

Chemosensory Cues Modulate Women's Jealousy Responses to Vocal Femininity

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Abstract

Jealousy responses to potential mating rivals are stronger when those rivals display cues indicating higher mate quality. One such cue is vocal femininity in women's voices, with higher-pitched voices eliciting greater jealousy responses. However, cues to mate quality are not evaluated in isolation. The steroid androstadienone (AND) is a putative sex pheromone that makes women perceive ambiguous stimuli as more masculine. We hypothesized that AND would decrease the association between vocal femininity and jealousy, as it induces a perceptual bias that is incongruent with the femininity of the voice. In a double-blind, within-subjects study, 70 heterosexual Chinese women in the periovulatory phase of their menstrual cycle came to the laboratory twice to listen to pairs of voices manipulated to sound more or less feminine. For each pair, the participants selected the voice that would elicit more jealousy if flirting with their partner. The results showed that vocal femininity provoked jealousy under control conditions, replicating previous findings. However, this effect was weakened when women were exposed to AND, suggesting that AND disrupts sensitivity to vocal cues about mate quality in same-sex competition. These results demonstrate a contextual modulation of jealousy responses to sexual rivals.

Introduction

Jealousy is a key psychological mechanism affecting romantic relationships. It arises when individuals perceive potential threats to their partnerships from others who exhibit high mate quality cues (Dijkstra & Buunk, 1998, 2001, 2002). Such threats trigger jealousy responses aimed at protecting relationships from rivals (Buss et al., 2000). Moreover, the intensity of the jealousy reactions correlates with the perceived mate quality of the rival, according to the mate quality–jealousy hypothesis (Lei et al., 2017). Specifically, individuals who display higher mate quality cues elicit more intense jealousy reactions from same-sex individuals compared to those displaying lower cues (O'Connor and Feinberg, 2012). The mate quality can be enhanced by emphasizing sexually dimorphic features, as attractiveness is positively associated with exaggerated sex-typical characteristics (Little et al., 2011). Consequently, higher sexual dimorphism provokes greater same-sex jealousy (Lei et al., 2017; O'Connor and Feinberg, 2012).

Human voices exhibit strong sexual dimorphism, with female voices typically having higher pitch than male voices (e.g., Chen et al., 2022; Puts et al., 2016). Higher-pitched voices are perceived as more feminine, indicating more feminine facial features and greater attractiveness, thus signaling good mate quality (Feinberg et al., 2005; Smith et al., 2016; Hughes & Puts, 2021; Pisanski & Puts, 2023; Puts et al., 2012 for reviews). However, some studies indicate that the relationship between female voice pitch and attractiveness may not be linear (Borkowska & Pawlowski, 2011; Cussigh et al., 2020) and Pisanski et al. (2018) found that men preferred low-pitched female voices. Vocal features influence mating perceptions through their association with underlying mate quality. For instance, higher-pitched voices in women may be associated with better health (Vukovic et al., 2010) and reproductive success (Atkinson et al., 2012). The pitch–reproduction link may stem from inherent estrogen levels (Feinberg, 2008). While androgens generally lead to a deeper voice pitch, estrogens are believed to counteract this effect (see Lindholm et al., 1997; see also Zamponi et al., 2021 for an overview). Furthermore, high inherent estrogen

levels within the normal range indicate fertility and conception likelihood (Venners et al., 2006). Therefore, a higher-pitched female voice may signal mate quality through the association between estrogen and fertility (Abitbol et al., 1999; Atkinson et al., 2012; Pipitone & Gallup, 2008; Klatt et al., 2020). Nevertheless, Puts et al. (2013) found no between- or within-female associations between estradiol and F0 in a sample of 202 women. At the perceptual level, research consistently shows that higher-pitched female voices are perceived as more feminine and attractive by both sexes (e.g., Puts et al., 2011).

Vocal femininity is positively associated with jealousy. For example, feminine female voices elicit greater jealousy in heterosexual women when they imagine their romantic partner interacting with such individuals, supporting the mate quality-jealousy hypothesis (O'Connor & Feinberg, 2012; Puts et al., 2011). Furthermore, women may have more aggressive thoughts toward women with higher-pitched voices, especially when they are primed with long-term mating goals (Zhang, 2016). Recently, a large cross-cultural study across 22 countries found that women tended to choose higher-pitched female voices as sounding more flirtatious and more attractive to men (Aung et al., 2024). These findings confirm that women's vocal femininity (i.e., high-pitched voice) triggers increased jealousy from other women.

Social judgments of sexually dimorphic features (e.g., the jealousy–femininity link) may be affected by other factors, such as chemosignals. Androstadienone (androsta-4,16,-dien-3-one; AND), a putative human sex pheromone, occurs naturally in male semen, axillary hair, and axillary skin surface (Gower & Ruparelia, 1993). AND can influence human social cognition and decision-making. For instance, AND has been shown that it increases women's perception of ambiguous information toward masculinity (Zhou et al., 2014) and enhances women's perceived attraction to men and masculine features (Cornwell et al., 2004; Niu & Zheng, 2020; Saxton et al., 2008; but also see, Hare et al., 2017; Lundström & Olsson, 2005). Additionally, AND can induce submissive and withdrawal responses during competitive social

interaction, indicating that AND may act as a dominance threat (Banner et al., 2018; Banner & Shamay-Tsoory, 2018). These findings indicate that AND affects both sexual dimorphism perception and social cognition, and may therefore potentially influence women's jealousy responses.

In the current study, we investigated how AND affect women's jealousy responses to other women's vocal femininity. Given that AND causes stimuli to be perceived as more masculine (Zhou et al., 2014), we propose that when AND is paired with incongruent stimuli (i.e., female stimuli), it may weaken women's jealousy judgments that are associated with the vocal femininity of other women. Therefore, we hypothesize that AND will weaken the association between women's jealousy and other women's vocal femininity.

Methods

Participants

Using campus advertising, we recruited 70 healthy Chinese female student volunteers ($M_{\text{age}} = 20.59$ years, $SD = 1.53$; age range = 18–24) from a local university to participate in this study. All of the female participants were tested during the estimated periovulatory phase of their menstrual cycle (i.e., around the time of ovulation), which was estimated using the backward counting method with the confirmed onset of next menses (see the procedure section for details). We chose women in the periovulatory phase because women's jealousy varies depending on the menstrual phase, with higher levels of jealousy reported when they are fertile than when they are not (Cobey et al., 2012). Data from 10 participants were removed because five participants did not complete the study and five participants reported an irregular menstrual cycle (i.e., the length of menstrual cycle beyond the scope of 25–35 days, Schmalenberger et al., 2021). Thus, our final sample for analysis included 60 participants ($M_{\text{age}} = 20.52$ years, $SD = 1.53$). This sample size was adequate to detect a moderate effect of AND on sexual dimorphism related perception (Cohen's $d = 0.6$,

Zhou et al., 2014), at 95% power, which requires a minimum of 39 participants. Additionally, individuals with psychiatric/neurological disorders or taking psychotropic medications were not eligible to participate. All of the participants self-reported as heterosexual (Kinsey score = 0) with normal hearing, normal sense of smell, and no respiratory conditions. The participants were asked to abstain from smoking, consuming caffeine, alcohol, and any behaviors that could cause strong odor (e.g., use of perfume, strong-smelling cosmetics, and strong-smelling foods) for 24 h before the experimental session. All of the participants provided written informed consent. They were paid RMB40 (~US\$6) per hour. The University Ethics Committee approved the experimental procedures, which were in accordance with the Declaration of Helsinki.

Voice Stimuli

The voice stimuli were derived from 20 voice samples of young Chinese women (age range 18–35 years), which were recorded using an Audio-Technica AT-4041 cardioid condenser microphone at a sample rate of 44.1 kHz at 16-bit amplitude quantization. The stimulus sample size was decided based on previous studies with similar task paradigms (e.g., Aung et al., 2024; Jones et al., 2018; Watkins et al., 2010). The voice providers came to the laboratory and recorded their voices in person, and were different from the participants who took part in the jealousy judgment task. The word “Hi” (“嗨” in Chinese) was extracted from each recording. Then, we increased or decreased the pitch of each voice by 0.5 equivalent rectangular bandwidth (ERB) to create a more feminine (i.e., higher-pitched) and a more masculine (i.e., lower-pitched) version of the voices using the pitch synchronous overlap add method (PSOLA, France Telecom) in Praat software (Boersma & Weenink, 2013). This method alters the pitch of a voice while keeping all other aspects of the acoustic signal relatively constant (Feinberg et al., 2005). This manipulation has been widely used in other studies of human voice perception (e.g., Montano et al., 2017; Puts et al., 2011). By following this protocol, we created 20 pairs of female voice stimuli, and

the F0 range of feminized voice were from 235 Hz to 315 Hz and F0 range of masculinized voice were from 188 Hz to 259 Hz (see supplementary material for the fundamental frequency of each voice).

Olfactory Stimuli

There were two olfactory stimulus conditions: the AND solution (500 μM in 1% v/v clove oil propylene glycol solution) and the carrier solution (control condition, 1% v/v clove oil in propylene glycol). The concentration of AND used in our study (500 μM) is comparable to that of freshly produced apocrine sweat and is therefore arguably ecologically relevant (Gower et al., 1994). The olfactory stimuli were presented in two identical 40 ml polypropylene jars, each holding 5 ml of a clear liquid and connected by a Y-structure to two Teflon nosepieces. The utility of a clove oil carrier solution to mask odors produced by AND has been consistently validated (Ye et al., 2019; Zhou et al., 2014). Additionally, both the AND solution (500 μM in 1% v/v clove oil propylene glycol solution) and the carrier solution (control condition, 1% v/v clove oil in propylene glycol) have been shown to be perceived with comparable levels of pleasantness, intensity, and familiarity (as suggested by Ye et al., 2019).

Procedure

Participant prescreening was conducted online, with potential female participants being asked about the average length of their menstrual cycle over the past three months. Menstrual cycle length was defined as the number of days between the onset of two menses (e.g., Gangestad et al., 2016; Puts, 2006). If the participants reported that their length of last menstrual cycle beyond the scope of 25–35 days (Schmalenberger et al., 2021), they would remain on the waiting list until their last menstrual cycle was between 25 and 35 days. Before participating, the participants were asked when their last menses started, and the backward counting method was used to calculate their estimated ovulation date (Gangestad et al., 2016), based on their average menstrual cycle length over the past three months. Additionally, the

onset of their next menses was confirmed by the participants when their next menstrual cycle started. All of the female participants were tested during the periovulatory phase of their menstrual cycle.

On the day of the test, the participants were unaware of the purpose of the experiment. Upon arrival, they completed an informed consent form and a demographic information form. Next, they were randomly assigned to one of two experimental conditions, namely the AND condition or the control condition, and completed the experimental task.

The experiment was conducted on a computer in a quiet room in the laboratory, with the participant alone. The laboratory window was opened at least one hour before the participants arriving to eliminate odors and maintain ventilation during the experiment. During the voice judgment task, the participants were continuously exposed to either the AND solution or the control solution. They held the jar with their non-dominant hand, positioned the nosepieces inside their nostrils, and continuously inhaled through their nose and exhaled through their mouth while performing the experimental task.

This study employed a within-subjects design. After a gap of one day, the participants returned to the laboratory at the same time of day. They were assigned to the other condition (i.e., first the AND condition, then the control condition, or first the control condition, then the AND condition) and completed the same task again. After the experiment, the participants were asked to report the start date of their next menses. Using the actual start date of their next menses, the actual length of their menstrual cycle was calculated. Then, the test days were converted to a normalized 28-day cycle using the following formula: $(\text{days from the onset of last menses} / \text{actual menstrual cycle length}) * 28$. However, if the participants' actual menstrual cycle length beyond the scope of 25-35 days, they were excluded from the analysis because of their irregular menstrual cycle, and their data were removed. The testing time in menstrual

cycles days (normalized) were not significantly different between the AND ($M_{\text{days}} = 14.81$, $SD = 3.15$) and control condition ($M_{\text{days}} = 14.75$, $SD = 3.60$), $t(59) = 0.24$, $p = .810$.

Voice judgment task

In the voice judgment task, the participants were given the following instructions (in Chinese) following O'Connor and Feinberg (2012): “You will hear two female voices. Select which voice would make you more jealous if flirting with your romantic partner. If you are not currently in a romantic relationship, please imagine that you are.” Each participant was presented with the 20 pairs of female voices (each pair consisting of a feminized version and a masculinized version of the same voice, each lasting less than 1s). The trial order and presentation order of the feminized and masculinized versions of the voices (within trials) were fully randomized. All voices were set to a constant volume before the experiment and played through headphones.

Results

The participants' responses to the voice judgment task were analyzed using mixed binary logistic regression analyses in R version 4.1.0 (R Core Team, 2021), with lmerTest version 3.1.0 (Kuznetsova et al., 2017). Before analysis, the variables were re-coded. The dependent variable of the forced-choice option was a binary choice, dummy coded as 0 = masculinized voice (i.e., lower-pitched) vs. 1 = feminized voice (i.e., higher-pitched). The independent variables were effect coded: olfactory condition as control condition (- 0.5) vs. AND condition (+ 0.5); order of olfactory conditions as AND, then control (- 0.5) vs. control, then AND (+ 0.5). In each model, olfactory condition, order of olfactory conditions, and their interaction were entered as fixed-effect factors. Subject ID and voice ID were entered as random-effect factors.

The intercept was significant ($beta = 1.55$, $SE = 0.13$, $z = 11.57$, $p < .001$), indicating that on average, the female participants selected the feminized voices significantly more often than the masculinized voices. This means that women felt more jealous

when they imagined a scenario in which their romantic partner interacted with women with more feminine voices. Additionally, there was a significant main effect of olfactory condition ($beta = -0.29$, $SE = 0.11$, $z = -2.72$, $p = .007$), suggesting that compared with the control condition ($M = 0.82$, $SE = 0.02$), the participants showed a reduced frequency of choosing feminine voices in the AND condition ($M = 0.77$, $SE = 0.02$) (Fig. 1). This finding indicates that AND may have affected the salience of this vocal parameter in the jealousy judgment task. In other words, in the face of intrasexual competition, AND blunted women's sensitivity to mate threat cues in other women's voices. There were no significant effects of order of olfactory conditions ($beta = -0.08$, $SE = 0.24$, $z = -0.34$, $p = .731$) or the interaction between the treatment and order of olfactory conditions ($beta = -0.24$, $SE = 0.21$, $z = -1.15$, $p = .251$), indicating that the results were not affected by olfactory condition order. Additionally, we ran the analysis again with the variable order of olfactory condition removed, and the pattern of the results remained consistent, showing that the main effect of olfactory condition was significant ($beta = -0.30$, $SE = 0.13$, $z = -2.29$, $p = .022$).

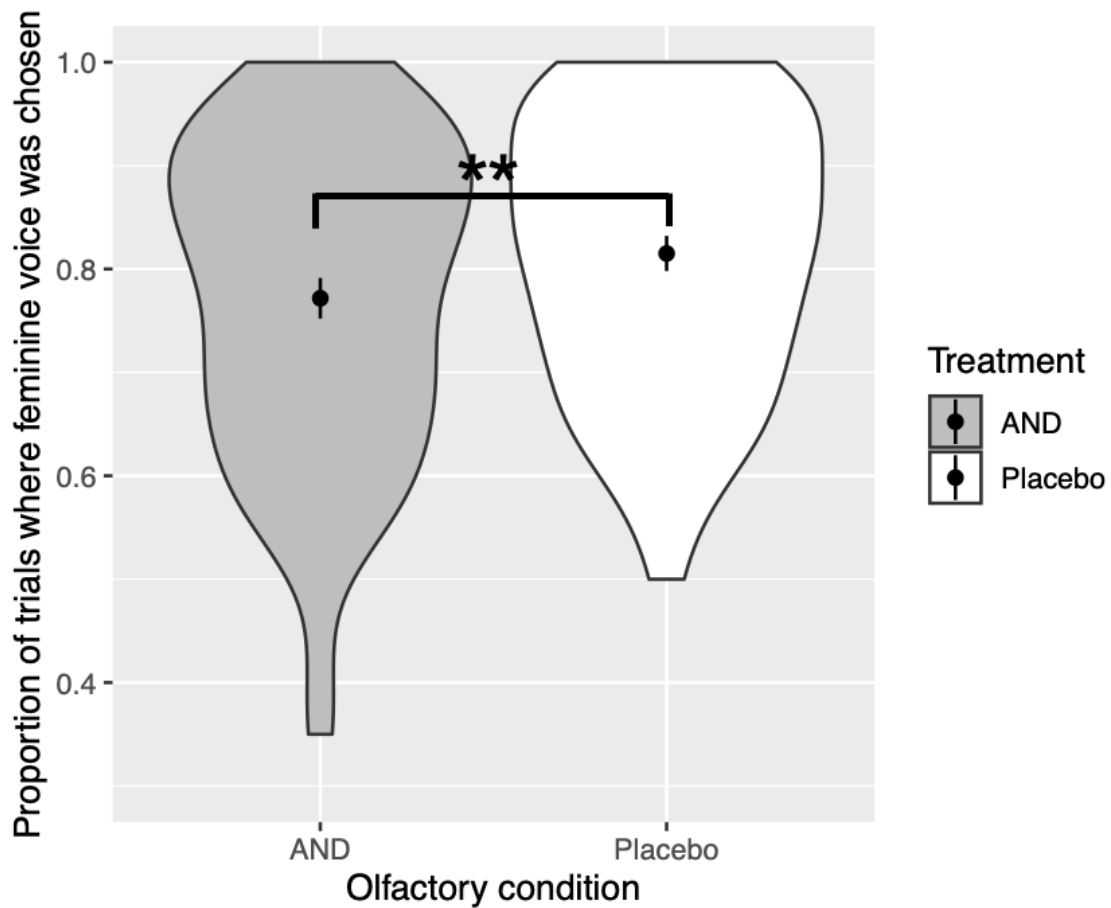


Fig 1. Results of the voice judgment task. The violin plots show the distribution of the participants' responses to other women's vocal femininity on jealousy judgment. The dots indicate the mean and the error bars represent the SE of each group. $**p < .01$

Moreover, we performed additional analyses to check the effect of AND. Specifically, we first ran a regression analysis that regressed the participants' proportion of feminine version choices the second time onto their proportion of feminine version choices the first time (model 1: using the participants' judgment data from their first participation in the experiment to predict their judgment selection during their second participation), and then included the olfactory condition variable in the next step of the regression model (model 2: add the olfactory condition variable to model 1). The results revealed that model 2 had a significantly better fit to the data than model 1, $F(1, 57) = 8.77, p = .004$, and the R-squared value increased from 47.30% to 54.33%.

This indicates that the olfactory condition played a role in explaining the changes in the participants' responses between their first participation and their second participation.

Discussion

This study investigated the effect of AND on women's sensitivity to vocal cues about potential threats when making jealousy judgments in same-sex competition scenarios. The results showed that the female participants perceived other women's voices as more jealousy-inducing when the voices were more feminine (i.e., higher-pitched), but the association between femininity and jealousy was attenuated when they smelled AND. This finding suggests that AND may blur women's sensitivity to vocal cues about potential threats from other women in same-sex competition scenarios.

The effect of AND on women's sensitivity to feminine vocal cues in jealousy judgment may be due to AND impacting on participants' perception of sexually dimorphic information (Zhou et al., 2014). This could lead to decrease the selection of feminine voices as more jealousy-inducing in the two-alternative-choice task. Specifically, Zhou et al. (2014) reported that smelling AND systematically biases heterosexual women's perception of sex-specific stimuli (gaits of walkers) as more masculine (less feminine). Moreover, women perceive higher levels of female femininity as more threatening in competitive contexts (e.g., Lei et al., 2019; O'Connor & Feinberg, 2012; Puts et al., 2011). In the current study, the female participants smelled AND while making jealousy judgments about other women's voices, in same-sex competition scenarios. Given that AND affects women's perception of sexual dimorphism, and vocal femininity is a core threat cue, AND is likely to influence jealousy judgments, leading to the selection of feminine voices moving slightly towards chance level. This may explain why we observed that when the female participants smelled AND, their sensitivity to jealousy-inducing feminine vocal cues decreased.

Sexually dimorphic cues play a crucial role in mate selection and are known to trigger jealousy in mate competition scenarios (Lei et al., 2019; O'Connor & Feinberg, 2012; Puts et al., 2011). The present study investigated the impact of incongruent sexually dimorphic cues presented in different modalities, specifically olfactory (AND) and auditory (vocal cues), on jealousy judgments. Our findings suggest that the multisensory experience of sexually dimorphic cues can have a significant influence on mating behavior. In the context of same-sex competition scenarios, the perception of masculinity/femininity in vocal cues was mediated by the presence of AND, a putative human pheromone. It is important to note that AND may not directly signal masculinity or femininity but rather influence the perception of sexual dimorphism. This nuanced role of AND in shaping perceptions highlights the complexity of how individuals interpret and respond to sexually dimorphic cues in social contexts. The results of our study raise intriguing questions about the impact of incongruent sexually dimorphic cues from different modalities on jealousy judgments. The presence of conflicting cues, such as a masculine voice with a feminine scent or vice versa, may lead to a blurring of sexual dimorphism perception, potentially affecting jealousy judgments in mate competition. This highlights the need for further research on the multisensory experience of sexually dimorphic cues in human mating. By shedding light on the interplay between olfactory and auditory cues in the perception of masculinity/femininity and its implications for jealousy judgments, our study contributes to a better understanding of how individuals navigate mate competition scenarios. Future research could delve deeper into the mechanisms underlying the integration of multisensory cues and their impact on social judgments, offering valuable insights into the complexities of human mating behavior.

Another explanation is that AND may function as a dominance signal, inducing submissive and withdrawal responses during competitive social interactions (Banner & Shamay-Tsoory, 2018). This could inhibit aggressive responses such as jealousy. However, Banner and Shamay-Tsoory (2018) only tested male participants. Research indicates that the effect of AND is not uniform across the sexes (Wu et al., 2023; Ye

et al., 2019, 2023; Zhou et al., 2014). For example, Zhou et al. (2014) found that AND only impacted heterosexual women's sexual dimorphic perception, but not in heterosexual men. Similarly, Ye et al. (2019, 2023) and Wu et al. (2023) demonstrated sex-dependent effect of AND on emotional perception and reaction. The dominance-signaling effect of AND observed by Banner and Shamay-Tsoory (2018) may be male-specific, which is also explained by the intrasexual competition of males and can be tested by replicating the effect on male participants. Moreover, women's jealousy is more strongly affected by rivals' attractiveness than to dominance (Pollet & Saxton, 2020). Therefore, the dominance-signaling explanation requires careful consideration.

Few studies have investigated the effects of AND on women's perceptions of other women. As a putative sex pheromone, previous studies have primarily focused on the effects of AND on gender perceptions of male stimuli, male attractiveness, and non-sex-related social cognition (e.g., emotion, aggression) (e.g., Hare et al., 2017; Wu et al., 2023; Ye et al., 2019, 2023; Zhou et al., 2014). The effects of AND on female stimuli perception remain largely unexplored. Based on the effect of AND observed in our study, we suggest that AND may attenuate femininity-related perceptions of female stimuli, warranting further investigation.

Our results show that Chinese women perceive other women's feminine voices as jealousy-inducing. Previous studies on jealousy judgments has focus predominantly on Western populations (O'Connor and Feinberg, 2012; Puts et al., 2011), with limited evidence from non-Western populations primarily using facial stimuli (Lei et al., 2019). Our findings align with existing literature showing that both Western and Chinese women perceive female femininity as jealousy-inducing (Lei et al., 2019; O'Connor and Feinberg, 2012; Puts et al., 2011). This cross-cultural consistency may indicate that jealousy judgments are linked to a universal biological mechanism, as briefly discussed in the introduction.

Limitations

There are limitations in the current study that should be acknowledged. First, the female participants' menstrual cycle status in the current study was self-reported and therefore may be inaccurate (Gloe et al., 2023). However, it should be noted that the purpose of collecting menstrual cycle status was not to investigate the effect of menstrual cycle or hormonal levels on jealousy judgment, but to ensure that our results were not due to menstrual cycle effects.

Moreover, we selected only participants during the periovulatory phase, as women are more sensitive to jealousy during the periovulatory phase of their menstrual cycle (Cobey et al., 2012). Future studies could investigate the effect of AND in other phases of the menstrual cycle to determine whether its effect was heightened during the ovulation phase. Indeed, the effect of AND may be heightened in ovulation phase. Given that during the ovulation phase, women are more sensitive to jealousy (Cobey et al., 2012) and to other women's voice changes (Ostrander et al., 2018), the negative effect of AND on jealousy could be more salient when the level of jealousy is high (i.e., there are more room of variance for observing the decrease in the proportion of choosing feminine voice as more jealousy). As a result, the effect of AND may more salient during the ovulation phase than other menstrual phase.

Additionally, the forced-choice method we used showed that feminine vocal characteristics influence jealousy when voices vary only in pitch, but could not show whether these effects are strong enough to influence jealousy when combined with other factors in real-world situations (e.g., the content of a conversation). The forced-choice method can be criticized for its low ecological validity because it compares voices that only differ in a single parameter. Given that the difference in percentage of choosing the feminized voice as more jealousy-inducing between the AND and control groups was 5%, the effect of AND may be smaller in more ecological everyday living environments. Nevertheless, in the comparison analysis, when the

olfactory condition variable was added to model, the R-squared value increased from 47.30% to 54.33%, indicating that AND does play a role in jealousy judgment.

Finally, individual differences (e.g., relationship status, Little et al., 2002; individuals' levels of masculinity/femininity, Pipitone et al., 2016; cultural background, Aung et al., 2024) may play a role in the social judgment of voices and, consequently, influence the results, which should be taken into account and tested in future studies.

Conclusion

In conclusion, we show the direct effect of AND on women's perceptions of jealousy from other women's vocal cues. Our study revealed that smelling AND decreased women's jealousy sensitivity toward other women's vocal femininity when they imagined a scenario in which their romantic partner interacted with other women. This demonstrates that AND can influence women's perceptions of other women and may decrease femininity related perception of female features.

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