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Chapter 3

THE EFFECT OF DIET ON HUMAN BODILY ODORS

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ABSTRACT

One of the most underestimated and poorly understood aspects of diet is its influence on human body odor. Humans have a distinct odor signature which arises from a combination of genetic and environmental factors. The link between genes and body odor is well appreciated, and an understanding of the influences of environmental factors such as emotional state, reproductive phase, and health status, is underway. Research into the impact of diet upon bodily odors, however, has been somewhat neglected. A recent study found that consumption of red meat for a period of two weeks decreased the pleasantness and increased the intensity of male axillary odor when judged by opposite-sex raters. Changes in bodily odors have also been linked to the consumption of food such as soya beans, plants from the *Alliaceae* or *Brassicaceae* families, strongly-flavored spices, fish, and milk-based products. This chapter critically reviews the literature on various aspects of food influencing human body odor and suggests several avenues for future research.

INTRODUCTION

It is a widely acknowledged fact that human eating habits affect physical appearance and attractiveness. As appearance has a bearing on human relations, diet may be relevant to social interactions, albeit indirectly. However, eating habits may modify not only human visual appearance, but also, and more directly, human olfactory qualities. Although odor is probably the least understood of the senses, human bodily odor may well be influential within human social interaction. Individual body odor profiles are thought to be fairly stable across time [1], and these odor profiles may impact upon human partner choice [2-5] and familial recognition [1, 6, 7]; specific odors of bodily origin may also have even more direct influences on human

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behavior [8-10]. In spite of this, researchers have paid only limited attention to the effects of eating habits on bodily odors. The aim of this chapter is to review our current knowledge on how various components of food influence human bodily odors and to show directions for future research. We will start with a short introduction of the sources and physiology of non-dietetic body odor, then continue with a more detailed analysis of dietetic factors.

Odor Sources in the Human Body

General human body odor originates from body parts such as the axilla, scalp, mouth and lungs, genital and anal regions, feet etc. Skin is colonized by a number of bacteria and eukaryotic *Malassezia*; their metabolic activity on either exfoliating skin cells or chemicals produced in the skin glands results in external body odor [11]. Skin glands are categorized as three different types: sebaceous glands, eccrine glands and apocrine glands [12]. Sebaceous glands produce oily chemicals whose main function is to protect the skin from environmental stress. The main function of the eccrine glands is perspiration. They produce mostly water, salts and some amino acids, although the actual amount and composition varies according to physical activity, environmental temperature, hydration levels, etc. Under normal conditions, neither sebaceous nor eccrine glands have a large impact upon body odor; rather, this is left to the apocrine glands, which are mainly concentrated in the face, genital region and, in particular, the armpits. These glands produce short chain fatty acids and androstene steroids together with other compounds. Fresh apocrine gland secretions are milky in color and odorless; the smell itself results from bacterial activity. Armpit bacteria include coryneforms, propionibacteria and micrococci [13].

Genetic Factors

Human body odor is specific to each individual and thus has been characterized as an "odor signature" [6, 14], shaped in part by genetic factors. Genetic influences have been demonstrated in twin experiments, where both humans and dogs can detect the similarity in the body odor of twins, even when they live apart [15, 16]. Other studies show that the body odor of parents and offspring or individual siblings can be matched at better-than-chance levels by individuals not acquainted with the body odor donors [17]. Further, research on body odor attractiveness has found that it is influenced by genes of the Major Histocompatibility Complex or MHC [2, 18]. This is a highly variable gene complex whose products play a crucial role in the immune response. Across species, there is evidence that individuals tend to prefer mates whose MHC genes differ from their own; MHC-based mate choice may derive from odor cues [19, 20].

Environmental Factors

Environmental influences on bodily odor include 1) emotional state, 2) reproductive status, 3) health and 4) diet; for a review, see [21]. The results of several studies suggest that emotional states such as fear or happiness can be perceived by others through the medium of smell. Most of these studies are based on emotions induced by comedies or horror movies while the target individuals wear cotton pads in their armpits to collect odor samples [22, 23]. Individuals not acquainted with the targets are able to distinguish happiness and fear on the basis of the odor at levels greater than chance.

Although ovulation in humans is not apparent in the same way as in some other primates [24], recent evidence shows that female body odor fluctuates across the menstrual cycle, becoming most attractive around the time of ovulation [25, 26]. These changes are not restricted to axillary odor but have also been observed in vaginal smells [27]. Axillary odor changes were not found in women taking oral contraceptives, suggesting that the changes are under the control of steroid hormones [25].

Various diseases are accompanied by a distinctive smell, a fact acknowledged by ancient physicians for diagnostic purposes. Some genetic disorders cause changes in metabolic pathways due to the absence or scarcity of a particular enzyme. This may result in a distinctive smell caused by a specific by-product or its metabolites. An example of such a disorder would be trimethylaminuria, the inability to transform trimethylamine to trimethylamine *N*-oxide [28]. The ingestion in particular of choline-containing food by affected individuals can result in the excess, unmetabolised trimethylamine being excreted in breath, urine and sweat, giving rise to an unpleasant smell which, in extreme cases, is similar to that of decomposing fish. Various infectious diseases can also cause changes in the bodily odor of the patient. This smell is mostly caused by the metabolic activity of the infectious agent and/or by the immune response. For instance, skin diseases such as wounds or ulcers are accompanied by a distinctive foul smell [29].

EFFECT OF DIET

Healthy human body odor is also affected by diet. The first observations of the effects of food on odor were carried out in rodents. Beauchamp [30] found that female guinea pigs preferred the odor of male guinea pigs fed on a diet designed for guinea pigs over that of guinea pigs fed on a diet for laboratory rats. More recently, it was shown in meadow voles that scents from the anogenital marks, feces and urine of males fed with lower protein portions were smelled by females for a shorter time (i.e. demonstrating lower mating interest) than were the scents of males fed on a high protein diet [31]. A further study by the same team investigated the effect of food deprivation on body odor attractiveness in meadow voles and found that the odors of females deprived for 24h were found less attractive. 48h after they were re-fed they became as attractive as at baseline [32]. The effect of diet-related odors is not restricted to mammalian species, but has also been found to influence odor preferences in fish. More specifically, juvenile Arctic charr (*Salvelinus alpinus*) prefer siblings on the same diet over those on different diets [33].

Although the rodent studies neatly demonstrate the principle of dietary influence on odor, their direct relevance to humans is questionable, as the main source of rodent chemical communication is urine, where metabolites from digested food can be directly detected. In contrast, in humans, the most significant source of body odor is probably the armpit region; urine is of minor relevance.

A demonstration of the general effect of diet on human bodily odor was made in the 1970s by Wallace who found that human smellers could distinguish monozygotic twins from their hand odors only if the twins consumed different diets [34]. Similarly, dogs cannot discriminate infants on the same (breast- or bottle-fed) diet [15]. Researchers in human body odor studies tend to ask their subjects to avoid specific foods thought to affect body odor, including garlic, onion, chilies, pepper, vinegar, blue cheese, cabbage, radish, fermented milk products and marinated fish [35-37], yet this list is based more on everyday experience than on experimental data. In fact, our knowledge of the effect of specific foods on human bodily odors is highly limited. Below, we are going to review both the direct and indirect evidence on this issue.

One source of bodily odors derives from the digestive processes themselves. Gas is produced within the digestive system by the action of bacteria on endogenous sources such as intestinal mucins and on dietary material which has not been digested in the small intestine [38]. This consists mainly of dietary fiber and complex polysaccharides, as are found in relatively large quantities in legumes such as soya and other beans [39]. These gases eventually emerge as flatus. A large portion of flatus consists of non-odorous gases such as oxygen, nitrogen, carbon dioxide, hydrogen and methane [40]. Flatus malodor is associated with sulphurous gases; one study that provoked flatulence by the consumption of pinto beans and lactulose found that concentrations of hydrogen sulphide, whose odor is reminiscent of rotten eggs, was most strongly correlated with flatus malodor, and that methanethiol, smelling of decomposing vegetables, probably also contributed [40]. Foods containing particularly high levels of sulphur include some breads, dried fruits, brassicas such as broccoli and cabbage, and soya flour [41].

There are also aromatic foods of plant origin that impact upon bodily odors. The distinctive post-ingestive malodor of plants from the *Alliaceae* family, including garlic and onion, is associated with various sulphurous gases such as allyl methyl sulfide [42]. The consumption of garlic, particularly raw garlic, affects breath odor [43], and gives rise to reports of changes in body odor [44]. Breath odor is affected both by gases from the oral cavity, probably due to trapped particles of garlic, and also from allyl methyl sulfide in the gut, an odor source which may linger for several hours after garlic consumption [43]. Analytic studies suggest indirectly that plants of the *Brassicaceae* family (e.g. broccoli, cauliflower, kohlrabi), which are a significant component of various European cuisines, may influence human breath and axillary odor, since they emit high amounts of dimethyl trisulphide and other sulphur compounds when boiled [45].

In humans, dietary odors have also been shown to enter into the domain of mother-infant interactions. Studies in mice and humans have shown that maternal food choices during gestation can affect offspring food preference postnatally [46, 47]. Mice whose mothers were fed garlic during gestation preferred garlic over onion, unlike control mice whose mothers were fed a garlic-free diet [47]. In humans, the infants of mothers who consumed anise during pregnancy showed a post-natal preference for the odor of anise [46]. Such preferences may be learnt prenatally either by stimulation of the olfactory receptors via the bloodstream, or from direct exposure to the amniotic fluid [47]. Certainly, adult raters can detect recent maternal garlic consumption from the odor of amniotic fluid [48], and the odor of maternal amniotic fluid is known to exert a calming influence on human infants [49]. Postnatally, the mother's diet can also affect milk taste and odor. Carrot, vanilla, garlic and alcohol flavors have all been shown to cross from the mother's diet to her milk, affecting suckling behavior [50-54].

For instance, infants whose mothers ingested garlic capsules breastfed longer and sucked more compared to controls. Also, two hours after garlic consumption by the mother, adult panelists rated the odor of the milk as smelling stronger and more like garlic [53].

There are also a few clinical reports of peculiar body odors in newborn babies that appear to result from the mothers' diet. Cumin, fenugreek or curry have been detectable in separate instances in the odor of newborn infants, following consumption of spicy food by the mother [55]. In a similar case in Turkey, a newborn baby smelled of maple syrup, which is a diagnostic sign of maple syrup urine disease [56]. Laboratory tests did not confirm the diagnosis and further discussion with the mother revealed instead that before the delivery she ate food containing fenugreek. Leaves of this plant (family *Fabaceae*) are widely used as a spice in traditional cuisine in Mediterranean countries such as Turkey and contain 3-hydroxy-4,5-dimethyl-2(5H)-furanone which is responsible for its distinctive odour [57]. Early food preferences may persist through childhood [54], and it is therefore conceivable that maternal odors induced by diet should have long-term or even life-long effects on the diet of the offspring [58].

SUBJECTIVE PERCEPTIONS OF BODILY ODORS INDUCED BY DIET

As far as we know there is only one study that focused directly on how ratings of human body odor are affected by diet, or more specifically, by the consumption of red meat [59]. The authors asked half of their male odor donors to keep to a meat-free diet and half to eat red meat every day for a period of two weeks. For the last four days of the diet, all of the food, differing only in meat content, was provided to the participants. On the final day, participants wore cotton pads in their armpits for 24h. The odor of the pads was then rated by a group of female students for its intensity, pleasantness and attractiveness. A month later the whole procedure was repeated; this time, the donors previously on a meat diet consumed a meat-free diet, and vice versa. Data analysis showed that the odor of the donors when on the red meat diet was judged as less pleasant and more intense compared to their odor when on a non-meat diet (figure 1). At this point it is not clear what amount of meat must be eaten to be discernable in body odor. Neither do we know for how long such an effect lasts. It would also be interesting to test whether eating poultry or fish produces a similar effect. Some anthropologists have remarked that individuals in communities where fish are eaten on a daily basis smell of fish [12], possibly due to trimethylamine, an odorous substance abundant in fish. Likewise, anecdotally, consumers of products based on cows' milk smell unpleasant to people in cultures where cows' milk is not consumed. This second finding is particularly interesting because of the link between genetic and cultural variation. The ability to digest milk is mediated by the lactase gene, a gene which is only maintained in adults amongst populations with a history of animal domestication and adult milk consumption [60]. Alcohol, too, is associated with population-level differences in ethanol metabolic ability [61], and, anecdotally, affects body odors. The co-occurrence of genetic differences and dietetic practices allows for an interesting gene-culture evolution. Could body odor be one of the proximate mechanisms by which cultural and genetic dietetic differences are maintained? Direct explorations of these phenomena remain to be made.

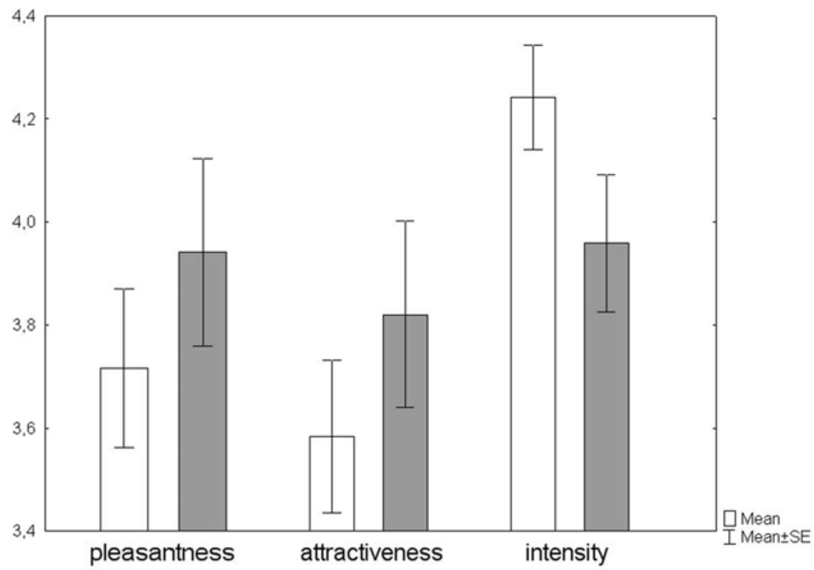

Figure 1. Mean ratings (±S.E.) of axillary odor pleasantness, attractiveness and intensity when body odor donors were on a “meat” diet (white bars) and when on a “non-meat” diet (grey bars). Differences are significant at p=0.01 (repeated measures ANOVA). Reprinted from Havlicek and Lenochova (2006) with permission from Oxford University Press.

CONCLUSION

Eating habits affect social interactions both directly (e.g. via culturally-based food practices) and indirectly (e.g. due to the effects of weight on attractiveness). However, since food choices affect bodily odors, eating habits may also influence social interactions in a more subtle way. For instance, body odor is thought, albeit amidst some controversy, to influence human partnership formation by providing information on MHC compatibility [18-20]. Experimental work in rodents has demonstrated that diet may be more salient than MHC type in affecting bodily odors [62, 63], and spiny-mouse pups have been shown to prefer the odor of heterospecific females fed on a familiar diet compared to the odor of conspecific females fed on an unfamiliar diet [64]. These results suggest that diet may interact with, or mask, individually-specific odors denoting gender, species etc. Unfortunately at this point, we can only speculate about the effects of specific dietetic compounds on subjective perceptions of human bodily odors, and the interaction between diet and individual genetically-based body odors.

Different dietetic habits between cultures and communities may also contribute to differences in body odors between populations, and contribute to xenophobic beliefs that individuals of other cultures smell bad, although much of the aversive effect of some odors is likely to be a simple effect of unfamiliarity [65]. For instance, Chinese people living in the United States report conscious efforts to reduce odors associated with their traditional foods in the domestic and personal domains [66]. However, if genetic and cultural practices remain linked, the study of food choices and genetic diversity may be an inspiring model for gene and cultural interactions.

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