor tests were conducted with surrogates from the infants' home cages that were also of the rearing color. Odor preferences, therefore, could have been based on a combined effect of odor and color and not just on odor. This possibility seems unlikely, however, in that the group of infants reared on all of the colors throughout the experiment showed as strong a preference for their own odorous surrogate, regardless of its color, as did the groups that were reared on one color for the entire period.

Notes

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Appendix C

Olfactory Influences on the Human Menstrual Cycle

Pharmacology, Biochemistry and Behavior, V 13, pp. 737-738, 1980.

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Olfactory Influences on the Human Menstrual Cycle

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RUSSELL, M. J., G. M. SWITZ AND K. THOMPSON. *Olfactory influences on the human menstrual cycle.* PHARMAC. BIOCHEM. BEHAV. 13(5) 737-738, 1980.—Two groups of women were compared for the timing of the onset of their menstrual cycles. One group was rubbed on the upper lip (directly beneath the nose) with a mixture of alcohol and underarm perspiration collected from a single female donor. The other group was rubbed with plain alcohol. The group which received the perspiration showed a significant shift in the timing of their menstrual cycles which conformed closely with the donor's monthly cycle. This is a preliminary study which supports the hypothesis that the time of menstrual onset may be modified by olfactory cues.

Menstrual cycle   Olfactory influences   Human female

THAT olfactory cues have a significant influence on the endocrine and reproductive systems of a wide variety of mammals including primates is well established; a number of reviews have been written on the subject [1, 2, 6, 8, 9]. Recently, three laboratories working independently have shown that some rudimentary form of olfactory communication also occurs in humans [3, 4, 7]. These studies demonstrated that odors can be used: by breast feeding infants in identifying their mothers, by adults in recognizing specific individuals and by adults and children in determining the sex of strangers. In our present study we wished to determine if olfactory cues might also influence the hormonal or reproductive status of humans in a manner similar to that found in other mammals. Women who live in close proximity experience synchronization of the onset of their menstruation; McClintock [5] has demonstrated that this menstrual synchrony is not due to changes in food, awareness of menstrual timing or lunar cycles and suggested that the only significant factors seem to be the amount of time the women spend together and the length of their cycles. We wished to determine if olfactory cues of one woman could influence the timing of menstrual onset in other women.

METHOD

For this purpose 16 women were recruited to act as volunteer subjects. None of these women were taking oral contraceptives and none were accepted who were having sexual relations with other women. Their mean age was 28.5 years (range 19–39). The purpose of the experiment was explained to each subject and then we asked them to allow us to place an odor on their upper lip, just below the nose three times a week for a period of four months. The odor for each presentation was collected from the axillary region of a female donor subject. This donor was selected according to a number of criteria: she had a history of a very regular menstrual cycle of 28 days and no significant history of menstrual problems. She had demonstrated a previous experience of "driving" another woman's menstrual cycle on three separate occasions, over three consecutive years, i.e. a friend had become synchronous with her when they roomed together in summer and dissynchronous when they moved apart in the fall. She did not use underarm deodorant nor shave under her arms. During the experiment she was not allowed to use a deodorizing or perfumed soap, and was not allowed to wash under the arms during the odor collection period.

The odorants were collected by having the donor wear square 4×4 in. cotton pads under each arm for a period of twenty-four hours. The pads were then removed and each was cut up into four equal pieces and four drops of 70% alcohol were placed on each piece. The pieces of pad were then put in individual glass vials and frozen in dry ice. When the subject arrived, her sample was take from the dry ice and allowed to thaw for two minutes and rubber on her upper lip. The subjects were then allowed to go about their normal business, but asked not to wash their faces for the next six hours.

The subjects in the control group received the same treatment, but did not receive the odor. Because of subject attrition the final number of subjects was eleven, with five in the experimental group and six in the control group. The study ran for a total of five months, with a one-month pretreatment period and a four-month treatment period. The subjects did not know in which group they had been placed. The date of the subject's menstrual onset was determined by questioning her when she came to the laboratory.

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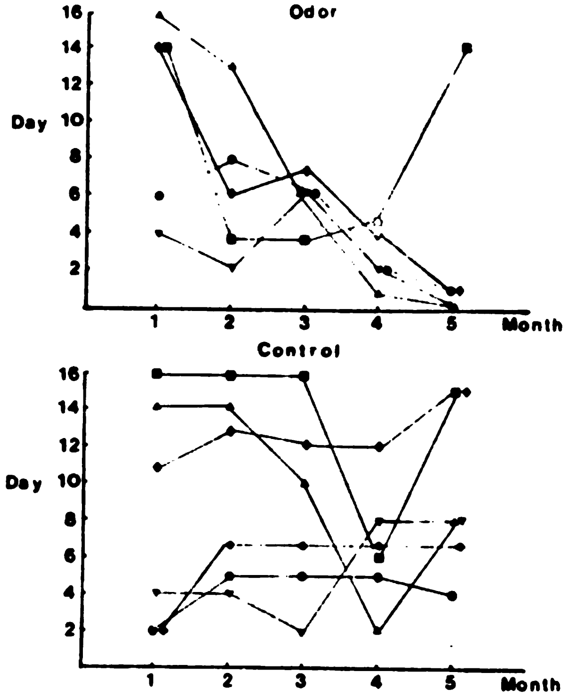

FIG. 1. The difference (in days) between each subject and the donor's onset of menstruation are plotted for the experimental and control groups. Each line represents one individual.

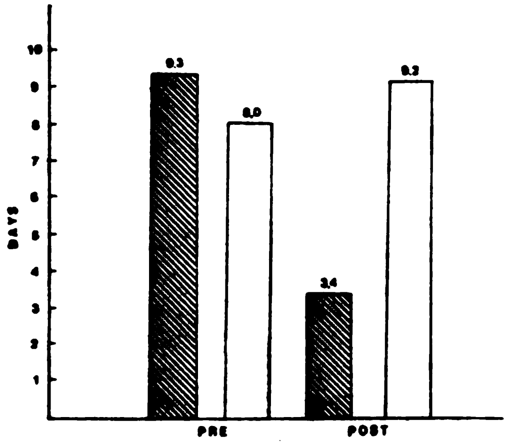

FIG. 2. The mean difference of the onset of the menstrual cycle of the donor and the menstrual cycles of the subjects before and after treatment with the odorant. The hatched bar is the experimental group and the open bar is the control group. The post score is the mean of the individual values in the fifth month.

RESULTS AND DISCUSSION

The individual results from this experiment are shown in Fig. 1. The mean difference in days (Fig. 2) from onset of the menstrual cycle of the subjects from the donor was 9.3 days in the pre-treatment month and 3.4 days post treatment for the experimental group and 8.0 days for the pre-treatment month and 9.2 days post treatment in the control group. Analysis of variance for repeated measures showed statistical significance of $p<0.01$ (F at 3.81). Four subjects synchronized to within one day of the donor's onset.

The data indicate that odors from one woman may influence the menstrual cycle of another and that these odors can be collected from the underarm area, stored as frozen samples, for at least short periods, and placed on another woman. Further, the experiment supports the theory that odor is a communicative element in human menstrual synchrony, and that at least a rudimentary form of olfactory control of the hormonal system is occurring in humans in a similar fashion to that found in other mammals.

While this study has been conducted in the context of olfaction, it is also possible that volatile substances were being transferred to the nose that the subject had no awareness of and therefore cannot properly be considered odors. It is also possible that the mechanism of transfer did not involve the nose at all, but diffusion of chemical compounds through the skin which may occur when the sample was placed on the subject's upper lip. We hope that these questions and others will be answered with further studies in this area of research.

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Appendix D
Mothers' Identification of Their Infant's Odors

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Mothers' Identification of their Infant's Odors

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Human mothers can identify their infants by smell alone at 6 hours post partum after a single exposure to their babies. This ability persists to 48 hours post partum with no improvement with additional experience. Fathers were not able to make the same discrimination.

Key Words: Infant attachment; Infant odor.

INTRODUCTION

In this report we provide evidence that mothers can identify their infants by smell alone. This finding is surprising insofar as olfactory influences in infant recognition have been largely ignored in human studies. Recognition is a prerequisite to successful attachment, and failure of such attachment may explain why children removed from their mothers at birth and maintained separately for brief periods suffer much higher incidences of battering and failure to thrive after returning to their natural parents (Bowlby, 1975; Klaus and Kennell, 1976). Similar survival deficits have been demonstrated in a number of other altricial mammals which have been experimentally inflicted with analogous separations. In nature, recognition is probably based on the sensory modalities working in concert, but to identify those modalities that may be involved in the process of recognition it is necessary to investigate each individually. We have chosen to look at olfaction, because it has been largely ignored in human mother–infant recognition despite the fact that olfactory cues are important in the attachment behavior of other mammals (Kaplan and Russell, 1974; Klopfer and Klopfer, 1968; Leon, 1974; Rosenblatt, 1972). In previous reports we and others have demonstrated that human infants can identify their mothers by odor (Macfarlane, 1975; Russell, 1976). In this report we provide evidence for the complementary observation; i.e., that mothers can identify their infants using a similar cue.

METHOD

Twenty-six mothers were recruited from the "well baby" nursery of the University of California San Francisco Medical Center. All were fullterm pregnancies (mean gestational age 39.4 weeks), vaginally delivered without remarkable complications. Mean age of the mothers was 30.8 years. Half of the mothers were tested at 6 hours post-partum and the other half at 48 hours post-partum.

The test consisted of the presentation to each mother of three babies, one of which was the mother's own and the other two unfamiliar. All the babies were similarly washed, clothed, and placed in standard hospital bassinets. The mother was blindfolded and asked to smell each infant and then guess which was her own. This test was repeated three times in succession with the order of presentation randomized between tests. The babies generally slept throughout the procedure. When and if an infant vocalized during the test, the bassinets were rearranged and the test repeated. The mothers were also questioned to determine if they could detect any vocal cues. In all cases the infant's body was covered with

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a blanket and the mother was directed to the infant's head. The sex of the infants was mixed. Mothers were not given feedback as to their accuracy during the experiment.

It is standard hospital practice at the University of California Moffitt Hospital that mothers are allowed to hold and be with their infants for a half-hour immediately after birth. The infant is then separated from his mother for approximately 6 hours while the infant is given a physical examination and the mother is allowed to rest. During this separation we recruited 13 mothers. The mothers were then tested immediately upon the infant's return without the mother having any further contact with her baby. At this time after delivery the mothers are generally experiencing fatigue but are well enough to be tested.

RESULTS

At six hours post-partum mothers are able to identify their offspring at a rate greater than would be predicted by chance ($p < .01$). The test used a goodness of fit model which compared the observed frequencies of recognition to that expected by chance, using the Kolmogrov–Smirnov test (Conover, 1971). This test was selected, rather than the binomial expansion as a conservative strategy. The total percentage of correct guesses was 61%, compared to 33% that would be expected by chance.

At 48 hours post-partum a separate, parallel group of 13 mothers was tested. In addition to the brief experience immediately after birth, these mothers were allowed as much additional exposure to their infants as they wished after the approximately 6 hours of separation after birth. Mothers at this time were rested and generally more animated than they were at 6 hours. At 48 hours post-partum mothers are again able to identify their offspring more frequently than would be expected by chance ($p < .01$). The total percentage of correct guesses was 58%. This does not differ significantly from the 61% obtained at 6 hours. There did not appear to be any significant relationship between the number of children she had previously borne and the mother's ability to identify her infant, but the sample size is too small to draw any strong conclusions.

In addition to the mothers tested, ten fathers were asked to perform the same tests. The fathers had variable amounts of experience with their offspring and were tested anywhere from 24 to 48 hours after the birth of their child. Fathers were able to identify their child only 37% of the time, which is not significantly different from the 33% which would be expected by chance.

It was not entirely unexpected that mothers might be able to identify their offspring by odor after 48 hours, insofar as they did have experience with their infant providing an opportunity for them to learn the odor specific to their child. We were surprised, however, that the subjects would be able to identify their babies with so brief an exposure as was afforded the 6-hour group.

DISCUSSION

A possible explanation of these findings is that the mothers are recognizing that odor which is most similar to their own. The mothers and infants might have a recognizable odor similarity because they have shared nutrition during gestation and they have similar genetic makeups. The mother could be discriminating between the infants by simply recognizing that odor which is most familiar. This is not a likely explanation, however, because the fathers are not able to make the same discrimination. Previous studies have shown that husbands can recognize their wives' odor (Hold and Schleidt, 1977) and so they should also be able to recognize their infant if the discrimination was made on the basis of its familiarity. Further, they make an equal contribution to the infants' genetic makeup and the infant should have a shared olfactory familiarity with the father. These results seem best interpreted as possible evidence for a sensitive period immediately after birth for mothers to learn the specific odor of their child. That the fathers could not make such an identification even with more experience indicates that this early sensitivity is a characteristic of females not shared by males.

Several factors may have mitigated against an even higher percentage of correct guesses. Infants, despite attempts to treat them the same, were noted to differ considerably in the amount of odor they exuded, and the testing situation (the mother's bedside) was not ideal for olfactory psychophysical judgments, insofar as others in the room contributed their own odors, both natural and artificial, to the milieu.

The source of the discriminable odor cue is unclear, but informal interviews with successful mothers indicates to us that the infant's breath might be the primary cue.

While it appears that for some mothers odor was not sufficient by itself for infant identification, the results of this study do provide evidence that odor may well be an important contributory cue for accurate identification of the infant by the mother during an early developmental period that marks the beginning of attachment.

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Appendix E
Human Olfactory Communications

From Muller-Schwartze, D. and Silverstein, R. (Eds) *Chemical Signals in Vertebrates Vol. III.* Plenum, New York, 1983.

HUMAN OLFACTORY COMMUNICATIONS

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INTRODUCTION

It has been known for some time that most mammals use odors as a means of intraspecific communication (see Cheal and Sprott, 1971; Bronson, 1971; Doty, 1976; Shorey, 1976; Müller-Schwarze and Mozell, 1977, Mykytowycz, 1977; for reviews). However, until recently little attention has been paid to the possibility that humans might also use smell as a means of communication. This review examines the areas of olfactory communication that are known to be of significance in animals: individual recognition, scent marking, sexual identification, sexual attraction, and reproductive synchrony, and discusses the evidence for human olfactory communication in each of these areas. Suggestions are made for further research in this field.

INDIVIDUAL RECOGNITION

As early as 1877, Darwin observed that an infant would turn its head towards its mother when its eyes were closed and her breast was brought near. Darwin suggested that the infant might be attracted to either the mother's odor or her body heat. Pratt et al. (1930) reported that Pryer, Canestrini and Peterson Rainey did experiments to see if infants were attracted by the odor of their mothers' milk, but these early experiments yielded conflicting results and were not followed up. Then in the mid-seventies two laboratories working independently (MacFarlane, 1975; Russell, 1976) reported work that was nearly identical in procedure and strikingly similar in result. Both of these studies examined the head-turning and routing reflex of hungry sleeping infants to the presence of odors from breast pad:

that had been worn by either their own mother or by an unfamiliar mother. Both of these studies found that the infants showed no measurable responses to either of the odors at two days post-partum, but that some infants were able to discriminate their own mother's odor from an unfamiliar mother's odor by six days (MacFarlane, 1975) and virtually all of the infants were able to make the discrimination by six weeks (Russell, 1976). A later study by Schaal et al. (1980) also examined the response of infants to breast pads. By analyzing film recordings of infants, they determined that babies reduced their body movements more when they were exposed to the odors of their own mothers than when they were exposed to odor from unfamiliar mothers.

The results of the above studies indicate that infants are not able to identify their mothers at two days of age, but can discriminate their own mother from an unfamiliar mother by the second week after birth. Two hypotheses can be drawn from these results. One hypothesis is that the babies are capable of making the discrimination at birth, but that we are not able to demonstrate the infants' ability by either of these methods of measurement. This "in utero" hypothesis suggests that the baby is exposed to some mixture of the mother's body chemistry while living in an amniotic fluid and that the infant is simply responding to similar airborne constituents that are perceived as odors after the baby is born. None of the experiments done to date either proves or disproves this hypothesis. The present evidence suggests that a second hypothesis based on "extra-uterine" learning is more plausible, however. The olfactory threshold of infants is quite high at birth and drops steadily for the first week (Lipsitt et al., 1963), suggesting that the infant may not be capable of making the relatively subtle olfactory discriminations necessary for identification of its mother until after the first week of life. Also, the evidence from the other sensory modalities (Carpenter, 1974) indicates that an infant is not able to identify its primary caretaker until the second week of life. MacFarlane (1976, p. 112) has pointed out that historically humans have had a high maternal death rate, and that it is probably not advantageous for human infants to form the immediate attachments found in some other species (Hess, 1973). It is to the infant's advantage to have an initial period of attachment flexibility before forming a bond with a primary caretaker. Delaying the ability to identify this caretaker would be a simple means of postponing this attachment bonding and encouraging "Allomothering," or adoption by alternate parents.

Data on specific types and sources of odor that human infants use for maternal identification are not available, but work with primates suggests that infants are both able to recognize odors that are indigenous to the infant's primary caretaker (Kaplan, 1977), and to identify their own odor which they use to mark their primary caretaker (Kaplan and Russell, 1974). In these studies infant squirrel monkeys (*Saimiri sciureus*) were raised on cloth covered surrogates to determine how infants identify their mothers during the early stages of life, and to assess the effects that perceptual qualities have on early attachment. Infants were raised in a variety of conditions to test their preference for visual, olfactor and tactile cues. Beginning when the infants were four weeks of ag and continuing at four-week intervals until they were six months of age, the infant squirrel monkeys were tested to determine their preferences for the color and odor of the surrogates that they had been raised on. A series of two-choice and four-choice preference tests showed that the infants recognized and greatly preferred surrogates upon which they had deposited their own odors, or surrogates that had been perfumed by the experimenter during early rearing (Kaplan, 1977) to either familiar visual cues or unfamiliar odors during early infancy. Later in life the animals showed a preference for visual cues. It is probable that human infants also use odors which they have deposited on their mothers, and their mothers' indigenous odors, as cues for olfactory identification.

If an infant is able to identify its mother by olfactory cues, can a mother also identify her infant? Schaal et al. (1980) have shown that at two days post-partum, mothers are able to discriminat the "T" shirts worn by their own infants from those worn by other infants. In a series of experiments at our laboratory (Russell et al., 1982), we have found that mothers are able to identify their own infants immediately after delivery. In this test, the mothers were blindfolded and presented with their own infant and two other infants, and asked to identify their own after sniffing the infants' heads. The mothers correctly identified their own infant in 61% of the trials. In an identical test, the fathers were not able to make this discrimination when tested from 24 to 48 hours after the birth of their children. The fathers achieved a correct response in only 37% of the trials in a three choice test. This may be because of the differing experiences of the mother and father with the child or differences in olfactory thresholds. Whatever the reason, in this experiment mothers were able to recognize their infants and fathers were not. Although it has not yet been demonstrated that fathers can identify their infants later in life, it seems likely that they would be able to do so with sufficient exposure.

Several studies have now been done to demonstrate that humans can also recognize other individuals by smell. Porter and Moore (1981) have shown that infants are able to identify odors of siblings and that parents can identify the odors of their children's "T" shirts. Unfortunately, this study did not consider the specific responses of fathers, so it is impossible to determine from the report if men are able to identify their children. Both men and women are able to identify both their own body odor as well as that of their mate (Schleidt, 1980; Hold and Schleidt, 1977; Wallace, 1977; Russell, 1976).

SCENT MARKING IN HUMANS

One of the advantages of olfactory cues over signals from other sensory modalities is that they persist over time, and some odors deposited on an object can be used later by the same individual that deposited it, or by different individuals when the depositor is no longer present. Scent marking is a common behavior in animals and is used for a variety of purposes ranging from marking territory to the expression of social status (Stoddart, 1980; Johnston, 1975; Theissen, 1968; Mykytowycz, 1965; Whitten and Bronson, 1970; Epple, 1974; Ralls, 1971; Barrette, 1977 and many others). Among the more common examples of scent marking studied in animals is the identification of home territories and nest sites. Scent marking often begins immediately after birth with the mutual exchange of odors by mothers and infants as a means of enhancing the ability of each to identify the other. Infant animals, including primates (Kaplan, 1977), kittens (Rosenblatt, 1972), sheep (Alexander, 1978) and rats (Leon and Moltz, 1972) recognize, and are strongly influenced by odors which are associated with their mothers, litter-mates and home area. Most often these infant animals show reduced signs of stress when their own odors or their mothers' odors are present in the environment.

There is evidence that recognition of one's own odor or the odor of kin are a significant means of reducing stress in human infants. Children will often scent mark a blanket or cloth toy with their own odor and then carry this marked object around with them. These "security blankets" are then used by the infant as an object of attachment when it is tired or away from its parents (Passman and Weisberg, 1975). Recently, I observed a particularly inventive three-year-old boy hold a cloth toy in a position which allowed the child to simultaneously suck its thumb, touch a soft portion of the toy, and have a select portion of the toy near his nose on several occasions when he was tired. When the child was asked why it held the toy in that position he responded "to get the smell right." In this manner, he was able to get contact comfort by using his thumb as a pacifier, touching the soft fur for tactile stimulation, and positioning the cloth for inhaling a familiar odor; all of which seemed to calm him and make him more relaxed when stressed or tired. The observation of this form of human scent marking is common, and has even been the subject of a popular cartoon character (Schultz), but those authors that have examined it have done so in the context of contact comfort rather than scent marking (Hong and Townes, 1976; Passman and Weisberg, 1975).

The objects are usually sucked and rubbed about the face by the child, so the mouth or the face may be the sources of the odor, although any familiar odor might have the same function and the source may be irrelevant. There is evidence which suggests why some infants attach to these objects and others do not. Hong and Townes (1976) have looked at attachment cross-culturally and found that "an infant's attachment to inanimate objects is lower in a culture or social group in which infants receive a greater amount of physical contact, including a higher rate of breast feeding, and in which the mother is more physically involved and available when the infants go to sleep."

With the possible exception of the sucking and rubbing motions of nursing infants, humans do not display behaviors that are readily identifiable as scent marking. Human body odors are deposited, however, in our environment on cloths, bedding, furniture, etc. Shaal et al. (1980) reported that infants spent more time in contact with "T" shirts that had been worn by their own mothers than with identical "T" shirts worn by other mothers. It may be that the familiarity of the odor is more important to the infant than whether the odor came from the infant itself or from its mother.

ODORS AND HUMAN SEXUAL BEHAVIOR

It is well established that olfactory cues play a significant role in the sexual behavior of a wide variety of animals, but the role olfactory cues play in human sexual behavior is poorly understood and often controversial (Hopson, 1979; Rogel, 1978; Doty, 1976; Comfort, 1974). In humans the three areas most frequently discussed are: 1) sexual identification, 2) sexual attraction, and 3) hormonal synchronization.

Sexual Identification

It is generally believed that human beings can detect differences between the sexes on the basis of odors given off by sexually specific sources such as vaginal secretions, smegma, and seminal fluid (Doty, 1977). Although no studies have been done to verify this commonly held belief, it seems likely that it is a correct assumption, at least in sexually experienced individuals.

The ability to discriminate genders by olfactory cues from sexually shared sources, such as underarm and hand odors, have been examined by several authors. Russell (1976), and Hold and Schleidt (1977) have tested the ability of adults to discriminate between sexes on the basis of axillary odors, and reported that both sexes were able to make gender identifications by axillary odors. Wallace (1977) found that sexual identifications could also be made on the basis of hand odors. McBurney et al. (1977) and Doty (1977) found that when odors were equated for intensity by a magnitude estimation procedure, the discriminations were much more difficult, and that physiological or behavioral cues that signal ovulation (Butler, 1974; Alexander and Noonan, 1979; Benshoof and Thornhill, 1979; Strassmann,1981). The fact that other primate species do have pronounced periods of estrus signaling (Hall, 1962; Goodall, 1965; Hausfater, 1975) suggests that our ancestors may have also had this trait, but that the evolutionary trend has been for women not to provide any cues of their period of ovulation for males or themselves. Any odor that was given off as an attractant during ovulation would not be consistent with this evolutionary development, because it would identify when ovulation was occurring. Further, studies that have examined the incidence of sexual activity for increases in coital behavior around the ovulatory period do not show the significant increase that would be expected if such an attractant were present (James, 1971; Spitz, et al. 1975).

One possible hypothesis is that women have adapted to continuous sexual receptivity by constantly giving off an attractant odor. Cowley et al. (1977) have studied the effects of two odorous compounds, androstenol (5α-16-androsten-3α-ol, the boar attractant), and "Copulin" (a mixture of aliphatic acids found in vaginal secretions) on the responses of male and female students in an Assessment-Of-People test. In this study, subjects were asked to evaluate the qualities of other individuals while wearing masks that had been treated with one of the odorous compounds. The subjects did not know the purpose of the study or that they were being exposed to the odors. This study found that the women tended to judge the males more highly when androstenol was present, but that there were no changes in the responses of the males. Kirk-Smith et al. (1978) also used treated masks to examing the influence of the odor of androstenol on the subjects' judgments of photographs. In contrast to the results of Cowley et al., both male and female subjects rated photographs of women as "more attractive" and "better" in the presence of androstenol. In a third study of the effects of androstenol, McCollough et al. (1981) had subjects read an erotic passage while being exposed to either androstenol or Rose Water and found no change in emotional responsiveness in either men or women as measured by the Differential-Emotions-Scale questionnaire. While these findings cannot be compared directly because of the differences in techniques, it appears that there are enough differences in the results to make any general conclusions about the attractiveness of androstenol tentative at best. However, even if the results of Cowley et al. are confirmed, it will not be sufficient evidence to demonstrate a pheromonal response, as it is quite possible that any preference for this compound which is present in male secretions (Brooksbank et al., 1974; Sastry et al., 1980) is a learned preference due to associative learning. To demonstrate a pheromonal effect the chemical must stimulate particular aspects of behavior, in this case sexual attraction, and associative learning should be specifically excluded (Goldfoot, 1981; Beauchamp et al., 1976). Goldfoot (1981) has suggested some specific criteria for determining the existence of a pheromonal effect in primates and these same criteria should be used when considering human pheromones. These are: 1) compound specificity - a specific chemical or mixture of chemicals must be shown to have behavioral potency in conspecifics; 2) behavior specificity - a chemical must stimulate particular aspects of behavior rather than general responses such as arousal; 3) species specificity - a chemical must be active only in the same or related species; and 4) innate response - the behavior must be genetically based. Goldfoot (1981) has included "imprinting" in this last criterion, but Beauchamp et al. (1976) would exclude it.

Sexual Attraction

Another hypothesis is that odors may not be used for sexual attraction at all, but rather for negative sexual selection. In this hypothesis, the partner's odor is considered to be undesirable unless the aversion to the odor is overridden by some other factor, such as sexual arousal or habituation to the aversive odor. Stoddart (1980, p. 103) has suggested that in some animal species females are able "to discriminate between less desirable and more desirable males by their noses. When deprived of this ability, they accept all comers." This view is supported by the observation that sexual receptivity is enhanced by the removal of the olfactory bulbs of female rats (Satli and Aron, 1976).

The bulk of the evidence in humans shows that odors given off by males are found to be aversive rather than attractive. Much of the personal hygiene practices found in our society are activities which either reduce the intensity of our natural smell, or attempt to eliminate personal odors altogether. Studies of odor preferences in our culture demonstrate that male body odors collected on "T" shirts are viewed by both males and females as unpleasant (Hold and Schleidt, 1976; Schleidt, et al., 1981). Since the current evidence suggests that the major difference between male and female odors is the greater intensity of male odors, and these odors can be identified as belonging to specific individuals, it may be that males are using odors as a means of signaling their physical presence rather than as a sexual attractant. If this were combined with associative learning on the part of females, it would lead to a situation in which some male odors were attractive while others were aversive, depending on the personal experiences of the individuals involved. Lawless and Cain (1975) have shown that learned recognition of odors can be very long-lasting, and it is possible that early experiences may play a role in any associative learning which may occur in humans.

It is too early to rule out the possibility that human attractant pheromones exist, but the strong interest by the popular press and perfume industry makes it important that any claims for such a discovery be viewed cautiously. It is also important that research into this question be continued. Any improvement in our understanding of the behavioral and physiological functions of olfactory cues in sexual attraction or sexual development is likely to have significant social consequences.

Hormonal Synchronization

Two types of hormonal synchronization have been suggested in humans that may be related to olfactory cues; in one the continued presence of a male may increase the frequency of a woman's menstrual cycle; and in the other, women who are living in close proximity have concurrent menstrual cycles. Both of these effects have been demonstrated in a variety of animals including primates (Rowell and Dixson, 1975; Rosenblum, 1968; Harrington, 1975; Conaway and Sade, 1965; Vandenbergh and Vessey, 1968). The first demonstration that similar phenomena were occurring in humans was presented in a landmark paper by McClintock (1971). McClintock noted that menstrual synchrony was often reported by women in all-female living groups. She examined the timing of the onset of menstrual cycles for roommates and close friends on a college campus by asking dormitory residents to report the timing of their cycles. She questioned 135 women aged 17-22, and found significant correlations in the timing of cycles of women who spent time in close proximity (e.g., roommates). Further, McClintock found that women who reported that they were in the company of males more than three times a week tended to have shorter menstrual cycles than those who spent less time with males. McClintock concluded that "there is some interpersonal physiological process which affects the menstrual cycle" and suggested that it could be pheromonal in nature. Subsequent to this report, Graham and McGrew (1980), Russell et al. (1980), and Quadagno et al. (1981) have also reported menstrual synchronization in women. Two of these studies (Graham and McGrew, and Quadagno et al.) also looked for a shortening of the menstrual cycle for women with close contacts with men, but found none.

It is possible that this failure to find a shortening of the cycles with exposure to men is due to the fact that in the later studies male isolation time varied. Additional studies are needed to establish that increases in the frequency of menstrual cycles occur due to exposure to males.

Menstrual synchrony in humans is of particular interest because it has been well demonstrated that estrus cycles in animals are influenced by olfactory cues (Grau, 1976; Whitten, 1969; Vandenbergh et al., 1975; Müller-Schwarze, 1974; Bronson, 1971). McClintock demonstrated that the human phenomenon is not due to changes in diet, awareness of menstrual timing, or lunar cycles, and suggested that the only significant factor seemed to be the amount of time that the women spent together and the relative length of their cycles. That is, they are controlled by changes in unknown volatile compounds that are not caused by the individuals learning to respond. Rogel (1978), in a critical evaluation of the possible existence of higher primate pheromones suggested that "the most promising area in which to search for pheromonal control of higher primate sexual and reproductive behavior is menstrual synchrony, a phenomenon that suggests the action of a primer pheromone." (p. 862).

Russell et al. (1980) examined the menstrual cycles of college women after exposing them to the axillary secretions of another donor female. A single donor was selected who had a regular menstrual cycle of 28 days, and who claimed a previous history of "driving" another woman's cycle. That is, a friend had become synchronous with her when they roomed together in the summer and dissynchronous when they moved apart in the fall. The subjects were divided into two groups, one which received the odor on an alcohol treated pad and the other which received only the alcohol treated pad as a control odor. The odorant was applied to the upper lip three times a week. The number of participants was five in the experimental group and six in the control group. The study included a one-month pre-treatment period and a four-month treatment period. The subjects were informed of the nature of the experiment, but did not know which group they were in. The dates of the onset of the subjects' menstrual cycles were determined by questioning. The mean difference between the onset of the cycle of the subjects and the onset of the donor cycle was 9.3 days in the pre-treatment month and 3.4 days post-treatment for the experimental group; and 8.0 days for the pre-treatment month and 9.2 days post treatment in the control group. The results were statistically significant and support the view that odor is the communicative element in human menstrual synchrony.

Menstrual synchrony does suggest that some type of pheromone exists in humans and that the mode of action is similar to that found in other mammals, but it also raises a number of questions. First, this was a pilot study done with a single donor and these results should not be generalized to other women. Does this particular donor have some unique characteristics that make her able to modify the cycles of other women or would any woman with a regular cycle have a similar effect? Is the phenomenon really olfactory in the traditional sense? While the experiment was conducted in the context of an olfactory stimulus, none of the women involved in the study reported an awareness of changes in the odor of the sample that they received, suggesting that conscious awareness of an odor may not be necessary for modification of the cycle. We do not know from these studies which phase of the cycle is changing or how the phenomenon of synchrony is related to changes in ovulation. These questions and many others, will require further research in this area.

CONCLUSIONS

Humans do use their natural body odors as sources of information for non-verbal communication in a number of contexts. The best established of these is the recognition of self and individual family members by infants and adults. In addition to recognition of family members by odors that are indigenous to those individuals, it has been suggested that infants may be depositing scent marks on their mothers in a manner similar to other primates. These scent marks seem to be used to reduce anxiety in infants who place them on cloth toys or blankets, and may have similar functions at other times. Humans are also capable of gender identification through the use of olfactory cues from both sexually unique sources, such as vaginal secretions and seminal fluid, and sexually shared sources such as hand and axillary regions. The primary basis for the discrimination of the shared sources is a sexual dimorphism of greater odor intensity for males. Several studies have been done which suggest that odors are a significant factor in sexual attraction, but currently there is not sufficient evidence to support claims for an attractant pheromone. The hypothesis is presented that associative learning better explains the existing observations of sexual attraction in humans, but further research should be done which examines the role that odorants have on psychosexual function. Studies are also cited which report that body odors, particularly male ones, are aversive to many people; and that they may function to signal an individual's presence rather than as sexual attractants. There is evidence that a pheromone may exist for menstrual synchrony, however, and it is suggested that more research is needed to replicate and expand the work that has already been done in this area. Particularly, work should be done to determine what the relationship is between menstrual synchrony and ovulation. The identification of olfactory cues that could alter hormonal levels, change time of ovulation or effect implantation of the ovum would be a significant achievement, but there is little or no research to determine if any of these effects are possible.

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Appendix F
Subject Consent Form

Project approval No. 721917-01

UNIVERSITY OF CALIFORNIA, SAN FRANCISCO
CONSENT TO ACT AS A RESEARCH SUBJECT

Olfactory Influences on Infant-Parent Recognition

Scientists have found that infants are able to identify their parents by odors and believe that this recognition may be important for later development. We would like to find out more about odor identification in humans and the types of odors involved. That is why we are asking you and your baby to help us with the following experiment.

1) I agree to participate in this study. Michael Russell will perform the following experimental procedures on myself and my infant.

2) The test will be done in my home with my baby in its crib or bed. A plastic device for holding odor samples will be placed near my baby in such a manner that the baby is able to smell two odors at a time. Russell will then observe the baby's response to the odors by watching which way the baby's head turns and how it responds.

3) My baby's responses will be recorded with a television camera so that the test can be analyzed later in the laboratory.

4) Confidentiality will be protected as far as possible by using a coding system to identify all data. When the videotapes of the tests are analyzed they will be erased. Our names will not appear in any publication resulting from this study without my consent.

5) The smells will either be my breast odors or my baby's saliva samples or a control sample. To obtain these samples I will :

a) Wash my breast with soap (provided by the project) and wear a breast pad inside my bra.

b) Feed my infant with water from a standard baby bottle which has been modified by attaching a piece of absorbent material on the rubber nipple.

6) If I have any comments about participation in this study, I should first talk with the investigator Dr. George Stone (415) 476-7407. If for some reason I do not wish to do this, I may contact the Committee on Human Research, which is concerned with protection of volunteers in research projects. I may reach the committee office between 8 and 5, Monday to Friday by calling (415) 476-1814, or by writing: Committee on Human Research, 116 Clinics Building, University of California, San Francisco, CA 94143.

7) I have received a copy of this consent form, and the study was explained to me by Michael Russell. He can be reached at (707) 762-1865.

8) Participation in research is voluntary. I have the right to refuse or to withdraw at any point in this study without jeopardy to my care. If I wish to participate I should sign this form.

Signature
for consent:_________________________________ Date____________

Print Name :_________________________________