Available online at www.sciencedirect.com
SCIENCE DIRECT®
European Journal of Obstetrics & Gynecology and Reproductive Biology xxx (2004) xxx–xxx
EUROPEAN JOURNAL OF OBSTETRICS & GYNECOLOGY AND REPRODUCTIVE BIOLOGY
www.elsevier.com/locate/ejogrb

Review

Human pheromones and sexual attraction

Karl Grammer[a], Bernhard Fink[a,*], Nick Neave[b]

[a]*Ludwig–Boltzmann-Institute for Urban Ethology, c/o Institute of Anthropology, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria*
[b]*Human Cognitive Neuroscience Unit, School of Psychology and Sport Sciences, Northumbria University, Newcastle upon Tyne, NE1 8ST, UK*

Received 30 April 2004; accepted 19 August 2004

Abstract

Olfactory communication is very common amongst animals, and since the discovery of an accessory olfactory system in humans, possible human olfactory communication has gained considerable scientific interest. The importance of the human sense of smell has by far been underestimated in the past. Humans and other primates have been regarded as primarily 'optical animals' with highly developed powers of vision but a relatively undeveloped sense of smell. In recent years this assumption has undergone major revision. Several studies indicate that humans indeed seem to use olfactory communication and are even able to produce and perceive certain pheromones; recent studies have found that pheromones may play an important role in the behavioural and reproduction biology of humans. In this article we review the present evidence of the effect of human pheromones and discuss the role of olfactory cues in human sexual behaviour.

Keywords: Pheromone; Human; Sexual attraction; Mate preferences; Menstrual cycle; Oral contraception

Contents

1. Introduction

The importance of pheromones in intra-species communication has long been known in insects. A classical example is bombykol, the sexual attractant of the butterfly *Bombyx mori*. Bombykol is produced by the female butterflies in odour glands of the abdomen. Male butterflies detect the pheromone with sensory cells, located in the antennae and can find the females by the gradient of her odour. As little as one molecule of bombykol is enough to stimulate the receptor cells and facilitate the orientation reaction. Several studies suggest that pheromones play an important role also in mammalian social behaviour and thus in humans as well.

* Corresponding author. Tel.: +43 1 4277 54769; fax: +43 1 4277 9547.
E-mail address: bernhard.fink@ieee.org (B. Fink).

0301-2115/$ – see front matter
doi:10.1016/j.ejogrb.2004.08.010

The present article reviews the current evidence how pheromones influence human life and interactions and discusses the consequences for human sexual attraction and mate-choice.

1.1. Smell

According to Kohl et al. [1] the sense of smell has largely been underestimated in reproductive behaviours and it has long been assumed that humans are 'microsmatic' (poor smellers) and rely essentially on visual and verbal cues when assessing potential mates. Certainly visual stimuli play a key role in the perceptions of others within a sociosexual context, especially at a distance, but when individuals get closer and personal intimacy is increased, it is likely that smell also plays a key role a variety of sociosexual behaviours. Recent studies have indeed suggested that olfaction (conscious and unconscious) can play a significant role in human reproductive biology. Zajonc's [2] 'affective primacy' hypothesis states that both positive and negative affect can be evoked with minimal stimulus input and only minor cognitive involvement. Olfactory signals induce emotional responses even if an olfactory stimulus is not consciously perceived: this is due to the fact that olfactory receptors not only send projections to the neocortex for conscious processing (e.g. the nature of a particular aroma) but also to the limbic system for emotional processing (e.g. memories and affect associated with a particular smell).

1.2. Pheromones

The term 'pheromone' was introduced by Karlson and Luscher [3] and it derives from the Greek words 'pherein' (to carry) and 'hormon' (to excite). Pheromones are referred to as 'ecto-hormones' as they are chemical messengers that are emitted into the environment from the body where they can then activate specific physiological or behavioural responses in other individuals of the same species. According to McClintock [4] pheromones can be divided into two classes. Firstly, 'signal pheromones' produce short-term behavioural changes and seem to act as attractants and repellents. Secondly, 'primer pheromones' produce longer-lasting changes in behaviour via their activation of the hypothalamic–pituitary–adrenal (HPA) axis [4]. In particular, it is assumed that primer pheromones trigger the secretion of GnRH from the hypothalamus, which in turn triggers the release of gonadotropins (LH, FSH) from the pituitary gland. These gonadotropins influence gonadal hormone secretion, e.g. follicle maturation in the ovaries in females, testosterone and sperm production in males. In support, in various species the short-term exposures of females to males have been associated with a corresponding rise in testosterone [5]. Four specific functions of pheromones have been determined: opposite-sex attractants, same-sex repellents, mother–infant bonding attractants and menstrual cycle modulators [6]. It is the first category that this review will focus upon though may draw upon evidence from the other categories wherever relevant.

1.3. Pheromone detection

In most mammals, a specialised region of the olfactory system called the vomeronasal organ (VNO), also referred to as 'Jacobson's organ' is responsible for pheromone detection. The principal evidence that the VNO plays a role in mammalian pheromone detection comes from lesion studies where removal of the VNO produces reliable impairments in reproductive behaviours [7]. The VNO is located above the hard palate on both sides of the nasal septum and it is lined with receptor cells whose axons project to the accessory olfactory bulb, which sends its projects to the hypothalamic nuclei [8]. Pheromones can thus potentially influence sexual and reproductive behaviours and endocrine function via the HPA axis [9]. There has been some scepticism concerning the ability of humans to detect and respond to pheromones due to the facts that VNO appears to vestigial in some primates, and the accessory olfactory bulb is not discernable in humans [9].

However, it has since been reported that humans do possess a functional VNO that responds to pheromones (even in picogram amounts) in a sex-specific manner [10–12]. Recently, the identification of a pheromone receptor gene expressed in human olfactory mucosa has further strengthened the case for a functioning VNO [13]. Further evidence comes from patients with Kallmann's syndrome, which occurs due to the underdevelopment of the olfactory bulb in the embryo and minimal GnRH secretions from the hypothalamus. Individuals have underdeveloped gonads, lack secondary sexual characteristics, are anosmic, and preliminary research indicates that they show no response to pheromones (personal communication cited in [1]).

1.4. Pheromone production

The main producers of human pheromones are the apocrine glands located in the axillae and pubic region. The high concentration of apocrine glands found in the armpits led to the term 'axillary organ', which is considered an independent 'organ' of human odour production. Apocrine glands develop in the embryo, but become functional only with the onset of puberty. At sexual maturation, they produce steroidal secretions derived from 16-androstenes (androstenone and androstenol) via testosterone, and as such, the concentrations of several 16-androstenes is significantly higher in males [14]. Freshly produced apocrine secretions are odourless but are transformed into the odorous androstenone and androstenol by aerobic coryeform bacteria [15]. In the vagina, aliphatic acids (referred to as copulins) are secreted and their odour varies with the menstrual cycle [16]. It is now possible to isolate

and manufacture synthetic human pheromones and such compounds are often used in research as they are relatively easy to make, convenient to store, and easy to apply.

1.5. Pheromone effects on animal reproductive behaviours

Preliminary studies in the 1960s demonstrated that exposure to boar odour elicited the mating stance in females. Subsequent experiments showed that application of male urine or semen to the female's snout also produced the same effect. Studies have appeared to demonstrate a number of confirmed effects of pheromones in animals. Firstly the 'Lee-Boot Effect' [17] describes the effects of the social environment on the female reproductive cycle. The authors noted that when female mice were housed 4 in a cage their oestrous cycles became synchronised and extended. Secondly, the 'Whitten effect' [18] confirmed that female mice housed together displayed an extended oestrous cycle, but further noted that when a male was introduced the females ovulated synchronously 3–4 days later. The substance was found to be androgen-based pheromones secreted in the male's urine.

Thirdly, the 'Bruce effect' [19] describes the effect of housing pregnant mice with males that were not their original mates. Within 48 h of such pairings, significantly more miscarriages were observed in the females. Subsequent mating with the new male within 3–6 days then always followed the failed pregnancy. The inclusion of castrated or juvenile male strangers had no such effects. This appears to be a male tactic of blocking the pregnancy by a previous male and bringing the female quickly into oestrous. Finally the 'Vandenburgh effect' [20] notes that young female rats exposed to adult males for 20 days after weaning entered puberty earlier than female pups not exposed to males. Male pheromones stimulate puberty, probably by releasing LH, which stimulates follicular growth, presumably so that they can mate earlier. A related effect was noted in that female mice housed alone attain puberty earlier than female mice housed together, females can thus delay puberty in their conspecifics, probably by suppressing LH and FSH release from the anterior pituitary gland.

1.6. Pheromones and human reproductive behaviours

Several authors have speculated that pheromones may influence human sociosexual behaviours (e.g. [21,22]) and evidence for the effects of putative pheromones on human sexual behaviours has come from several sources:

1. Human correlates of animal effects

   McClintock [23] reported that human female college students demonstrated synchrony in their menstrual cycles when housed in shared accommodation (Lee–Boot effect). Preti et al. [24] extended this research by applying extracts of female sweat to the upper lips of female volunteers three times per week for 4 months. At the end of this time the participants showed significantly greater menstrual synchrony than volunteers in a control group. Cutler et al. [25] also showed that the application of male axillary secretions to the upper lips of female volunteers also had a regulatory effect on the menstrual cycle (Whitten effect). Ellis and Garber [26] showed that girls in stepfather-present homes experienced faster puberty than girls in single-mother homes, the younger the daughter when the new male arrived on the scene then the earlier her pubertal maturation (Vandenburgh effect).
2. Laboratory studies

   In an early report, Kirk-Smith et al. [27] asked 12 male and female undergraduates to rate photographs of people, animals and buildings using 159-point bipolar scales (e.g. unattractive–attractive), while wearing surgical masks either impregnated with androstenol or left undoctored. Mood ratings were also completed. In the presence of androstenol, male and female stimuli were also rated as being 'warmer' and 'more friendly'. Van Toller et al. [28] showed that skin conductance in volunteers exposed to androstenone was higher than that of non-exposed volunteers thereby providing evidence as to the physiological effects of pheromone exposure. However, Benton and Wastell [29] had groups of females read either a neutral or a sexually arousing passage whilst exposed to either androstenol or a placebo substance. While sexual arousal was higher in the 'arousal' condition, the authors found no evidence that exposure to androstenol had influenced sexual feelings.

   Filsinger et al. [30] asked males and females to rate vignettes of a fictional target male and female using semantic differentials, and also to provide a self-assessment of mood. The test materials had been sealed into plastic bags, which were either impregnated with androstenol, androstenone, a synthetic musk control, and a no-odour control. Females exposed to androstenone produced lower sexual attractiveness ratings of the target male, while males exposed to androstenol perceived the male targets to be more sexually attractive.

   The interpretation from such studies is further complicated by two factors. Firstly, female olfactory sensitivity is moderated by the menstrual cycle with smell sensitivity peaking at ovulation [31]. Benton [32] reported that androstenol application influenced ratings of subjective mood at ovulation, and Grammer [21] found that females rated androstenone differently at various phases of their menstrual cycle. Secondly, the use of oral contraception may affect smell sensitivity and gonadal hormone levels thereby possibly disrupting pheromone detection. Use of the contraceptive pill does indeed appear to influence female perception of androstenone [21].

   More recently Thorne et al. [33] employed a repeated-measures, double blind, balanced crossover design to assess the possible influence of menstrual cycle phase

and contraceptive pill use. Sixteen pill and non-pill users were tested during both menses and mid-cycle in both pheromone-present and pheromone-absent conditions. During each session (four in all) the volunteers rated male vignette characters, and photographs of male faces, on various aspects of attractiveness. Pheromone exposure resulted in significantly higher attractiveness ratings of vignette characters, and faces. Use of the contraceptive pill or menstrual cycle phase had equivocal effects on some vignette items but neither had any influence on female ratings of male facial attractiveness.

Not all laboratory studies have found positive results however (e.g. [34]), and some authors are sceptical that higher primate reproductive behaviours are significantly influenced by pheromones [35]. Thus, while the current scientific opinion regarding the existence of human pheromones remains positive, opinion remains divided as to whether such substances do in fact influence human sociosexual behaviours. This is probably due to the fact that while a wealth of laboratory-based studies has been conducted, very different methodologies mean that comparisons between studies are difficult. Furthermore, methodologically solid double blind, placebo-controlled, crossover studies are few and far between, the Thorne et al. [33] study being an exception. However, that study was laboratory based and simply required participants to rate the attractiveness of hypothetical opposite-sex characters based on written descriptions and photographs. The ecological validity of such laboratory-based studies is therefore questionable.

3. Real-life studies

While laboratory studies are able to exert more control over the varying factors involved, of potential greater relevance are studies assessing the effects of pheromones in real-life situations. Early studies were, however, not promising. For example, Morris and Udry [36] prepared aliphatic acid smears, formulated to mimic concentrations shown to be effective in enhancing monkey reproductive behaviour. The solution was smeared on the chests of 62 married women on eight randomly assigned nights through three menstrual cycles. Volunteers did not report any increase in sexual intercourse on these test nights. However, Cowley and Brooksbank [37] asked males and females to wear a necklace either containing an opposite-sex pheromone or a control substance while they slept. The next day, they found that women who had worn the male pheromones in their necklace reported significantly more interactions with males than the control group.

Two studies which have often been cited as the strongest evidence yet provided for the influence of pheromones on human sociosexual behaviour are those of Cutler et al. [38] and McCoy and Pitino [39]. Both studies employed double blind, placebo-controlled methods and focussed upon the effects of synthetic pheromones on self-reported sociosexual behaviours in young men [38] and women [39]. In the first study [38] 38 male volunteers recorded the occurrence of six socio-sexual behaviours (petting/affection/kissing; formal dates; informal dates; sleeping next to a partner; sexual intercourse; and masturbation) over a 2-week 'baseline' period. Over the next 6 weeks the volunteers kept the same records while daily applying a male pheromone or a control substance added to their usual aftershave lotion. The authors reported that a significantly higher proportion of pheromone users compared to placebo users showed an increase from baseline in 'sexual intercourse' and 'sleeping next to a romantic partner'. In general 58% of the pheromone group compared to 19% of the placebo group showed increases in two or more behaviours compared to baseline; 41% of the pheromone group compared to 9.5% of the placebo group showed increases in three or more behaviours compared to baseline.

In the second study [39] 36 female volunteers recorded the occurrence of the same six socio-sexual behaviours and an additional behaviour 'male approaches' over a 2-week 'baseline' period. Over the next 6 weeks they then either applied a synthetic female pheromone or a control substance added to their usual perfume on a daily basis. While the groups did not differ in their sociosexual behaviours at baseline, a significantly higher proportion of the pheromone group showed increases in the following behaviours: 'sexual intercourse', 'sleeping next to a partner', 'formal dates' and 'petting/affection/kissing'. However, as pheromone exposure can shift the timing of ovulation, the authors recalculated the data to only include the first experimental cycle. After these recalculations the pheromone group only significantly differed from the placebo group in 'sexual intercourse' and 'formal dating'. In terms of percentages, three or more sociosexual behaviours increased over baseline in 74% of pheromone users but only 23% of placebo users. As there was no increase in self-reported masturbation the authors argued that the changes did not reflect changes in sexual motivation, but that the pheromones had ''positive sexual attractant effects...'' (p. 374).

The results of these studies appear to provide impressive evidence for the effects of synthetic pheromones on sexual attractiveness. However, there are a number of methodological problems with the studies, which make the findings less emphatic. Firstly, the studies did not control for the attractiveness of the volunteers nor make allowance for this when allocating the conditions. If for example the pheromone groups had contained slightly more attractive individuals than the control groups, then subsequent positive effects attributed to pheromones may be misleading. Secondly, all the data were of the self-report kind (prone to error and subjective bias especially as 'backfilling' was allowed in the second study) and as such no objective record of the putative effects of pheromone versus placebo were obtained. Thirdly the groups differed widely in terms of

their dating status with some being married, some in long-term relationships and others being single. Those in relationships would have certainly recorded more of certain sociosexual behaviours than the single volunteers, it would have been better if the entire subject pool were single males seeking more dating/sex opportunities. Fourthly, the baseline period of 2 weeks is difficult to equate with a testing period of 6 weeks even though average differences from baseline were analysed. How can we be sure that the social behaviour of the volunteers changed not as a result of pheromone exposure but by other factors during the experimental period, e.g. going on holiday, celebrating at an office party? While the actual behaviours were recorded, the context within which those behaviours occurred was not controlled for.

The evidence from these two studies thus indicates that certain sociosexual behaviours are increased in males and females who wear pheromones, compared to baseline. However, the studies do not convincingly show that the pheromone and placebo groups were well matched; that the baseline and experimental conditions were matched in terms of various temporal and behavioural factors; that objective changes in sociosexual behaviours did occur; and that the pheromones served as a 'sexual attractants' rather than say a mood enhancer, confidence builder, etc.

4. Genetic signalling

Various 'good genes' theories of sexual selection have emphasised the importance of immunocompetence [40,41] in that females can obtain good genes for their offspring by mating with males whose genes are complementary to their own. A possible mechanism by which this can be achieved is via body odour. The major histocompatibility complex (MHC) is a large chromosomal region containing closely linked polymorphic genes that play a role in immunological self/non-self recognition; this genetic information is relayed by androgen-based pheromones [42]. Numerous studies in rodents have now established that MHC genotype is involved in odour production, and such odours are used in individual discrimination [43]. House mice learn the MHC identity of their family during development and avoid mating with individuals carrying familial MHC genes; they do so through the use of odour cues from urine (e.g. [44,45]). Is there any evidence that humans possess these abilities?

Some studies have shown that women seem to prefer the odours of immunocompatible men. Wedekind et al. [46] HLA-typed (Human Leukocyte Antigen is the human MHC) 49 women and 44 men and asked the women to rate the attractiveness of the odours of t-shirts worn by three MHC-similar and three MHC-dissimilar men. Women rated the odour of the MHC-dissimilar men as 'more pleasant', and this odour was significantly more likely to remind them of their own mate's odour. Interestingly, the preferences of women taking an oral contraceptive were reversed—they preferred the MHC-similar odours. This could be due to the fact that oral contraceptives mimic the effects of pregnancy, and pregnant females may be attracted to MHC-similar individuals who are likely to be close kin and potential reproductive helpers.

In a similar study, Thornhill and Gangstad [47] measured bilateral physical traits in males and females and then asked the volunteers to wear the same T-shirt for two consecutive nights. Opposite-sex participants then rated the shirts for 'pleasantness', 'sexiness' and 'intensity'; donor's facial attractiveness was also assessed by different opposite-sex volunteers. Non-pill users in the fertile phase of their menstrual cycle gave the T-shirts worn by symmetrical males higher ratings; this was not seen in females using the contraceptive pill, or in females at unfertile phases of their cycle. Female symmetry had no influence on male ratings. The authors proposed that the so-called 'scent of symmetry' is an honest indicator of male genetic quality.

In a real-life study of actual mate choices, Ober et al. [48] found evidence for HLA-dependent mate preferences in a population of Hutterites (a small, genetically isolated religious sect). They found that couples were less likely to share MHC haplotypes than chance, and in couples that had a similar MHC they demonstrated unusually long inter-birth intervals (unconscious avoidance of inbreeding?).

Milinski and Wedekind [49] HLA-typed males and females and then asked them to smell 36 scents commonly used in perfume/aftershave. They rated each scent on whether they liked it or not, and whether they would use it on themselves. The authors reported a significant correlation between HLA and scent scoring for themselves but not for others, showing the people unconsciously select perfumes to enhance their own body odours that reveal their genetic make-up.

1.7. Pheromones and the battle of the sexes

Differential parental investment theory [50] predicts that when looking for long-term relationships females should seek out and choose males who are ready to invest resources in their offspring. This minimizes female investment, but maximizes overall investment through added male assistance. In contrast, males are expected either to attempt copulation frequently and with as many fertile females as possible, or to develop a long-term pair bond. This helps to ensure that either a large number of offspring survive without significant paternal investment, or that male parental investment occurs primarily when another male does not father offspring.

According to this theory, it is adaptive for females and males to develop and use cognition in mate selection, which takes into account biological constraints. Thus, mate selection is a task of information processing, and evolution

would have favoured individuals who were able to quickly and reliably process information that allowed them to make appropriate mating decisions. Adaptive cognition could be expected to lead to optimal decision-making under a wide spectrum of socio-economic constraints. The existence of ubiquitous sex specific differences in mate selection criteria [51] attests that male and female cognition is adapted to the biological constraints of mate selection.

Neither males nor females can perceive ovulation in humans consciously. This is surprising in the light of the fact that it has been shown to be associated with a number of overt physiological and behavioural changes. One 'unconscious' mechanism associated with these menstrual cycle changes might be that of olfactory perceptions.

Alexander and Noonan [52], and Symons [53] have argued that hidden oestrous has evolved because females need to trick males into forming a bond. Males unaware of female' s fertility would remain bonded to ensure impregnation and paternity. A female providing clues to her ovulation might risk losing male investment, due to paternal uncertainty and the limited temporal reproductive interaction. This development would implicate the male fear of cuckoldry as an evolutionary pressure [50]. The outcome would be that the female's ability to secure paternal care is affected by mechanisms that increase temporal aspects of the pair bond and enhance male confidence of paternity.

In contrast with this line of argument, Benshoff and Thornhill [54] and Symons [53] have proposed a second evolutionary scenario in which hidden oestrous evolved to increase the chances of successful cuckoldry by females so they ''can escape the negative consequences of being pawns in marriage games'' ([55] p. 350). Once monogamy is established, a female's best strategy would be to copulate outside the pair bond because she can then obtain superior genes with a certain expectation of paternal investment. In this case the outcome is genetically superior offspring.

These two hypotheses imply different impacts of heritable traits. If those genes which induce paternal care were relevant for offspring success, a male paternity-securing function for lost oestrous would be possible. If there are other relevant traits not related to paternal care but relevant to offspring survival, then hidden oestrous could allow females to exploit occasional opportunities to mate outside the pair bond [56]. In both cases, male knowledge of ovulation may be selected against because it would hinder the female's mating strategies [52,57].

Recently, the second hypothesis has received considerable support. Bellis and Baker [58] conducted a study of 2708 females and found those 13.8% of 145 'unprotected' extra-pair copulations (EPC) occurred during the fertile period and were preceded in most cases by intra-pair copulations (IPC). EPCs were rarely followed by IPCs. According to his study EPC and thus female infidelity peaks at ovulation. The authors conclude that these results hint at female-induced sperm competition, which would be expected by the second hypothesis of the evolutionary function of concealed ovulation discussed above. Still it is unclear what proximate mechanism or mechanisms cue female EPC at ovulation. The assumption that concealed ovulation serves to deceive males is common to all these theories. Supposedly, females deceive males about the fertile phase of the menstrual cycle to help ensure male parental investment, which yields an optimal number of offspring. Additionally, concealed ovulation helps females to monopolize reproduction and, as a consequence, forces males to develop reproductive strategies for gaining access to ovulating females. It is reasonable to expect male counter strategies would develop against the deceptive attempt by females to conceal ovulation. Grammer [21] described a possible male counter strategy: the evolution of the androstenone–androstenol signalling system. In his study, 290 female subjects rated the odour of androstenone. A change in assessment throughout the menstrual cycle was found: at the time of ovulation the women found the scent of androstenone, the most dominant odour of the male armpit, to be more pleasant than on the other days of the menstrual cycle. These results suggest that there is a change in the emotional evaluation of males triggered by the reaction to androstenone. The findings support previous results by Maiworm [59], which were of borderline significance. Male body odour is usually perceived as unattractive and unpleasant by females but this evaluation changes at the point in the menstrual cycle when conception is most likely. This finding is underlined by the fact that anosmia to androstenone also varies with cycle. At the conceptual optimum we find fewer anosmic females. It could be suggested that changes in anosmia during the cycle could also be a female strategy, although more data need to be gathered to prove this hypothesis. Thus the change in female attitudes towards male body odour could have a strong impact on mate selection and perhaps self-initiated copulations by females. If we regard the androstenol–androstenone-signaling system, the situation for androstenol seems clear, it makes males more attractive for females. Female advantage in this case is nil, unless fitter males produce more androstenol. The situation is more complicated because producing androstenol inevitably produces androstenone. The androstenone production has a disadvantage in its unpleasantness. Hence attractiveness-enhancing androstenol immediately oxidizes to androstenone, which repels females. A non-producing male could do quite well in a population of producers, because females would not be repelled by his body odour. So the attractiveness-enhancing component of the smell does not seem to be the main, or at least only, function of the signalling system. Regarding androstenone, the fact that females assessed its odour as more pleasant at the time of ovulation could be of advantage for males, as odorous males will be more successful when approaching ovulating females, rather than non-ovulating females. This suggests that males use a kind of passive 'ovulation-radar' for the detection of the actually hidden ovulation.

Females faced with an evolved male strategy to detect hidden ovulation would be likely to develop a counter strategy. One possible strategy could be to manipulate male cognition and thus adaptive male information processing in mate selection. Research on many species of non-human primates (especially on rhesus monkeys) has shown the ability to perceive ovulation by smell. Although normally motivated to copulate, when sexually inexperienced rhesus males were made anosmic they showed no further sexual motivation despite a powerful visual cue: the female's swelling [60]. Furthermore, rhesus males show no interest in ovariectomized rhesus females, presumably because ovariectomized rhesus females lose the odour characteristic of ovulation. Rhesus males regain interest in copulation when the vaginal secretions from non-ovariectomized females are applied to ovariectomized females. Studies on menstrual cycle fluctuations in the fatty-acid composition of women's vaginal fluids indicated that a similar type of signalling system might also exist in humans [16, 61–63]. For example, human vaginal secretions have a composition that is similar to the vaginal secretions of female rhesus monkeys. The application to ovariectomized female rhesus monkeys, either of human, or rhesus vaginal secretions, induced similar activation of rhesus male sexual interest [64].

The behaviourally active fraction of the rhesus vaginal secretions—referred to as 'Copulins'—consists of volatile, short-chained fatty acids [65]. These same substances (i.e., the short-chained fatty acids: acetic, propanoic, butanoic, methylpropanoic, methylbutanoic, methylpentanoic acid) occur in human vaginal secretions, albeit in slightly different amounts [16]. In addition, the composition of these copulins varies during the menstrual cycle [62].

Cowley et al. [66] found that rhesus vaginal secretions change peoples' assessment of other people, and that the application of copulins tends to yield a more positive impression of females. Doty et al. [67] used a questionnaire to evaluate the intensity and pleasantness of different vaginal fluids from a complete menstrual cycle. They found that odour at ovulation was both the most intense odour and the least unpleasant.

In a study by Juette (unpublished data) synthesized female vaginal secretions ('Copulins') were tested for their ability to act as signals for males. Menstrual, ovulatory and pre-menstrual fatty acid compositions of Copulins and an odourless water control were presented to 60 non-smoking male subjects for 25 min in a double-blind experiment. To control for changes in sex hormones that were induced by copulins, saliva-samples were taken before and after presentation. While inhaling either a composition of copulins or a control, males rated pictures of females for attractiveness. It was shown that ovulatory fatty acid compositions stimulated male androgen secretion and changed the discriminatory cognitive capacities of males with regard to female attractiveness in that males became less discriminating. As we can learn from the above examples, human pheromones seem to work as beautifully balanced 'strategic weapons' in the 'battle of the sexes' and the 'war of signals' resulting from asymmetric investment theory.

2. Conclusion

As we can learn from the reviewed studies on pheromones, the model of humans being only optical animals has to be revised. Human sociosexual interactions are influenced by pheromones, even if they cannot be detected consciously. Pheromones have the potential to influence human behaviour and physiology and so there has to be asked the question, in which way the modern striving for cleanliness and odourlessness affects our everyday social lives and human reproductive success in the future. What we know at the moment, as many studies in the last few years have pointed out, is that the human sense of smell has by far been underestimated in the past and that humans, like other animals, use olfactory signals for the transmission of biologically relevant information.

References

[1] Kohl JV, Atzmueller M, Fink B, Grammer K. Human pheromones: integrating neuroendocrinology and ethology. Neuroendocrinol Lett 2001;22:309–21.
[2] Zajonc RB. Feeling and thinking: preferences need no inferences. Am Psychol 1980;35:151–75.
[3] Karlson P, Luscher M. 'Pheromones': a new term for a class of biologically active substances. Nature 1959;183:55–6.
[4] McClintock MK. Human pheromones: primers, releasers, signallers or modulators? In: Wallen K, Schneider E, editors. Reproduction in context. Cambridge, MA: MIT Press; 2000. p. 335–420.
[5] Graham JM, Desjardins C. Classical conditioning: induction of luteinizing hormone and testosterone secretion in anticipation of sexual activity. Science 1980;210:1039–41.
[6] Cutler WB. Human sex-attractant pheromones: discovery, research, development, and application in sex therapy. Psychiat Ann 1999;29:54–9.
[7] Wysocki CJ, Lepri JJ. Consequences of removing the vomeronasal organ. J Steroid Biochem Mol Biol 1991;39:661–9.
[8] Tirindelli R, Mucignat-Caretta C, Ryba NJP. Molecular aspects of pheromonal communication via the vomeronasal organ of mammals. Trends Neurosci 1998;21:482–6.
[9] Halpern M. The organization and function of the vomeronasal system. Ann Rev Neurosci 1987;10:325–62.
[10] Monti-Bloch L, Jennings-White C, Berliner DL. The human vomeronasal system: a review. Ann N Y Acad Sci Nov 30 1998;855:373–89.
[11] Smith TD, Siegel MI, Mooney MP, Burdi AR, Fabrizio PA, Clemente FR. Searching for the vomeronasal organ of adult humans: preliminary findings on location, structure, and size. Microsc Res Tech 1998;41:483–91.
[12] Grosser BI, Monti-Bloch L, Jennings-White C, Berliner DL. Behavioural and electrophysiological effects of androstadienone, a human pheromone. Psychoneuroendocrinology 2000;25:289–99.
[13] Rodriguez I, Greer CA, Mok MY, Mombaerts P. A putative pheromone receptor gene expressed in human olfactory mucosa. Nat Genet 2000;26:18–9.

[14] Brooksbank BWL, Wilson DAA, MacSweeney DA. Fate of androsta-4, 16-dien-3-one and the origin of 3α-hydroxy-5α-androst-16-ene in man. J Endocrinol 1972;52:239–51.
[15] Gower DB, Ruparelia BA. Olfaction in humans with special reference to odourous 16-androstenes: their occurrence, perception and possible social, psychological and sexual impact. J Endocrinol 1993;137:167–87.
[16] Michael RP, Bonsall RW, Kutner M. Volatile fatty acids, 'Copulins', in human vaginal secretions. Psychoneuroendocrinol 1975;1:153–62.
[17] van der Lee S, Boot LM. Spontaneous pseudopregnancy in mice. Acta Physiol Pharmacol Nee 1955;4:442–3.
[18] Whitten WK. Modification of the estrous cycle of the mouse by external stimuli associated with the male. J Endocrinol 1956;13: 399–404.
[19] Bruce HM. An exteroceptive block to pregnancy in the mouse. Nature 1959;184:105.
[20] Vandenburgh JG. Effect of the presence of the male on the sexual maturation of female mice. Endocrinology 1967;81:345–9.
[21] Grammer K. 5-α-androst-16en-3α-on: a male pheromone? A brief report Ethol Sociobiol 1993;14:201–8.
[22] Miller EM. The pheromone androstenol: evolutionary considerations. Mankind Q 1999;39:455–67.
[23] McClintock MK. Menstrual synchrony and suppression. Nature 1971;229:244–5.
[24] Preti G, Cutler WB, Garcia CR, Krieger A, Huggins GR, Lawley HJ. Human axillary secretions influence women's menstrual cycles: the role of donor extracts of females. Horm Behav 1986;20:474–82.
[25] Cutler WB, Preti G, Krieger A, Huggins GR, Garcia CR, Lawley HJ. Human axillary secretions influence women's menstrual cycles: the role of donor extracts from men. Horm Behav 1986;20:463–73.
[26] Ellis BJ, Garber J. Psychosocial antecedents in variation in girls' pubertal timing: maternal depression, stepfather presence, and marital and family stress. Child Dev 2000;71:485–501.
[27] Kirk-Smith M, Booth MA, Carroll D, Davies P. Human social attitudes affected by androstenol. Res Comm Psych Psychiat Behav 1978;3:379–84.
[28] Van Toller C, Kirk-Smith M, Lombard J, Dodd GH. Skin conductance and subjective assessments associated with the odour of 5α-androstan-3-one. Biol Psychol 1983;16:85–107.
[29] Benton D, Wastell V. Effects of androstenol on human sexual arousal. Biol Psychol 1986;22:141–7.
[30] Filsinger EE, Braun JJ, Monte WC. An examination of the effects of putative pheromones on human judgements. Ethol Sociobiol 1985;6:227–36.
[31] Doty RL, Snyder PJ, Huggins GR, Lowry LD. Endocrine, cardiovascular, and psychological correlates of olfactory sensitivity changes during the human menstrual cycle. J Comp Physiol Psychol 1981;95:45–60.
[32] Benton D. The influence of androstenol, a putative human pheromone—on mood throughout the menstrual cycle. Biol Psychol 1982;15:249–56.
[33] Thorne F, Neave N, Scholey A, Moss M, Fink B. Effects of putative male pheromones on female ratings of male attractiveness: influence of oral contraception and the menstrual cycle. Neuroendocrinol Lett 2002;23:291–7.
[34] Black SL, Biron C. Androstenol as a human pheromone: no effect on perceived attractiveness. Behav Neural Biol 1982;34:326–30.
[35] Rogel MJ. A critical examination of the possibility of higher prinmate reproductive and sexual pheromones. Psych Bull 1978;85:810–30.
[36] Morris NM, Udry J. Pheromonal influences on human sexual behaviour: an experimental search. J Biosocial Sci 1978;10:147–57.
[37] Cowley JJ, Brooksbank BWL. Human exposure to putative pheromones and changes in aspects of social behaviour. J Steroid Biochem Mol Biol 1991;39:647–59.
[38] Cutler WB, Friedmann E, McCoy NL. Pheromonal influences on sociosexual behaviour in men. Arch Sex Behav 1998;27:1–13.
[39] McCoy NL, Pitino L. Pheromonal influences on sociosexual behaviour in young women. Physiol Behav 2002;75:367–75.
[40] Hamilton WD, Zuk M. Heritable true fitness and bright birds: a role for parasites. Science 1982;218:384–7.
[41] Folstad I, Karter AJ. Parasites, bright males, and the immunocompetence handicap. Am Nat 1992;139:603–22.
[42] Jordan WC, Bruford MW. New perspectives on mate choice and the MHC. Heredity 1998;81:239–45.
[43] Hurst JL, Payne CE, Nevison CM, Marie AD, Humphries RE, Robertson DHL. et al. Individual recognition in mice mediated by major urinary proteins. Nature 2001;414:631–4.
[44] Alberts SC, Ober C. Genetic variability of the MHC: a review of non-pathogen-mediated selective mechanisms. Yb Phys Anthropol 1993;36:71–89.
[45] Brown JL, Eklund A. Kin recognition and the major histocompatibility complex: an integrative review. Am Nat 1994;143:435–61.
[46] Wedekind C, Seebeck T, Bettens F, Paepke AJ. MHC-dependent mate preferences in humans. Proc R Soc Lond B 1995;260:245–9.
[47] Thornhill R, Gangstad SW. The scent of symmetry: a human sex pheromone that signals fitness? Evol Hum Behav 1999;20:175–201.
[48] Ober C, Weitkamp LR, Cox N, Dytch H, Kostyu D, Elias S. HLA and mate choice in humans. Am J Hum Genet 1997;61:497–504.
[49] Milinkski M, Wedekind C. Evidence for MHC-correlated perfume preferences in humans. Behav Ecol 2001;12:140–9.
[50] Trivers RL. Parental investment and sexual selection. In: Campbell B, editor. Sexual selection and the descent of man 1871–1971. Chicago: Aldine; 1972. p. 136.
[51] Buss DM. Sex differences in human mate preferences—evolutionary hypothesis tested in 37 cultures. Behav Brain Sci 1989;12:1–49.
[52] Alexander RD, Noonan KM. Concealment of ovulation, parental care, and human social evolution. In: Chagnon NA, Irons WG, editors. Evolutionary biology and human social behavior. Scituate: North Duxbury Press; 1979.
[53] Symons D. The evolution of human sexuality. Oxford: Oxford University Press; 1979.
[54] Benshoof L, Thornhill R. The evolution of monogamy and concealed ovulation in humans. J Soc Biol Struct 1979;2:95–106.
[55] Gray JP, Wolfe LD. Human female sexual cycles and the concealment of ovulation problem. J Soc Biol Struc 1983;6:345–52.
[56] Strassman B. Sexual selection, paternal care, and concealed ovulation in humans. Ethol Sociobiol 1981;2:31–40.
[57] Daniels D. The evolution of concealed ovulation and self-deception. Ethol Sociobiol 1983;4:87–96.
[58] Bellis MA, Baker RR. Do females promote sperm-competition? Data for humans Anim Behav 1991;40(5):997–9.
[59] Maiworm RE. Influence of androstenone, androstenol, menstrual cycle, and oral contraceptives on the attractivity ratings of female probands. Paper presented at the 9th Congress of ECRO; 1990.
[60] Michael RP, Keverne EB. Pheromones in the communication of sexual status in primates. Nature 1968;218:746–9.
[61] Michael RP, Bonsall RW, Warner P. Human vaginal secretions: volatile fatty acid content. Science 1974;186:1217–9.
[62] Preti G, Huggins GR. Cyclical changes in volatile acidic metabolites of human vaginal secretions and their relation to ovulation. J Chem Ecol 1975;1(3):361–76.
[63] Waltman R, Tricom V, Wilson Jr GE, Lewin AH, Goldberg NL, Chang MMY. Volatile fatty acids in vaginal secretions: human pheromones? Lancet 1973;2:496.
[64] Michael RP. Determinants of primate reproductive behavior. Acta endocrinol 1972;166(Suppl.):322–61.
[65] Curtis RF, Ballantine JA, Keverne EB, Bonsall RW, Michael RP. Identification of primate sexual pheromones and the properties of synthetic attractants. Nature 1971;232:396–8.
[66] Cowley JJ, Johnson AL, Brooksbank BWL. The effect of two odorous compounds on performance in an assessment-of-people test. Psychoneuroendocrinology 1977;2:159–72.
[67] Doty RL, Ford M, Preti G. Changes in the intensity and pleasentness of human vaginal odors during the menstrual cycle. Science 1975;190:1316–8.