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ORIGINAL PAPER

Shaving of axillary hair has only a transient effect on perceived body odor pleasantness

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Abstract In contrast to other apes, humans have relatively greater amounts of armpit hair, which is thought to retain signaling molecules. Although armpit shaving is widespread cross-culturally, its effect on body odor has been little investigated. In four experiments, we tested the effect of shaving and the subsequent regrowth of axillary hair. Armpit odors were collected from men who regularly shaved (group S) or who had never shaved (group N) their armpits before. The samples were subsequently rated by women for intensity, pleasantness, and attractiveness. In Experiments I, II (group N) and III, subjects firstly shaved one armpit and then let the hair regrow over 6 or 10 weeks. In Experiments I, II (group S) and IV, subjects shaved both armpits before the sampling and subsequently shaved one armpit during the same period, leaving the second armpit unshaved. Odors of the shaved armpits were rated more pleasant, attractive, and less intense compared to the unshaved armpits (Experiment I (group N)). However, no significant differences found in Experiments II and III (group N) suggest the effect of shaving is relatively minor. Moreover, there were no significant differences in odor comparing unshaved armpits with armpits after 1 week of regrowth (Experiments I, II (group N) and III) or comparing regularly shaved armpits with armpits after 1 or 3 weeks of regrowth (Experiments I, II (group S) and IV). The odor of shaved armpits was rated significantly more attractive compared to the armpits where hair had been regrowing for 6 or 10 weeks.

Keywords Armpit · Attractiveness Human · Olfaction · Scent · Smell

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Introduction

The last two decades have witnessed an outburst of interest in human chemical ecology, both in the scientific literature and the popular media. The majority of studies have focused on genetically related traits influencing body odor, particularly in mate choice and mother–infant contexts. These include research on individuality, gender, MHC, and other aspects intrinsic to the odor carrier (for recent reviews see Hays 2003; Wysocki and Preti 2004; Havlicek and Roberts 2009). However, as in other species, human body odor is also shaped by numerous environmental factors. Most non-genetic variation can be accounted for by differences in reproductive status, emotional state, infections, and grooming habits (such as using perfumes or deodorants) (reviewed in Havlicek and Lenochova 2008). For instance, it has been repeatedly demonstrated that men find the body odor of women not taking oral contraceptives most appealing when conception is most likely (e.g. Kuukasjärvi et al. 2004; Havlicek et al. 2006). Dietary habits may also have a profound effect on body odor. Havlicek and Lenochova (2006) recently showed that the odor of men on a red meat diet was judged less attractive than on a meat-free diet.

The axillary region is the most intensely studied body part regarding chemical communication. Human axillary odor has an individual character dependent on specific microflora present in the human armpit area (Shelley et al. 1953). Aerobic coryneforms, propionibacteria, staphylococci, and micrococci are the major axillary microbial organisms (Rennie et al. 1991). These microorganisms metabolise the products of axillary glands, creating volatile odors (Rennie et al. 1991; Gower et al. 1994; Natsch et al. 2003). The axillary area has some unique features, such as, the abundance of apocrine glands. This led some theorists to speculate that in humans the axillary products specifically evolved for communication (e.g. Comfort 1971). The location might be especially advantageous due to the upright posture of modern humans (Pawlowski 1999). Another specific feature is the presence of axillary hair which has been proposed to serve to retain chemical compounds active in communication processes (Cohn 1994). This is supported by the study of Nixon et al. (1988) who found 16-androstenes in the axillary hair extracts. Some of these compounds, in particular androstenol, androstenone and androstadienone, have been shown to influence various social interactions (Cowley and Brooksbank 1991; Jacob et al. 2002; Lundstrom et al. 2003; Pierce et al. 2004; Saxton et al. 2008; for review see Havlicek et al. 2010). Other odoriferous axillary chemicals, in particular various saturated and unsaturated fatty acids, are also thought to bind to armpit hair (Zeng et al. 1991; Natsch et al. 2003, 2006). Moreover, other great apes have apparently less hair in their armpits (S Lhota personal communication) which is again suggestive of the idea that human axillary hair could have evolved as an adaptation.

Shaving of axillary hair is a widespread practice not only within the context of Western cultures but also in the Near East, India and elsewhere. In Western cultures, armpit shaving is regarded as a social norm in women, with the overwhelming majority of women regularly performing it (Tiggemann and Kenyon 1998; Tiggemann and Hodgson 2008). Recently, it is becoming popular among men as well. However, actual figures, together with a record of the social profile and motives of men engaged in this grooming activity, are missing. Interestingly, the effect of axillary hair shaving on body odor hedonics has not attracted much research attention. Until almost 60 years ago, as far as we know, only one study had addressed this issue. It found that removal of axillary hair in men resulted in a marked reduction or elimination of axillary odor for the next 24 h (Shelley et al. 1953). However, the raters indicated only whether they were able to smell any odor; their judgments on odor hedonics or strength were not recorded. Moreover, the effect of odor dynamics due to hair growth on subjective perception was not tested in the study.

The aim of our study was to test the effect of armpit shaving in men and the consequential influence of axillary hair growth on axillary odor hedonics, as rated by women. The putative function of axillary hair is to retain armpit chemicals and therefore we expected that armpit shaving would decrease the intensity and increase the pleasantness and attractiveness of the axillary odor. Simultaneously, we expected that the odor of armpits with regrowing hair would be rated more intense and less pleasant and attractive compared to the odor of regularly shaved armpits. To test our hypothesis, we performed four independent experiments with male odor donors who regularly shaved their armpits (group S in Experiments I and II, and Experiment IV) as well as those who had never shaved their armpits before (group N in Experiments I and II, and Experiment III). As has been found repeatedly, both odor sensitivity and odor preferences change in females across the course of the menstrual cycle (Doty et al. 1981; Hummel et al. 1991) and are also affected by hormonal contraception (Caruso et al. 2001; Roberts et al. 2008). Thus, our sample of odor raters consisted of both users (Experiment II) and non-users (Experiments I, III and IV) of hormonal contraception. Experiments I and II explored the effect of up to 6 weeks of hair regrowth and Experiments III and IV continued for an extended period of 10 weeks (see Fig. 1 for a schedule of the procedure). Different donors participated in each experiment, and the same was true for the vast majority of the raters (four raters who participated in Experiment III and three raters in Experiment IV took also part in Experiment I).

Methods

Subjects

To avoid body odor fluctuations across the menstrual cycle, we chose only male subjects as odor donors. All of them were students of various Prague universities, and none reported dermatological or other diseases. Sexual orientation has previously been found to have an effect on hedonic ratings of body odor (Martins et al. 2005; Sergeant et al. 2007). We therefore take this factor into account by asking our odor donors: "What is your sexual orientation?" One donor in Experiment III and two in Experiment IV identified themselves as homosexual. Excluding homosexual donors did not significantly affect the results. The donors were awarded 1000 CZK (approximately US $55) as compensation for their time and potential inconvenience. The number of samples used for the analyses of individual sessions and the overall analyses varies as some of the donors did not attend all of the sampling sessions (e.g. due to illness). We further excluded from the analyses samples in which more

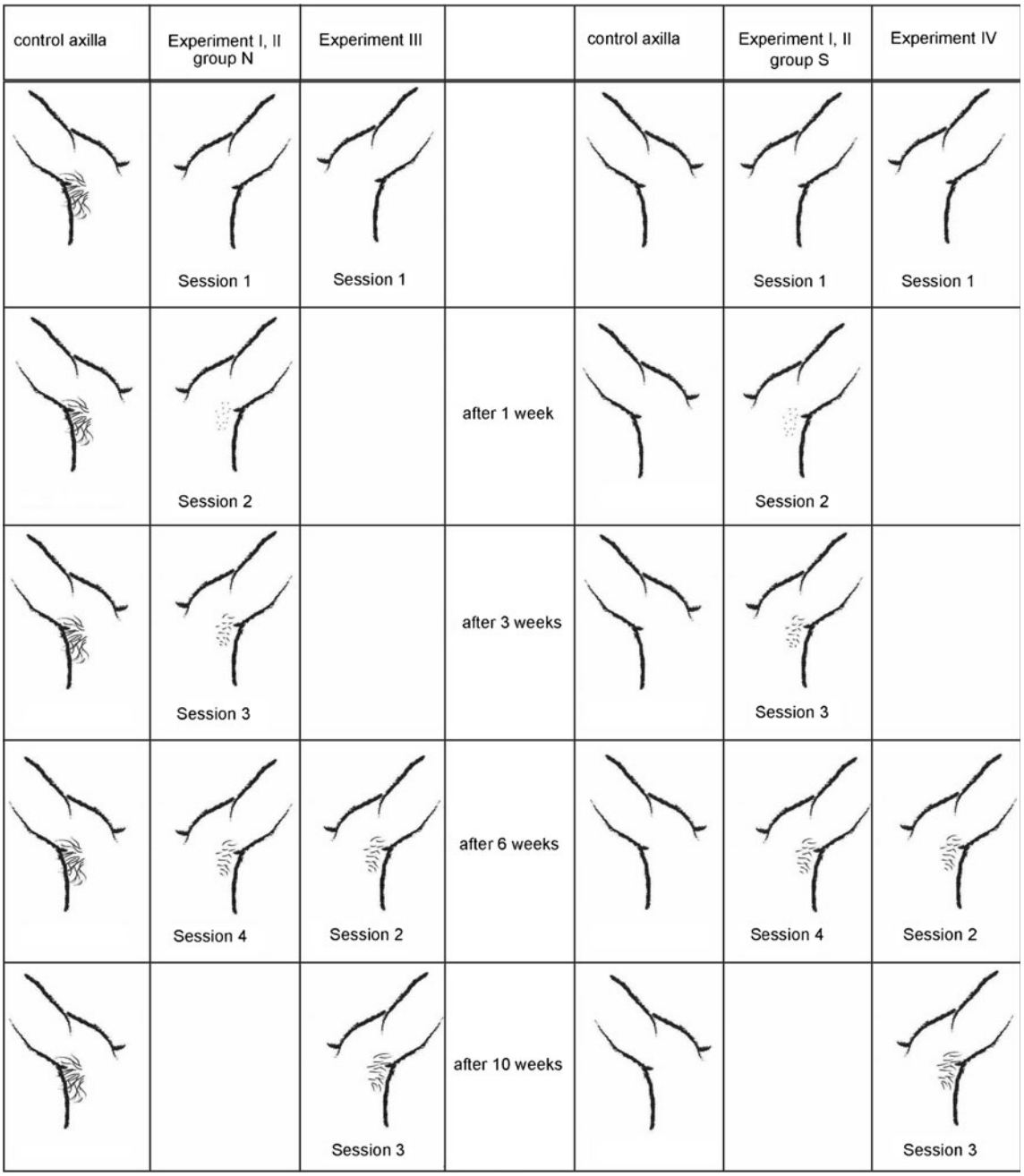

Fig. 1 Male armpit treatments across sessions. Note that the control axilla in group N of Experiments I and II and in Experiment III was unshaved. In contrast, the control axilla in group S of Experiments I and II and in Experiment IV was regularly shaved. Experiments I and II consisted of four sampling sessions and Experiments III and IV consisted of three sampling sessions

than half of the women reported contamination by smoke or perfume. Female students participated as raters in all experiments. They were unpaid but received a 100-g chocolate bar after each testing session. The number of raters varies between individual sessions as some of them did not attend all rating sessions. Table 1 summarizes the number of samples and raters used and excluded from particular analyses.

Experiment I

Eleven men (mean age, 20.7; range, 20–23 years) served as odor donors. They comprised two experimental conditions: group N (n=6) who had never shaved their armpits before and group S (n=5) who had been regularly shaving their armpits for at least 1 year. Thirty female raters (mean age, 24.2; range, 18–30 years) participated in this experiment. To

Table 1 Numbers of subjects and temperatures across individual sessions in Experiments I–IV

		Donors N (excluded)	Donors S (excluded)	Raters (absent)	Outdoor temperature (°C)	Indoor temperature (°C)
Experiment I	Session 1	6	5	28 (2)	3.4	19
	Session 2	5 (P)	5	29 (1)	4.4	17–20
	Session 3	6	4 (A)	24 (6)	15.7	20–21
	Session 4	6	5	21 (9)	14.5	18–19
	OA	5	4	19		
Experiment II	Session 1	5 (S)	5	25	3.8	17–20
	Session 2	4 (S, A)	5	19 (6)	7.4	18–19
	Session 3	6	5	24 (1)	15.5	20–21
	Session 4	6	5	18 (7)	15.1	19–19.5
	OA	4	5	12		
Experiment III	Session 1	12		17	7.2	20–21
	Session 2	11 (P)		13 (4)	2.1	17–19
	Session 3	12		15 (2)	5.5	17–18
	OA	11		12		
Experiment IV	Session 1		11	20	6.6	18–20
	Session 2		10 (A)	18 (2)	4.6	16–19
	Session 3		11	17 (3)	11.2	18–19
	OA[a]		10	15		

Donors N indicates men who had never shaved their armpits before and donors S men who regularly shaved one of their armpits across the four experimental sessions. The capital letters in brackets indicate the reason why a particular donor was excluded from the analyses. Values in brackets (raters column) indicate the number of raters who did not attend a particular session. Analyses of individual sessions included all non-excluded donors and raters in each session. Temperature measurements represent the average daytime temperature during the individual sampling sessions ("Outdoor temperature") and the range of temperatures during the rating sessions ("Indoor temperature")

A absent, *P* contaminated by perfume, *S* contaminated by smoke, *OA* overall analyses

[a] Data of subjects who took part in all sessions and adhered to all instructions were included

avoid a possible effect of menstrual cycle phase on odor perception, we only recruited subjects using hormonal contraception (21 users of single-phase hormonal contraception and nine users of another type of hormonal contraception).

Experiment II

Eleven men (mean age, 23.0; range, 20–26 years) participated as odor donors. Six had never shaved their armpits (group N), and five had been regularly shaving their armpits for at least 1 year (group S). Twenty-five women (mean age, 23.7; range, 19–32 years) participated as raters. To assess possible effects of the menstrual cycle on odor perception, we recruited only subjects not using hormonal contraception. All raters but one reported having a normal menstrual cycle length (23–35 days). The cycle length was estimated according to the reported usual length of the cycle. The day of the menstrual bleeding onset was considered to be the first day of their cycle. The menstrual cycle data were split into fertile (days 7–14) and non-fertile phases (days 1–6 and days 15–28) in a 28-day cycle following a simplified protocol used by Havlicek et al. (2006). If the cycle length was other than 28 days, the end of the fertile phase was computed as $F=L-14$, where F is the last day of the fertile phase and L the length of the cycle. Numbers in the fertile phase per session were as follows: Session 1, 10 out of 25; Session 2, 6 out of 19; Session 3, 11 out of 22; Session 4, 5 out of 18.

Experiment III

Twelve men (mean age, 21.8; range, 19–28 years) who had never shaved their armpits participated in this experiment as odor donors. Seventeen women (mean age, 22.9; range, 19–28 years) using hormonal contraception (ten of them used single-phase hormonal contraception) participated as raters.

Experiment IV

Eleven men (mean age, 21.9; range, 19–27 years) who had been regularly shaving their armpits for at least 1 year before the study started participated as odor donors. Twenty raters (mean age, 22.6; range, 19–27 years) using hormonal contraception (15 of them used single-phase hormonal contraception) participated in this experiment.

Odor sampling procedure

In Experiments I and II, odor samples were provided four times over 6 weeks to test the effect of hair regrowth (see below for details). Following the initial sampling session (Session 1), the subsequent sessions took place after 1 (Session 2), 3 (Session 3) and 6 weeks (Session 4).

In Experiments III and IV, odor sampling was carried out three times over 10 weeks. Specifically, following the initial sampling session (Session 1), the subsequent sessions took place after 6 (Session 2) and 10 weeks (Session 3).

In Experiments I, II (group N) and III, the effect of shaving on formerly non-shaved armpits and the temporal effect of hair regrowth was tested by asking each subject to shave one of his armpits, randomly assigned by the experimenter, the evening before the first odor sampling, and then let the hair grow (see Fig. 1).

In Experiments I, II (group S) and IV, the effect of hair growth on shaved armpit odor was tested by asking subjects to shave both their armpits every other day for 1 week before the sampling for Session 1. Subsequently, they shaved one armpit every other day during the 6- or 10-week experimental period, and the second armpit was left unshaved (see Fig. 1). The side of armpit to regrow was again randomly assigned by the experimenter.

Two days before each sampling session, the subjects were provided with cotton pads, a T-shirt, a plaster, two zip-lock plastic bags for storing the odor samples, razors (Wilkinson Sword Extra II Sensitive), non-perfumed soap (Sara Lee Household and Body Care, Sweden) and an instruction sheet. The donors were instructed to refrain from the following activities 2 days before collecting the samples and on the day of wearing the pads: (1) using perfumes, deodorants, antiperspirants, aftershave and shower gels; (2) eating meals containing garlic, onion, chili, pepper, vinegar, blue cheese, cabbage, radish, fermented milk products, marinated fish; (3) drinking alcoholic beverages or using other drugs; (4) smoking; (5) sexual activity; (6) sleeping in a bed with a partner or pet. Whilst wearing the pads, they were also asked to avoid intense physical activity (e.g. jogging, playing football, etc.).

Odor samples were collected using elliptical pads approximately 9×7 cm in size made of 100% cotton (Ebelin cosmetic pads, DM-drogerie markt, www.dm-drogeriemarkt.cz) worn in the armpits (cf methods in Havlicek et al. 2005, 2006). In the evening before the sampling session, the odor donors showered without using even the non-perfumed soap. In the morning (7 a.m.) the donors applied their cotton pads to both armpits using 3 M™ Micropore™ surgical tape and wore them for 24 h. Sampling length was kept constant across the experiments as it can affect the quality of the samples (Havlíček et al. 2011). To avoid odor contamination from the donors' clothes or from the background, donors wore the white 100% cotton T-shirts provided (previously washed without washing powder) as the first layer of their clothing. The following morning they put the pads into the two labeled zip-lock plastic bags and handed them back to the experimenters.

The average outdoor temperatures (source: Research Institute of Crop Production in Prague) during individual sampling sessions are shown in Table 1. However, the actual temperatures for individual donors might vary slightly as they spent the sampling day in various parts of Prague.

Odor rating procedure

The experimental procedure is based on a within-subjects design as the same group of raters assessed the odor samples repeatedly across all sessions. Odor ratings started within an hour after collecting all the samples to minimize the possible influence of further bacterial activity on the samples. The ratings took place in a quiet, ventilated room. Indoor temperatures during individual sessions are shown in Table 1. Cotton pads were placed into 500-ml opaque glass jars labeled by a code. The testing procedure lasted from 9 a.m. to 6 p.m. Individual raters attended each rating session approximately at the same time of day. This procedure minimizes a possible diurnal effect on the olfactory abilities and temporal changes of the odors. The total sample set consisted of 22 axillary samples (two from each donor) in Experiments I, II and IV and of 24 axillary samples in Experiment III. Additionally, we used two non-human samples to control for possible fluctuations in the raters' odor preferences. One was of floral origin, cinnamon (75% cinnamal, 14% eugenol and several other minor compounds) and one of animal origin, castoreum (a musky complex compound that originates from the beaver's anal gland; we used a mixture of 33% dipropylene glycol, 16% thujopsene, 10% gurjunene, 9% benzyl benzoate, 8% cederene and several other minor compounds manufactured by the chemical industry). In both cases, two drops (i.e. approximately 0.1 ml) of 100% essence (Aroma Corp. Decin) were put on a cotton pad and was placed into a 500-ml opaque glass jar labeled by a code, thus replicating the procedure used with the body odor samples.

Each rater assessed all samples. The samples were divided into two equal subsets. The order of the subsets was randomized in Session 1, and in the subsequent sessions, the order of the subsets was the same as in Session 1. The order of samples within a subset was randomized for each of the sessions. The raters had a break of approximately 10 min between assessing the two subsets to avoid sensory adaptation, when they were offered refreshments and asked to complete a questionnaire regarding their age, health status, menstrual cycle and partnership status.

Each rater washed her hands with non-perfumed soap before the rating to avoid rating bias caused by hand odor. They were told about the origin of the samples (i.e. male axillary samples and the two essence samples), but they were not further informed about the aims of the experiment.

The samples were rated on 7-point scales for their (1) intensity, (2) pleasantness, and (3) attractiveness. Both ends of each scale were anchored by verbal descriptions (e.g. very unpleasant to very pleasant). For explorative purposes, we also obtained ratings on masculinity. However, some raters found judging this variable difficult. According to our preliminary analyses, ratings of masculinity were in general positively correlated with intensity ratings and did not show any systematic trend in relation to shaving status. For these reasons, results on masculinity are not included here. The ratings were written down immediately after sniffing each stimulus, but the time spent by sniffing was not restricted. Raters were also asked to note whether they detected any contamination by smoke or perfume.

The overall rating procedure was same across all experiments. The only difference was that in Experiments III and IV, we used a more sensitive test paradigm (the equivalent of a forced-choice test). Within each subset, the samples were paired. Each pair consisted of samples acquired from the left and right armpit of a particular donor, and raters were instructed not to use the same value within each pair (samples of one person) for any of the assessed variables (e.g. pleasantness). This procedure is designed to detect subtle effects as it generally strengthens the differences between the tested groups.

Statistical analysis

The statistical package Statistica 7.1 was used for all analyses. The data adhered to the requirements for parametric tests. As our design was a within-subject one, we used a paired *t* test to test the effect of treatment within a session and a repeated measures analysis of variance (ANOVA) to test the dynamics of hair growth across individual sessions. Our aim was to test possible changes in the perception of axillary odor of shaved and unshaved armpits; therefore, we used mean subject (raters') ratings as the unit of the analysis. We used post hoc tests (Fisher LSD test) only when the main effect of the ANOVA was significant. To assess any possible effect of the menstrual cycle in Experiment II, we also included a binary factor (fertile/non-fertile phase, for details on criteria see section "Subjects") as an independent variable within a repeated measures ANOVA. We did not use Bonferroni adjustments for multiple tests in order not to decrease the statistical power of our relatively small sample sizes (Nakagawa 2004). Further, we tested specific hypotheses concerning the effect of shaving (in contrast to the universal null hypothesis). In such cases, adjustments are not recommended as they inflate the chance of type II error (Perneger 1998).

We also analysed our data with mean donor ratings as the unit of the analysis (results are not shown). The results showed similar trends as with raters as the unit of the analysis, but were not statistically significant and are not reported further. Correlations among rated variables were computed by using Pearson correlations for each session in all four experiments.

Results

Experiment I

In Session 1, we found a significant difference between the odors of shaved and unshaved armpits of donor group N. The axillary odor of shaved armpits was rated as more pleasant (t_{27}=2.80; p=0.009), more attractive (t_{27}=2.28, p=0.03) and less intense (t_{27}=6.55; p<0.001) than the odor of unshaved armpits. No significant difference was found between the axillary odors from unshaved armpits and armpits with regrowing hair in sessions 2, 3 and 4 (all p values>0.08) (Table 2). To test the effect of axillary hair growth on odor perception, we compared the ratings from all four sessions by a repeated measures ANOVA. The ratings of unshaved axillae served as control. We did not find a significant effect of armpit treatment, repeated measure or any interaction with pleasantness (all p values>0.055), or attractiveness (all p values>0.11). There was a significant repeated measure effect of intensity ($F_{3,36}$=2.70; p=0.05), but no interaction with armpit treatment. Post hoc analyses showed that the odor samples from Session 3 were rated significantly more intense compared to Session 1 (p=0.03) and Session 2 (p=0.01).

Each person from group S shaved both armpits the day before the first sampling session. We found no significant differences between the ratings of the left and right shaved armpits in Session 1, nor in pleasantness (all p values>0.07), attractiveness (all p values> 0.09) or intensity (all p values>0.12) between repeatedly shaved armpits and armpits with regrowing hair in the other three sessions (Table 2). To test the effect of axillary hair growth during all four sessions in group S, we again performed a repeated measures ANOVA. We did not find a significant effect of armpit treatment, repeated measure nor any interaction with pleasantness (all p values>0.24), attractiveness (all p values>0.21) or intensity (all p values>0.07).

To test possible fluctuations in the raters' odor preferences, we included two non-human samples (castoreum,

Table 2 Mean (standard deviations) ratings of pleasantness, attractiveness and intensity in Experiment I

	Session 1		Session 2		Session 3		Session 4	
Group N	U	S	U	R	U	R	U	R
Pleasantness	**3.235 (0.965)**	**3.532 (0.957)**	3.072 (0.944)	3.190 (0.898)	3.380 (0.808)	3.331 (0.908)	3.182 (1.155)	3.233 (1.104)
Attractiveness	**3.216 (0.973)**	**3.480 (1.046)**	3.090 (0.982)	3.147 (1.005)	3.277 (0.809)	3.163 (0.908)	3.125 (1.143)	3.373 (1.040)
Intensity	**4.255 (1.050)**	**3.589 (1.190)**	4.096 (0.966)	3.864 (1.156)	3.954 (1.118)	3.913 (1.173)	3.927 (1.042)	3.811 (1.078)
Group S	S	S	S	R	S	R	S	R
Pleasantness	3.649 (0947)	3.526 (1.008)	3.647 (0.839)	3.365 (0.941)	3.250 (0.892)	3.356 (1.218)	3.528 (1.032)	3.593 (0.921)
Attractiveness	3.469 (0.983)	3.354 (0.981)	3.540 (0.775)	3.279 (1.039)	3.190 (0.907)	3.235 (1.186)	3.528 (1.016)	3.500 (0.932)
Intensity	3.630 (1.159)	3.849 (0.995)	3.523 (1.090)	3.842 (1.132)	4.298 (1.011)	4.377 (1.286)	3.590 (1.163)	3.624 (1.324)

Group N indicates donors who had never shaved their armpits before and group S donors who regularly shaved one of their armpits across the four experimental sessions. Values in bold significantly differ at $P<0.05$. The ratings are based on the judges using hormonal contraception

U mean values in the unshaved armpits, *R* mean values in the armpits with regrowing hair, *S* mean values in the shaved armpits

cinnamon) in each testing session. We performed a repeated measures ANOVA for castoreum ratings and did not find a significant effect for any of the tested characteristics (e.g. pleasantness) (all p values>0.54). For cinnamon, we found a significant repeated measure effect for pleasantness ($F_{3,18}$=4.10; p=0.01) and attractiveness ($F_{3,18}$=4.11; p=0.005). Based on post hoc analyses in Session 1, the cinnamon essence was rated as more pleasant (p=0.05) and more attractive (p=0.008) than in Session 2. In Session 3, it was rated as less pleasant (p=0.002) and less attractive (p=0.003) compared to Session 1. The cinnamon samples from Session 4 were rated as more pleasant (p=0.02) than samples from Session 3 and less attractive (p=0.002) than in Session 1. No significant changes in ratings of intensity of the cinnamon samples were found.

Experiment II

In Sessions 1 and 2, we found no significant difference between the ratings of shaved and unshaved armpit odors from donor group N (all p values>0.18). In Session 3, the axillary odor of the unshaved armpits was rated as more pleasant (t_{23}=2.37; p=0.03) and less intense (t_{23}=2.95; p=0.007) than the odor of the armpits with regrowing hair. On the contrary, in Session 4, the axillary odor of the unshaved armpits was rated as less pleasant (t_{17}= 2.76; p=0.01) and more intense (t_{17}=8.38; p<0.001) than the odor of the armpits with regrowing hair (Table 3). When controlling for the raters' menstrual cycle phase, qualitatively identical results were obtained.

To test the effect of axillary hair growth on odor ratings, we compared the ratings from all four sessions. Ratings of the unshaved axillae served as a control. We did not find a significant effect of armpit treatment, repeated measure or any interaction with pleasantness (all p values>0.31) and attractiveness (all p values>0.37). A significant repeated measure effect ($F_{3,22}$=8.45; p<0.001) and a significant interaction between armpit treatment and repeated measure for intensity ($F_{3,22}$=4.01; p=0.01) was found. Based on post hoc analyses, we found that in Session 4, the samples of unshaved armpits were judged as significantly more intense compared to Session 1 (p<0.001), Session 2 (p<0.001) and Session 3 (p<0.001). The other armpit of each donor was shaved for Session 1, and then the hair was left to regrow (i.e. in Sessions 2, 3 and 4). Further, changes in ratings of odor intensity were found. The samples of armpits with regrowing axillary hair from Session 2 were rated as less intense than the samples of the same armpits from Session 3 (p=0.02) and Session 4 (p=0.008).

To test possible differences between the ratings of axillary odors of the right and left armpit, each person from group S shaved both armpits before the onset of the

Table 3 Mean (standard deviations) ratings of pleasantness, attractiveness and intensity in Experiment II

	Session 1		Session 2		Session 3		Session 4	
Group N	U	S	U	R	U	R	U	R
Pleasantness	3.359 (1.149)	3.493 (0.955)	3.434 (1.243)	3.557 (1.118)	**3.490 (1.062)**	**3.220 (1.030)**	**3.198 (1.245)**	**3.559 (1.081)**
Attractiveness	3.347 (1.057)	3.318 (1.112)	3.320 (1.263)	3.478 (1.035)	3.579 (1.054)	3.437 (1.066)	3.269 (1.292)	3.473 (1.148)
Intensity	4.008 (1.028)	4.161 (0.766)	4.070 (1.173)	3.763 (1.148)	**3.955 (0.964)**	**4.432 (1.069)**	**5.261 (1.129)**	**4.550 (1.201)**
Group S	S	S	S	R	S	R	S	R
Pleasantness	3.985 (1.045)	3.896 (1.036)	3.087 (0.963)	3.108 (1.228)	4.044 (0.999)	3.748 (1.079)	4.068 (1.235)	3.657 (1.220)
Attractiveness	3.717 (1.148)	3.694 (1.125)	3.016 (1.088)	2.855 (1.205)	3.869 (0.931)	3.693 (0.873)	**3.975 (1.166)**	**3.381 (1.032)**
Intensity	3.589 (0.869)	3.665 (0.796)	4.913 (0.906)	5.129 (905)	3.587 (0.969)	3.414 (1.061)	4.142 (1.210)	4.233 (1.170)

Group N indicates donors who had never shaved their armpits before and group S donors who regularly shaved one of their armpits across the four experimental sessions. Values in bold significantly differ at $P<0.05$. The ratings are based on the judges not using hormonal contraception

U mean values in the unshaved armpits, *R* mean values in the armpits with regrowing hair, *S* mean values in the shaved armpits

experiment. First we compared ratings separately for each of the four sessions. The only significant differences found were that in Session 4, where the odor of the repeatedly shaved armpits was rated as more attractive ($t_{17}=3.07$; $p=0.007$) than the odor of the armpits with hair regrowth. Again when controlling for the raters' menstrual cycle phase, qualitatively identical results were obtained.

Subsequently, we tested the effect of axillary hair growth during all four sessions in group S. We did not find any significant effect of armpit treatment nor any significant interaction between armpit treatment and repeated measure for pleasantness, attractiveness and intensity (all p values> 0.35). However, there was a significant repeated measure effect for pleasantness ($F_{3,22}=6.33$; $p=0.001$), attractiveness ($F_{3,22}=8.41$; $p<0.001$) and intensity ($F_{3,22}=12.06$; $p<0.001$). Subsequent post hoc analyses showed that odor samples from Session 2 were rated significantly less pleasant (all p values< 0.01), less attractive (all p values<0.007) and more intense (all p values<0.02) compared to Sessions 1, 3 and 4, and that odor samples from Session 4 were rated significantly more intense compared to Session 1 ($p=0.002$). We also performed a repeated measures ANOVA for castoreum and cinnamon ratings and did not find a significant effect for any of the tested characteristics (all p values>0.09).

Experiment III

We found no significant differences in ratings of pleasantness, attractiveness or intensity between the odors of the shaved (or the armpits with regrowing hair) and unshaved armpits in any of the three sessions (all p values>0.47) (Table 4). To test the effect of axillary hair growth on odor, we compared the ratings from all three sessions. We did not find any significant effect of armpit treatment, repeated measure or any interaction with any of the rated characteristics (all p values>0.15).

For castoreum ratings, we found a significant repeated measure effect for pleasantness ($F_{3,18}=3.83$; $p=0.04$). In Session 2, the castoreum sample was rated as less pleasant compared to Session 1 ($p=0.03$) and Session 3 ($p=0.02$). For cinnamon, we did not find a significant effect for any of the tested characteristics (all p values>0.21).

Experiment IV

Each donor had regularly shaved both armpits before the onset of the experiment. In Session 1, we found no significant difference between the axillary odors from the right and left shaved armpits (all p values>0.06) (Table 5). No significant differences in pleasantness or intensity of the axillary odors were found between the repeatedly shaved armpits and armpits with regrowing hair in Sessions 2 and 3 (all p values>0.10). In Session 3, the odor of the repeatedly

Table 4 Mean (standard deviation) ratings of pleasantness, attractiveness and intensity in Experiment III

	Session 1		Session 2		Session 3	
	U	S	U	R	U	R
Pleasantness	3.484 (0.552)	3.419 (0.552)	3.521 (0.614)	3.591 (0.600)	3.559 (0.713)	3.594 (0.609)
Attractiveness	3.331 (0.671)	3.390 (0.519)	3.387 (0.678)	3.449 (0.595)	3.487 (0.807)	3.570 (0.558)
Intensity	4.086 (0.679)	4.066 (0.533)	3.873 (0.584)	3.868 (0.704)	3.736 (0.840)	3.658 (0.705)

No significant differences at $P<0.05$ were found. The ratings are based on the judges using hormonal contraception

U mean values in the unshaved armpits, *R* mean values in the armpits with regrowing hair, *S* mean values in the shaved armpits

shaved armpit was rated to be more attractive ($t_{16}=3.13$; $p=0.006$) than the odor of armpits with growing hair.

Subsequently, we tested the effect of axillary hair growth during all three sessions. There was a significant repeated measure effect for pleasantness ($F_{2,28}=6.09$; $p<0.01$), attractiveness ($F_{2,28}=4.48$; $p=0.02$) and intensity ($F_{2,28}=5.58$; $p=0.006$), but no interaction with armpit treatment. Odor samples from Session 1 were rated less pleasant compared to Session 2 and Session 3. The odor samples from Session 1 were rated less attractive compared to Session 3, and odor samples from Session 1 and Session 2 were rated more intense compared to Session 3. Repeated measures ANOVA for castoreum and cinnamon ratings did not reveal any significant effect for any of the tested characteristics (all p values> 0.07), suggesting that there were no systematic fluctuations in the raters' odor preferences.

Additional analyses

To explore relations between rated characteristics, we carried out correlational analyses between individual variables for each session. We found highly significant positive correlations between attractiveness and pleasantness in all four experiments (all $r=0.81$–0.92). Conversely, negative significant correlations between intensity and attractiveness (all $r=0.13$–0.57) or pleasantness (all $r=0.28$–0.63) were significant ($p<0.05$) in all but one case.

Some of the differences between shaved and unshaved armpits could be attributed to the particularly intense odor of unshaved armpits in some individuals. To check this possibility, we compared the ratings of the unshaved armpits between individual experiments. The ratings of intensity in Experiment I compared to other experiments were higher, though not significantly so.

We further tested whether the proportion of raters having previous experience with the odor studies varied across individual experiments. The proportion of such raters was 25%, 20%, 29% and 25% in Experiments I, II, III and IV, respectively. This factor could potentially explain the discrepancies between the experiments (see "Discussion" for details). However, we did not find significant differences.

Discussion

The main aim of this study was to test whether armpit shaving and subsequent hair growth influences the subjective perception of quality and/or intensity of axillary odor. We used two different approaches by comparing (1) ratings of axillary odor of one-shot shaved armpits and the unshaved armpits of the same donors who had never shaved their armpits before (Experiments I and II (group N) and Experiment III) and (2) ratings of the odor of regularly shaved axilla and axilla with regrowing hair (Experiments I and II (group S) and Experiment IV). The dynamics of odor development during hair growth was tested for 6 weeks in Experiments I and II, and for 10 weeks in Experiments III and IV.

In a series of experiments, we demonstrated that axillary hair grooming affects the perception of odor intensity, pleasantness and attractiveness. In general, our results show that

Table 5 Mean (standard deviations) ratings of pleasantness, attractiveness and intensity in Experiment IV

	Session 1		Session 2		Session 3	
	S	S	S	R	S	R
Pleasantness	3.162 (0.865)	3.180 (0.786)	3.403 (0.669)	3.540 (0.682)	3.580 (0.739)	3.451 (0.867)
Attractiveness	3.137 (0.873)	3.167 (0.915)	3.394 (0.800)	3.441 (0.745)	**3.645 (0.803)**	**3.343 (0.906)**
Intensity	4.472 (0.718)	4.253 (0.734)	4.501 (0.536)	4.459 (0.567)	4.084 (0.701)	4.181 (0.548)

Values in bold significantly differ at $P<0.05$. The ratings are based on the judges using hormonal contraception

R mean values in the armpits with regrowing hair, *S* mean values in the shaved armpits

the axillary odor of shaved armpits is rated as more pleasant, more attractive and less intense compared to the unshaved armpits of the same individual. However, the magnitude of the observed effect is presumably not very high as we found differences between the shaved and unshaved armpits only in Experiment I but not in Experiments II and III. Moreover, no differences were found between regularly shaved armpits (group S) and armpits where hair had been regrowing for 1 or 3 weeks. Only after 6 (Experiment II) or 10 (Experiment IV) weeks of hair regrowth were unshaved armpits judged to smell less attractive than shaved armpits. The lack of the effect in Experiment III and partially in Experiment IV is particularly striking as we used the more sensitive force choice paradigm which strengthens the differences between the tested groups.

Effect of one-shot shaving

Significant differences found in Experiment I (group N) but not in Experiments II and III may be due to differences in the donor's odor intensity between the experiments. It is possible that by chance the donors in Experiment I had stronger axillary odors compared to the other experiments. The higher intensity of the unshaved armpit may have resulted in higher differences compared to the shaved armpit. However, comparison of intensity of unshaved armpits across the experiments brings only limited support for this claim.

The negative results in group N obtained in Experiments II and III can be attributed to several factors. For instance, the raters participating in a human odor study for the first time might judge most of the samples rather negatively which in turn may obscure the differences between odors of shaved and unshaved axillae. This could result in lower variability in using our 7-point scale and lead to the so-called floor effect. Less intense and thus also more positive (those two scales are usually negatively correlated) ratings of previously experienced stimuli are a widely recognized phenomenon (e.g. O'Connell et al. 1994). However, the proportion of raters having previous experience with the odor studies did not vary between particular experiments.

The effect of one-shot shaving observed in Experiment I was only transient. One week after shaving the axillary hair, we did not find any significant differences compared to the odor of the unshaved armpit. Further, no significant differences in pleasantness or intensity were found between the axillary odors from the unshaved armpits and the armpits with regrowing hair for a period of up to 10 weeks in Experiments I and III. These results are in accord with the study of Shelley et al. (1953). They indicate that the axillary odor is not present for 24 h after armpit shaving, but is again perceivable after 48 h. However, the raters in the study of Shelley et al. indicated only whether they could smell any odor at all and did not judge its strength or pleasantness. Moreover, from the method description, it is not clear whether the raters could see the targets while smelling their armpits, a factor which might have biased the results.

Effect of regular shaving

The next aim of our study was to compare the odor of a regularly shaved armpit and the odor of an armpit with regrowing hair (group S). To our knowledge, this effect has not been studied previously. To avoid possible odor instability due to changes in microbial colonization in freshly shaved axilla we chose male donors who had been shaving their armpits regularly for at least 1 year before the beginning of the study.

We found no significant difference in pleasantness, attractiveness and intensity of the axillary odors between repeatedly shaved armpits and armpits with 1 or 3 weeks of hair regrowth. On the other hand, the odor of the repeatedly shaved armpits was rated as more attractive than the odor of armpits with 6 (Experiment II) or 10 (Experiment IV) weeks of hair regrowth. The results suggest that only relatively long hair causes differences perceived by humans. Anthropometrical observations state 0.9–1.0 cm per month axillary hair growth in Caucasian populations with minor individual and seasonal variability (Martin and Saller 1961). Although we did not measure hair length, we can estimate that it was about 1.5 cm after 6 or 2.5 cm after 10 weeks. Alternatively, a longer time may be needed to re-establish different bacterial population following long-term shaving compared with one-shot shaving.

The odor quality and intensity are probably not influenced only by the presence or removal of hair but also by changes in or damage to the skin due to shaving. Regular axillary shaving causes graver axillary skin damage than one-shot shaving (Marti et al. 2003). The modification of the skin surface in the armpit area may cause changes in the composition of axillary microflora and subsequently it may modify the intensity and/or quality of the axillary odor. Whether such changes can be perceived by human subjects should be addressed in future studies by employing subjects with one regularly shaved axilla and the other shaved singly. Moreover, in our study, we did not test the differences between the odor ratings of the unshaved and regularly shaved armpit. Nevertheless, as we found differences between the ratings of the regularly shaved armpit and the armpit with hair growing for 6 and subsequently 10 weeks and also between the one-shot shaved axilla and unshaved axilla, we may expect similar or greater differences between the unshaved and regularly shaved armpits.

Effect of hair growth

The influence of hair growth dynamics on body odor was tested by comparing the ratings across individual sessions.

We employed the same protocol in all testing sessions to make conditions as standard as possible. It included restrictions in the consumption of certain food and alcohol and in activities, the same sampling length, ratings attended at similar time of day and so on. However, it is important to note that there were still a number of external factors which could not be controlled and therefore the results of between session analyses should be interpreted with caution. One such intervening factor is the environmental temperature and humidity during the sampling sessions. Temperature positively influences intensity of perspiration and subsequently increases the humidity in the axillary area. Increase in temperature and humidity results in higher growth of a number of skin microflora (Hartmann 1983) as well as in the rate of colonization by axillary microorganisms which changes the intensity of axillary odor (Hopwood et al. 2005). In Experiments I and II, there was a relatively high increase in the environmental temperature (cca 10°C) between sampling Sessions 2 and 3 (see Table 1). This might be the reason why the odor samples (provided by men from group N) in Experiment I were rated more intense in Session 3 compared to Sessions 1 and 2. Another example of the possible environmental temperature influences might be the ratings in Experiment II. For instance, odor samples (provided by men from group S) from Session 4 (outdoor temperature, 15.1°C) were rated more intense compared to Session 1 (outdoor temperature, 3.8°C).

Yet another factor which might have a systematic effect on between-session comparisons is seasonal variation in eating habits. As mentioned above, we tried to control the diet components presumed to influence body odor. However, the effect of the diet is still a largely unexplored field (for a review, see Havlicek and Saxton 2009), and for instance the amount of meat consumed, which is known to influence the quality and intensity of body odor (Havlicek and Lenochova 2006), might have varied across the sessions. Other important factors, which influence the results in olfactory studies, are changes in mental condition (e.g. in mood) and subsequent changes in the olfactory preferences of raters. Also, possible habituation to the samples might influence the results. The results of the longitudinal part of our study suggest that the aforementioned factors probably had the main influence on changes in ratings of odor samples and as already mentioned above, the between session analyses should be interpreted with caution.

Other confounds and implications

Some of the results may be further attributed to higher noise caused by the fluctuations in both odor sensitivity, peaking around ovulation and preferences across the rater's menstrual cycle (Doty et al. 1981; Hummel et al. 1991; Grammer 1993; Pause et al. 1996). In Experiment II, where the raters did not use hormonal contraception, we unexpectedly found that the odor of the unshaved armpits was judged significantly more pleasant and less intense compared to the armpits with regrowing hair in Session 3. To check for this confounding factor, we included the data on menstrual cycle phase in the analyses. However, we did not find any effect of the cycle. Our further inspection of possible confounding factors (e.g. the donors' physical activities) also did not reveal any potential reason for the observed effect. In view of the negative results in Session 1 and the surprising result of Session 3, the overall picture in Experiment II is mixed. To increase the sensitivity of our experiments, we recruited only women using hormonal contraception in three other experiments. In contrast to non-pill users, olfactory functions in women taking contraceptive pills are expected to be relatively stable (Caruso et al. 2001, although see Doty et al. 1981 for different results). Analyses including menstrual cycle data in raters using hormonal contraception again did not affect the results (data not shown).

Another possible contributing factor might be the differences between axillary odor of the right and left armpit caused by the differences in the local microflora. It is not yet clear from the literature whether the left and right armpit microflora differs (Hopwood et al. 2005) or not (Leyden et al. 1981; Rennie et al. 1991). The side of armpit which was shaved was assigned randomly, although it is possible that the majority of donors shaved the stronger axilla, particularly given the small sample size, and this could obscure the results. As laterality may influence the intensity of the odor produced in each armpit, we checked our subjects' handedness, but did not find any difference among the individual experiments. Further, the comparison of the left and right shaved armpits (Session 1, group S in Experiments I, II and Experiment IV) and unshaved armpits between individual sessions in Experiments I, II and III (group N) showed its relative stability. Contrary to expectation, we found significant fluctuations in the intensity ratings among axillary odors of the unshaved armpits in Experiment II. However, in general, these comparisons support the assumption of similarity between both armpits and justify our within-subject design. Thus, the differences we found in particular sessions were probably not caused by distinctions between the axillary odor of the right and left armpits. This is in agreement with a recently published study which in general suggests no perceptional variation between armpit sides (Ferdenzi et al. 2009).

In our study as well as in Shelley et al. (1953), the effect of shaving was tested only in men. We chose this approach to avoid body odor fluctuations across the menstrual cycle (e.g. Kuukasjärvi et al. 2004; Havlicek et al. 2006). It is reported in most studies that adult women's body odor is generally weaker than men's (e.g. Hold and Schleidt 1977).

The magnitude of the observed effect of shaving is rather small and therefore it is a matter of debate whether conducting the same experiments with female donors would lead to similar conclusions. As in Western cultural settings, axillary hair removal is much more widespread in women (Tiggemann and Kenyon 1998; Tiggemann and Hodgson 2008) it should be tested experimentally, too.

As a consequence of this study, we suggest that shaving habits should be considered in human odor studies. This is a particularly important issue in studies employing a between-subjects design on individuals who might systematically differ in their grooming habits. For instance, Martins et al. (2005) tested the odor attractiveness of male and female homosexuals compared to heterosexual men and women. The number of individuals shaving their armpits, a habit more widespread in women and in the gay community, was not reported.

The differences observed between shaved armpits and armpits with axillary hair might be in fact far greater than our results show. Cotton pads worn by donors in their armpits represent a mechanical barrier for the retention of chemical compounds and therefore this treatment might partly substitute the assumed function of axillary hair (i.e. retention of volatile compounds). In our previous studies (e.g. Havlicek et al. 2006), we advocated the use of armpit pads instead of T-shirts as media for body odor collection as with T-shirts, the source of the odor cannot be specified. It is possible that for testing the effect of armpit hair the T-shirt method would be more suitable. At this point this issue remains only speculative as the validity of methods used in human chemical ecology has scarcely been tested (for a full discussion see, Lenochova et al. 2009).

In sum, our study shows that axillary hair shaving has an impact on body odor quality and intensity. However, the effect is relatively weak and was not observed in all experiments and also not when the hair was relatively short. One-shot shaving seems to have a relatively short-term effect as the development of an odor similar to unshaved axilla in one-shot shaved axilla was observed as early as after 1 week of hair regrowth. On the other hand, odor development of regularly shaved axilla after regrowth seems to be more profound as it differed from shaved axilla after 6 weeks. Our results are, in general, consistent with the idea that axillary hair developed for the retention of chemicals which may serve in chemical communication (Cohn 1994) and contribute to our emerging understanding of the complex nature of human chemical ecology.

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Conflict of interest The authors declare that they have no conflict of interest.

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