
Human Axillary Odor: Are There Side-Related Perceptual Differences?

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Abstract

Most studies on perception of human social odors in axillary sweat do not distinguish between samples from the right and left axillae. However, each axilla might not produce identical odor samples due, for instance, to the increased use of one arm as a result of lateralization. The aim of the present study was to test whether odor samples from the right and left axillae provided by right- and left-handed men were perceived differently by female raters. Participants were 38 males and 49 females, aged 19–35 years. Fresh odor samples (cotton pads worn underarm for 24 h) were evaluated for attractiveness, intensity, and masculinity, with left and right samples being presented as independent stimuli. A side-related difference emerged in left-handers only (no difference in right-handers): The odor from the axilla corresponding to the dominant side (left) was rated more masculine and more intense than the other side (right). This effect was limited to the ratings of a restricted group of females, that is, those who did not take hormone-based contraception and were estimated to be in the fertile phase of their menstrual cycle. In conclusion, future studies using axillary odor samples can consider left and right samples as perceptually equivalent stimuli when the participant samples are representative of the general population, which comprises relatively low proportions of left-handed men and spontaneously ovulating fertile women. The results also provide new evidence of the variation of female sensitivity to biologically relevant stimuli across the menstrual cycle.

Key words: axillary odor, body odor, contraception, handedness, menstrual cycle, sweat

Introduction

In most cases, studies on perception of human body odor from axillary samples do not consider their origin in the left or right armpits and do not specify whether samples come from one axilla or are a mix of both sides. In cases where the source is reported, some authors choose one side randomly (Havlicek and Lenochova 2006) or arbitrarily (Doty et al. 1978), assume that either side generates equivalent stimuli (Ackerl et al. 2002), or use one side as a control, whereas the other is undergoing a specific treatment (Heckmann et al. 2003). Although the latter study showed no intensity or pleasantness differences between odors sampled from the left and right axillae, recent evidence suggests that significant side-related differences in axillary odor composition can be observed in humans and primates (Dapporto 2008; Kuhn and Natsch 2009). Side-related perceptual differences have seldom been assessed in humans and especially not with handedness as a potentially influential factor.

When measuring the levels of androstenone in odor samples from the left and right axillae of 6 men, Bird and Gower

(1982) found that the axilla providing the highest level of androstenone “correlated with the handedness of the subjects, except for one individual” (p. 519). The fact that handedness “may correspond to the increased use of one arm” (p. 521), that is, the dominant arm, was suggested to cause such differences in axillary odor composition. A similar hypothesis has been proposed in a study on bromidrosis (excessive odor) to explain why the right axilla is more often reported to emit a more offensive odor than the left (Inaba M and Inaba Y 1992).

Axillary odor originates from initially odorless secretions of sweat and sebaceous glands (for reviews, see Stoddart 1990; Schaal and Porter 1991). Part of the compounds carried in these exocrine secretions is substrates for bacterial growth and can be transformed into odorous volatiles through enzymatic action of local skin microflora (Bird and Gower 1982; Rennie et al. 1991). As microbial population density does not appear to differ between left/right and dominant/nondominant sides of left- or right-handed males and females (Leyden et al. 1981), side-related odor

differences, if any, might arise from asymmetries in the qualitative rather than quantitative composition of the microflora and/or in the level of bacterial activity (due to differential skin gland output and local temperature/humidity, these resulting from the greater activity of one arm). Variations in perceived quality and intensity of axillary odor would thus be expected. However, conclusion of Bird and Gower (1982) with regard to handedness remains speculative, due to having only 6 odor donors, who were all apparently right handed, because they focused on one specific odor compound and because they subsequently failed to replicate this finding (Gower et al. 1985). Results of Inaba M and Inaba Y (1992) based on pathological individuals are also hardly generalizable to a healthy population. Thus, it remains unclear whether there is a side-related difference in the perceptual quality of axillary odor linked to arm lateralization. The present study aimed to clarify this issue.

Whether left and right axillary odor samples are perceptually different has methodological implications for research on body odor perception. Unlike most stimuli used in psychological studies on smell (that are readily available and can be stored over long time periods), body odor samples are constrained in terms of availability and stability. Collection of axillary odor samples usually takes from one night to several days (e.g., Schleidt et al. 1981; Roberts et al. 2005) and involves a careful protocol controlling hygiene, diet, alcohol consumption, and smoking during up to 7 days before sampling (e.g., Doty et al. 1978; Chen and Haviland-Jones 1999; Havlicek et al. 2005; reviewed in Lenochova et al. 2009). Further, intense bacterial activity altering odor quality (Stoddart 1990) limits the “shelf life” of axillary odor samples. Samples are thus used a few hours after collection (e.g., Wedekind et al. 1995) or after being frozen for several weeks (for tests of the effect of freezing, see Roberts et al. 2008; Lenochova et al. 2009). In sum, obtaining axillary odor samples is highly demanding for participants, time consuming for experimenters, and their subsequent use as stimuli is relatively short-lived. Therefore, the issue of whether right and left odor samples can be considered as equivalent stimuli has practical implications. It would indeed be advantageous for researchers if the number of samples could be doubled in each donor (i.e., if they could use left and right samples separately as identical stimuli).

The aim of the present study was to investigate whether left and right human axillae produce perceptually differentiable odors and whether such side-related differences are related to handedness. The hypothesis addressed here was that, due to increased mobilization of the dominant arm, the ipsilateral axilla should produce an odor evaluated as more intense compared with the odor sampled from the axilla on the non-dominant side. To test this, axillary odor samples from the right and left axillae were collected from right- and left-handed men and rated as independent stimuli by a group of women.

Materials and methods

Participants

After the study was approved by the Committee on Research Ethics of the University of Liverpool, 49 males aged 19–35 years, mostly University students and staff, were recruited to provide axillary odor samples on 1 of 5 sessions. Of these, 38 were included in the data analyses (age range: 19–35, mean [M] = 24.5, standard deviation [SD] = 4.9) after removing smokers whose samples were rated less attractive and more intense ($P < 0.05$ and $P = 0.095$, respectively, independent samples t -tests). Among these 38 donors, 23 were right-handed and 15 left-handed, according to the Edinburgh Handedness Inventory (Oldfield 1971) that gauged their hand, eye, and foot preference in executing 12 actions (among which 10 involved the hands). Distributions of right- and left-handed men were, respectively, 5/2 in session 1, 6/3 in session 2, 6/2 in session 3, 2/5 in session 4, 4/3 in session 5.

Fifty females aged 19–34 years were allocated equally to 5 groups and rated the odor samples from 8 to 11 males during 1 of 5 sessions. Although it would be preferable to have had all donors evaluated by all raters, this was not possible because of the difficulty in getting raters to attend 5 fixed sessions. Furthermore, had all men donated samples on the same day, this would have presented too many samples for women to rate due to olfactory fatigue. Female raters did not report any nasal congestion or olfactory dysfunction. They were instructed to avoid wearing perfumes on the testing day and not to smoke or eat/drink in the 30 min before the session, to avoid impairing their olfactory function. All but 1 woman, whose ratings were therefore discarded, reported menstrual cycles ranging between 21 and 40 days ($M = 28.3$ days, $SD = 3.5$). Thus, the ratings of 49 normally cycling females (age: $M = 21.7$ years, $SD = 3.3$) were used in the analyses. Of these, 26 reported taking hormone-based contraception (hereafter called by extension “pill users”) and 23 were not. Among the latter, 6 females were evaluated as being at high conception risk on the testing day (called “fertile nonpill users”, by contrast with the “nonfertile nonpill users”). To categorize cycle stage, the raters indicated the date of the first day of their last menstruation and their usual cycle length. The fertile phase of the cycle lasts 6 days (Dunson et al. 1999) and occurs just before the 14-day luteal phase (Lenton, Landgren, and Sexton 1984b), which is much less variable in length than the follicular phase of the cycle (Lenton, Landgren, Sexton, and Harper 1984a; Hodges 1987). Therefore, a backward counting method was preferred over a forward counting method based on the follicular phase; this method estimates the fertile period between days 20 and 14 from the end of the cycle (see e.g., Thornhill and Gangestad 1999). Distributions of pill users, fertile nonpill users, and nonfertile nonpill users were, respectively, 5/1/4 in session 1, 4/1/5 in session 2, 3/2/4 in session 3, 8/0/2 in session 4, and 6/2/2 in session 5.

Odor collection procedure

Male participants were instructed about how to collect axillary odors both orally and by using an illustrated instruction sheet provided with the required material. They also received reminders by email shortly before each key step of the 3-day testing period. Axillary odors were collected on oval cotton pads (9.5 × 6.5 cm, Boots, Boots UK Ltd.), fastened by the participants themselves onto their axilla with surgical Micropore tape (Boots). The pads were kept fastened for 24 h, from Wednesday morning to Thursday morning on either of 5 collection weeks (Session 1: December 2007, Session 2: January 2008, Sessions 3 and 4: February 2008, and Session 5: April 2008). Forty-eight hours before applying the pads (Monday morning), the participants began to refrain from drinking alcohol and eating strong foods (e.g., curry, chili and other spices, garlic, onion, pepperoni, blue cheese, cabbage, and asparagus). On Wednesday morning, before applying the pads, they were required to shower with a nonperfumed soap (Simple, Accantia Health & Beauty Ltd.) and not to use any scented products such as antiperspirants, deodorants, perfumes, or colognes. They also were instructed to avoid sport and sexual intercourse during the time they wore the pads. At the end of the collecting period (Thursday morning), participants placed samples from the right and left axillae in 2 distinctly identified ziplock bags. Eight to 11 participants returned their fresh samples to the laboratory on each collection day within 1.5 h after having removed them and before 10:00 AM. Questionnaires that they completed on their behaviors during the testing period (e.g., food, smoking, drinking, etc.) did not indicate any major infringements of these instructions.

Odor rating procedure

Immediately after being brought to the laboratory, odor samples were placed in separate numbered glass flasks. An unworn cotton pad was rubbed inside a plastic bag to give it the same visual aspect as the axillary samples and placed in one of the flasks to serve as a control. The flasks had a capacity of 500 mL and a diameter of 10 (bottom) and 4 cm (opening) and were 18 cm high (including 5 cm neck). They were previously washed with a nonperfumed detergent (Decon Neutracon, Decon Laboratories Ltd.), and their aperture was covered with aluminum foil.

Rating sessions took place between 11:00 AM and 6:00 PM in a well-ventilated room. The samples from 8 to 11 donors (i.e., between 17 and 23 samples including the control stimulus) were presented in a random order specified on an individualized check sheet (1 page per sample). The raters were not informed that the samples were pairs (left and right) from the same individuals, but they were aware of the nature of the stimuli. To evaluate a sample, the raters were instructed to shake the flask before removing the foil cap, to smell the sample ad libitum without touching the flask aperture with their nose, and to replace the cap immediately

afterward. The flask could be opened several times if needed. Each sample was evaluated on paper-and-pencil 9-point scales for attractiveness (ranging from -4 [not attractive at all] to +4 [very attractive]), intensity, and masculinity (ranging from 1 [not intense/masculine at all] to 9 [very intense/masculine]). The raters were instructed to take 15-s breaks between the samples and a 5-min break at mid task. Duration of the session varied between 20 and 30 min.

Data analyses

Following previous human odor studies (e.g., Wedekind et al. 1995; Roberts et al. 2008), analyses were performed using both raters and donors as units of analyses. Raw ratings and rating differences between the right and left axillae of a donor were analyzed by rater (averaged ratings given to 7, 9, 8, 7, and 7 donors in sessions 1, 2, 3, 4, and 5, respectively) to evaluate the impact of the rater's "fertility state" (i.e., pill users, nonfertile nonpill users, and fertile nonpill users). Analyses by donor were also performed (averaged ratings of 10 raters in all sessions except session 3 in which the answers of 9 raters were taken into account), without examining the effect of fertility state (due to the fact that all raters did not evaluate all donors, donors were rated by maximum 2 fertile nonpill users). First, repeated-measures analyses of variance (ANOVAs) were performed to investigate the existence of a main effect of side (difference between left and right axillae, without taking the handedness factor into account) on attractiveness, intensity, and masculinity ratings. For the analyses by rater, the fertility state factor was also included. Next, potential differences due to handedness were also investigated on 2 variables: right minus left differences and overall ratings. Here, 1-way ANOVAs (factor: handedness) and repeated-measures ANOVAs (factors: handedness and fertility state) were performed on both variables, with donors and raters, respectively, as the units of analysis. Effect size statistics were reported, using partial η^2 (percentage of variance explained by the effect) and power (acceptable when > 0.80, Cohen 1988). One-sample *t*-tests comparing the average "right minus left" difference from zero were used to determine the significance of the difference between each side.

Results

Preliminary analyses

Axillary odor quality was tested with donors as the units of analysis. On average, the axillary samples were more intense ($M = 5.18$, $SD = 1.18$ vs. $M = 3.27$, $SD = 1.94$; $t_{85} = 5.34$, $P < 0.001$, independent samples *t*-test) and more masculine than the control cotton pad ($M = 5.05$, $SD = 0.69$ vs. $M = 3.94$, $SD = 1.95$; $t_{85} = 3.34$, $P < 0.01$). Although axillary odor and control samples did not differ in attractiveness ($M = -0.33$, $SD = 0.99$ vs. $M = 0.16$, $SD = 1.85$, respectively; $t_{85} = 1.48$, $P = 0.142$), only the attractiveness of axillary samples

was significantly lower than zero ($t_{37} = 2.05$, $P < 0.05$ vs. control: $t_{48} = 0.62$, $P = 0.540$).

Attractiveness was negatively correlated with intensity ($r = -0.64$, $P < 0.001$) and masculinity ($r = -0.47$, $P < 0.01$), whereas masculinity and intensity were positively correlated ($r = 0.64$, $P < 0.001$).

Significant differences were found between sessions for masculinity only. Masculinity ratings were lower in session 5 than in sessions 2 and 3 (session effect: $F_{4,33} = 4.11$, $P < 0.01$; post hoc Tukey test for honestly significant difference [HSD] test, $\alpha = 0.05$). These differences might thus be due to chance as independent men took part in each session, rather than to a seasonal effect. The distribution of left- and right-handers and of rater fertility states did not differ across sessions ($\chi_4^2 = 4.22$, $P > 0.10$ and $\chi_8^2 = 7.24$, $P > 0.10$, respectively). Therefore, the likelihood that the following conclusions could have been influenced by differences in perceived masculinity across the sessions remains low.

Effect of side

No difference between left and right axillae was found for axillary odor attractiveness, intensity, or masculinity. Indeed, variance analyses revealed no significant effect of side (analyses by rater and by donor), no significant effect of fertility state, and no side by fertility state interaction (analysis by rater) for any of the 3 variables.

Difference between left and right axillae as a function of handedness

However, we found a significant difference between left and right axillae for intensity and masculinity ratings (but not for attractiveness) when the factor “handedness” was taken into account. With raters as the units of analysis, there was a significant main effect of handedness on the right minus left masculinity ($F_{1,46} = 8.26$, $P < 0.01$, partial $\eta^2 = 0.15$, power = 0.80) and intensity differences ($F_{1,46} = 5.69$, $P < 0.05$, partial $\eta^2 = 0.11$, power = 0.65). As shown in Figure 1, the right minus left differences were close to zero in right-handed males (masculinity: $M = 0.01$, $SD = 1.13$, 1-sample t -test $t_{48} = 0.05$, $P = 0.963$; intensity: $M = 0.04$, $SD = 1.47$, $t_{48} = 0.20$, $P = 0.839$), whereas it was negative in left-handed males (masculinity: $M = -0.33$, $SD = 1.26$, $t_{48} = 1.82$, $P = 0.075$; intensity: $M = -0.48$, $SD = 1.46$, $t_{48} = 2.31$, $P < 0.05$). This suggests that left-handed males give off a more masculine and more intense odor from their left axilla (dominant side) than from their right axilla. Moreover, the analysis yielded a significant handedness by fertility state interaction on the right minus left masculinity difference ($F_{2,46} = 4.42$, $P < 0.05$, partial $\eta^2 = 0.16$, power = 0.73). This interaction was due to the fact that the masculinity difference between left and right odor samples was predominantly found in left-handers when evaluated by the fertile nonpill users (1-sample t -test $t_5 = 4.27$, $P < 0.01$, and post hoc Tukey HSD test, $\alpha = 0.05$; Figure 2a). A similar profile was found for intensity,

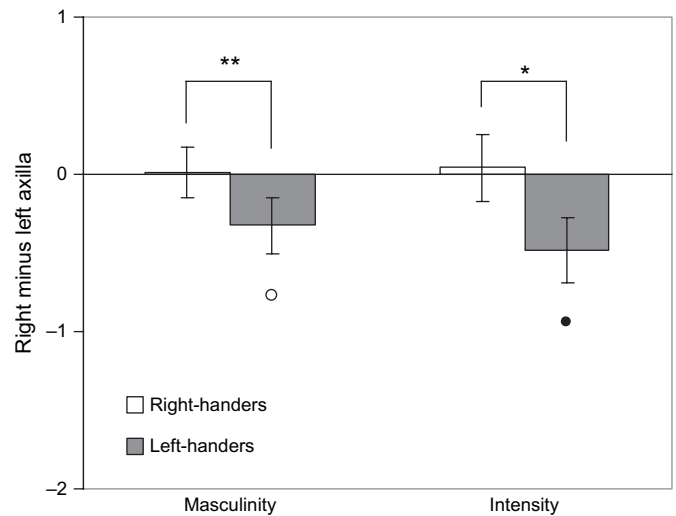


Figure 1 Odor masculinity and intensity differences between right and left axillary samples in right-handed and left-handed male donors. * $P < 0.05$; ** $P < 0.01$ (effect of handedness, ANOVA); open circle, $P < 0.10$; filled circle, $P < 0.05$ (difference to zero, 1-sample t -test).

although it was only marginally significant. There was a marginal main effect of fertility state on right minus left intensity difference ($F_{2,46} = 2.89$, $P = 0.066$, partial $\eta^2 = 0.11$, power = 0.54) and a stronger tendency of fertile nonpill users to perceive a difference between the left and right odor samples of left-handed men (1-sample t -test $t_5 = 2.26$, $P = 0.074$, and post hoc Tukey HSD test, $\alpha = 0.05$; Figure 2b). When donors were taken as the units of analysis, there was no significant effect of handedness on right minus left attractiveness, intensity, and masculinity differences (all P values > 0.304).

Effect of handedness

Direction of hand preference was not associated with differences in how axillary odor quality was evaluated (average ratings, without side distinction). Variance analyses revealed no significant effect of handedness (analyses by rater and by donor), no significant effect of fertility state, and no handedness by fertility state interaction (analysis by rater) for any of the attractiveness, intensity, or masculinity rating scales.

Discussion

The aim of the present study was to investigate the possibility of a perceived difference related to the sampling side of axillary odors. With male donors evaluated by female raters, results first showed that axillary odor samples from the left and right axillae did not differ in attractiveness, intensity, or masculinity. Second, without side distinction, right-handed and left-handed males did not differ on these dimensions either. Third, there was a significant side-related difference in left-handers only, whose dominant side (left axilla) emitted a more masculine and more intense odor than the

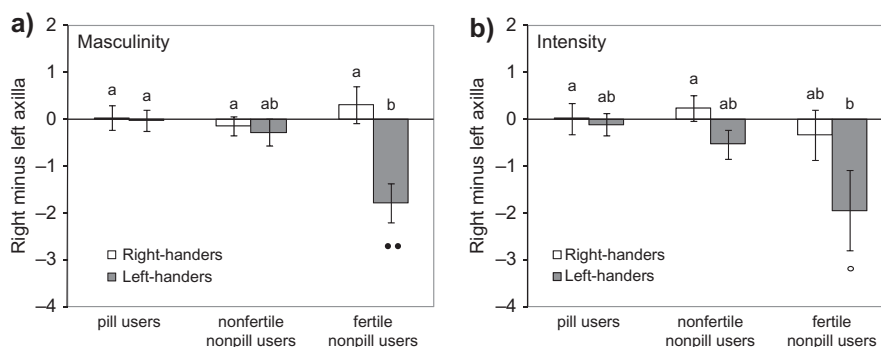


Figure 2 Odor masculinity (a) and intensity (b) differences between right and left axillary samples in right-handed and left-handed male donors evaluated by pill users, nonfertile nonpill users, and fertile nonpill users. Open circle, $P < 0.10$; filled circles, $P < 0.01$ (difference to zero, 1-sample t -test). Letters a and b identify significantly different groups according to a post hoc Tukey HSD test ($\alpha = 0.05$).

nondominant side. These effects were mainly due to perception of female raters who did not use hormone-based contraception and who were likely to be in the fertile phase of their cycle. Although it may be expected that these women were the most likely to detect any such effects (cf. Roberts et al. 2008), these raters accounted for a relatively small proportion of the sample and analyses thus had only moderate statistical power. In addition, left-handers and fertile nonpill users represent only a minority in the general population (about 10% left-handers; Raymond et al. 1996). Therefore, the main conclusion for future studies is that left and right male axillary samples can be considered as perceptually equivalent in attractiveness, intensity, and masculinity, when participants are representative of the general population and are recruited without specific selection on handedness or contraception/fertility variables. However, future studies such as those interested in perceptual differences related to conception risk, in mate-choice contexts for instance, might find it safer to recruit only right-handed donors if they intend to use separately left and right samples as comparable stimuli (e.g., to run 2 evaluation sessions in parallel). Some studies may also involve other configurations than the one investigated here (e.g., female donors, male raters) or might be unable to collect information about handedness or contraception/fertility. As a precaution in these cases, left and right samples might be combined (e.g., to maintain the number of available stimuli, pads could be halved and samples reconstituted with half a pad from each side).

Although side-related differences appear only under certain conditions in the present study, it brings new evidence and raises important questions in the domain of social odor perception and emission. First, only female raters who did not take hormone-based contraceptives (spontaneously ovulating) and were potentially fertile detected a difference in intensity and especially masculinity between left and right axillae. Sensitivity to a large variety of odorants is higher during the fertile phase of the menstrual cycle than in other phases in spontaneously ovulating women (Le Magnen 1952; Doty et al. 1981; Grillo et al. 2001; Navarrete-Palacios et al.

2003), whereas women in their nonfertile phase have similar levels of sensitivity as women using hormonal contraception (Caruso et al. 2001). In addition, this sensitivity peak around ovulation might be specific for compounds with a strong biological significance, as shown by Lundström et al. (2006) for androstadienone, a molecule secreted in the male axillary region (Gower et al. 1994; Saxton et al. 2008), compared with other odorants. Our results, however, do not reveal general differences in intensity ratings between rater groups, which one might have expected. Rather, they show a better ability to detect subtle side-related differences in intensity and, above all, masculinity. This result is nonetheless consistent with the idea that there is an increased awareness of stimuli that are closely related with mating and fertilization issues, at the time of ovulation (Lundström et al. 2006). Human social odors are indeed believed to facilitate selection responses optimizing outbreeding. It is likely that women rely particularly on masculinity features of body odor in this context, as they do in other modalities during their fertile window (faces, voices; reviews in Jones et al. 2008; Roberts and Little 2008). In addition, stronger odors are more likely to be considered as emanating from a man (Doty et al. 1978), and intensity and masculinity are highly correlated in our study. Therefore, it is also conceivable that higher sensitivity of women around ovulation leads them to be more sensitive to odor intensity and hence to variation in perceived masculinity.

Second, higher perceived odor masculinity and intensity on the dominant side, at least in left-handers, are in line with previous observations on asymmetries in axillary odor composition (Bird and Gower 1982) and rate of sweat production (Inaba M and Inaba Y 1992). These side-related differences might be the consequence of a higher odor production rate on the dominant side. The axilla on the more active side of the body might be warmer (due to increased blood flow) and more humid and thus harbor greater quantity of odorous volatile precursors (due to higher sweating rate). These slight variations in local environmental conditions would result in an increased activity of some microorganisms on the dominant side, releasing more and/or different odorous

compounds that lead to a more perceptually intense odor. As masculinity judgments are closely linked to, and could result from, odor intensity (Doty et al. 1978; Schleidt 1980; Havlicek and Lenochova 2006), the dominant side would also smell more masculine. But if this is so, why would this effect apply to left-handers only? One hypothesis is that there exists an underlying activity-independent asymmetry that makes the left axilla smell stronger and that the superimposition of the activity-based asymmetry described above would balance both sides in right-handers but emphasize the asymmetry in left-handers. Such a basic asymmetry is undocumented in humans—although sodium levels in sweat have been reported to be higher in the left axilla (Gibinski et al. 1971). Confirming this hypothesis would require further investigation of links between handedness and arm motor activity, as well as between motor activity, bacterial ecology, and odor production.

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