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Subthreshold amounts of social odorant affect mood, but not behavior, in heterosexual women when tested by a male, but not a female, experimenter

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Abstract

Previously, we have demonstrated that exposure to the endogenous steroid androstadienone has the ability to modulate women's mood in that they feel more focused [Lundstrom, J.N., Goncalves, M., Esteves, F., Olsson, M.J., 2003a. Psychological effects of subthreshold exposure to the putative human pheromone 4,16-androstadien-3-one. Hormones and Behaviour 44 (5), 395–401]. Here, we tested the hypothesis that androstadienone exposure would modulate participating women's mood and corresponding behavior as measured by a sustained attention task. Thirty-seven women participated in a double-blind, within-group experiment and were tested by either a female or a male experimenter. Effects on mood, psychophysiological arousal, sustained attention, and ratings of male facial attractiveness were assessed. Sensory detection of the experimental substance was rigorously controlled for by psychophysical testing. The results showed that exposure to a non-detectable amount of androstadienone modulated women's psychophysiological arousal and mood in a positive direction but did not change attention performance or rating of facial attractiveness. Moreover, mood effects were only evident when an experimenter of the opposite sex conducted the testing. This suggests that social context is important for mood effects of androstadienone exposure in women.

Keywords: Olfaction; Mood; Pheromones; Psychophysiology; Attention; Attraction

Pheromones were first defined almost half a century ago by Karlson and Lüscher as "... substances which are secreted to the outside by an individual and received by a second individual of the same species, in which they release a specific reaction, for example, a definite behaviour or a developmental process" (Karlson and Lüscher, 1959). Although still disputed, the notion of chemical communication among humans has gained increasing support in recent literature. Recent studies on the existence of human pheromones have mostly focused on endogenous androgens present in human sweat. Several such compounds have been proposed as putative pheromones, but singled out as the most likely candidate to date is the endogenous steroid 4,16-androstadien-3-one [(androstadienone); Bensafi et al., 2003; Jacob et al., 2001a; Jacob and McClintock, 2000; Kovacs et al., 2004; Savic et al., 2001]. Androstadienone is a member of the family of odorous 16-androstenes and can, among others, be found in male axillary secretion with a mean value of 228 pmol/total axillary hair weight (Nixon et al., 1988). Androstadienone is also found in women, although generally in much smaller concentrations (Brooksbank et al., 1972).

Since androstadienone is most abundant in males it is considered to be a putative male human pheromone. Support for that notion can be found in the literature showing that women seem to react stronger and in a more consistent way than men to exposure (Bensafi et al., 2004, 2003; Jacob et al., 2001a; Jacob and McClintock, 2000). The most consistently demonstrated effect in the above reported studies is that androstadienone exposure modulates mood. Interestingly, one study reported no such mood effect when exposure was

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paired with a neutral stimulus (Bensafi et al., 2003). However, the social context of the test situation proved to be of crucial importance since pairing androstadienone exposure with an emotionally arousing stimulus did modulate mood of the study participants (Bensafi et al., 2004). Moreover, Jacob et al. (2001a,b) found that the presence of a man during exposure to androstadienone was necessary to elicit an autonomic reaction in women. This suggests that in order for androstadienone exposure to elicit robust responses in women, the presence of an ecologically relevant context may be necessary. That ecologically relevant cues may be needed to facilitate pheromonal responses is indeed seen in the mammalian literature (Izard, 1983). However, so far, no candidate pheromone compound has been able to fulfill the original definition's most stringent requirement of being able to release a definite behaviour.

To ascertain whether demonstrated effects are induced by pheromone-like processes rather than by differences in perception between experimental and control stimuli, most previous studies have either compared intensity ratings of experimental and control odors (Bensafi et al., 2004, 2003; Savic et al., 2001) or used a masked near-threshold concentration and compared post-test verbal descriptors in an attempt to control for perceptual differences between experimental and control stimuli (Jacob et al., 2002, 2001a; Jacob and McClintock, 2000). However, lack of differences in intensity ratings does not necessarily mean that odors are qualitatively indiscriminable, and hence they could still give rise to different associations or cognitive processes. Studies have shown that both memory associations and differences in perceived quality of odors are capable of changing mood, autonomic nervous system (ANS) tone, and cortical responses (Alaoui-Ismaili et al., 1997; Anderson et al., 2003; Robin et al., 1999; Savic et al., 2000). Moreover, verbal descriptor tests depend heavily on participants' episodic memory and may not rule out the possibility that effects are due to conscious awareness of the substance of interest (Lundstrom et al., 2003b). We think that in understanding potential pheromonal processing in humans, a fundamental step is to monitor the effects of conscious perception as well as discriminatory performance.

Exposure of women to a subthreshold amount of androstadienone has been demonstrated to induce a heightened feeling of being focused.[1] In comparison with a perceptually indistinguishable control odor, a weak but persistent feeling of being more focused was obtained in two consecutive experiments (Lundstrom et al., 2003a). The authors speculated that androstadienone activated an attention-related mechanism. Recently, Gulyas et al. (2004) found further tentative support for this notion in that androstadienone exposure in women activated cortical regions associated with attention.

To investigate whether exposure to a subthreshold putative human pheromone would modulate attention performance, we exposed women to androstadienone while performing a task tapping sustained attention. To demonstrate that potential effects in this study were not due to conscious differences in perception, the participants' ability to correctly discriminate between experimental and control solutions was assessed with a psychophysical test. To test whether potential behavioral effects of exposure to androstadienone on the attention task would require being paired with ecologically valid contextual cues, we employed two experimenters of opposite sex. Recently, studies using sweat derivate compounds have indicated that they are able to alter viewer's perception of faces (Cornwell et al., 2004; Kovacs et al., 2004). To test whether androstadienone in fact holds the ability to modulate women's percept of male faces as indicated by Cornwell et al. (2004), the participating women rated perceived attractiveness of pictures of unknown males.

In the current study, we expected that androstadienone exposure would enhance positive mood and modulate ANS tone in the tested women, but especially so when a male experimenter conducted the testing. A specific hypothesis was that androstadienone exposure would once again enhance women's feelings of being *focused* and, consequently, performance in a sustained attention task.

1. Method

1.1. Participants

Thirty-seven women with a mean age of 25.35 (S.D. = ±4.63) years with a normal menstrual cycle were recruited through posters on the campus area. All participants reported absence of nasal congestion and infection, olfactory dysfunctions, use of tobacco products, and use of any hormonal substances, including oral contraceptives, during the last 6 months. All described themselves as heterosexual. Based on self report of menstrual onset, four participants were deemed to be tested during menses (days 1–5 from menstrual onset), 14 participants in the follicular phase (days 6–14), and 19 in the luteal phase (days 15–35) of their menstrual cycle. To asses potential difference in menstrual phase between participants tested by a different experimenter, a two-tailed independent Student's *t*-test with experimenter as the between group factor indicated that there was no statistical difference, $t\ (35) = 0.99$, P = ns. There were no significant effects of menstrual cycle phase for any of the dependent measures. Further, participants were kept naive to the experiment's main hypotheses and the identity of all stimuli involved. Participants were first informed about the main hypotheses after the completion of the whole experiment. In response to an open question in the end of the experiment, none of the participants revealed any knowledge about the true aims of the experiment.

[1] The word *focused* in Swedish (fokuserad) relates to a state of being attentive rather than being focused at a single object or individual.

1.2. Experimental solutions

Experimental and control solutions were prepared in identical vials and then coded by an independent chemist who revealed the code first after completion of the initial statistical analyses. The experimental solution consisted of a 250 μM concentration of androstadienone (Steraloid Inc.; purity ≥98%) dissolved in propylene glycol (WVR International; purity ≥99%) with an odor mask of 1% clove oil. Consequently, the control solution consisted of propylene glycol with 1% clove oil. The concentration of androstadienone was chosen based on the fact that several other studies on exposure effects of this compound have used the same concentration (Jacob et al., 2002, 2001a; Jacob and McClintock, 2000; Lundstrom et al., 2003a). It should be noted though that the naturally occurring concentration of androstadienone in human sweat is significantly lower than the concentration used here (Nixon et al., 1988), the latter being quite near the olfactory threshold (Lundstrom et al., 2003b). The odor mask consisting of 1% clove oil was therefore applied to prevent conscious detection of the androstadienone.

1.3. Attention task

To measure if exposure to androstadienone could modulate women's level of sustained attention, a computerized attention task was constructed (Öhman Multimedia Production, Stockholm, Sweden). The task consisted of adjusting the position of a smaller square inside a constantly moving larger square at all times for 20 min with the means of a joystick securely attached to the table. Performance feedback was given during the task via colouring of the smaller square that conveyed if the square was entirely inside, borderline, or completely outside of the larger square. Attention performance was recorded as the percentage of time the participant was able to keep the smaller square inside the larger square.

1.4. Psychological measurements

A questionnaire consisting of 10 adjectives (*social*, *open*, *relaxed*, *focused*, *sensual*, *energetic*, *happy*, *heavy*, *irritated*, and *down*) was employed to measure alteration of mood. These moods have in the past been altered by exposure to putative pheromones (Jacob et al., 2002, 2001a, 2000; Lundstrom et al., 2003a). Aggregated scales have in the past been repeatedly used in this context (Jacob et al., 2002, 2001a; Jacob and McClintock, 2000). The applicability of the adjectives to their current mood was rated by the participants on a visual analog scale (VAS) that ranged from *not at all* to *extremely*. The participants made a response by placing a mark on a 100-mm horizontal line. Visual analogue scales have been shown to measure even minor changes in affect with high reliability and validity (Folstein and Luria, 1973), and this is also the type of psychometric measurement that has been used in previous research on putative pheromones (Jacob et al., 2002, 2001a, 2000; Lundstrom et al., 2003a).

At the end of the experiment, participants were asked to provide attraction ratings of different pictures of males, viewed from the shoulders up with the gaze facing the camera. Pictures were presented with the stimulus presentation program Authorware 6.5 (Macromedia, San Francisco, US) individually and in randomized order on a computer screen. The attraction scale ranged from not at all attractive (−5), via neutral (0), to very attractive (+5), and the participant responded by clicking with a mouse on the corresponding value indicated under the picture. Forty pictures were selected from an online dating service and rated for attractiveness in a pilot study ($n = 4$). From that pool, 20 different pictures were selected to cover the whole attractiveness scale. Participants' response times measured from onset of stimulus presentation to rating were also measured.

1.5. Psychophysiological measurements

Finger pulse (FP) and skin temperature (ST) were simultaneously recorded and displayed using the PSYLAB7 integrated digital system for psychophysiology (www.psylab.com) utilizing a 40 Hz sampling rate with a mechanical high pass/low pass filter consisting of 1/28 Hz for FP and 1/14 Hz for ST, respectively. These two measures were chosen as measurements of ANS activity due to their non-invasive character that limited the time needed for experimenter participant interaction. FP was recorded with an IR photoplethysmograph, of a finger clip model, placed on the index finger of the non-dominant hand and on-line reduced to pulse rate expressed as beats per minute. ST was recorded with a cotton wrapped TMP5 temperature probe placed in the canal above the capitate bone of the lower end of the palmar surface and taped in position using micropore tape. Psychophysiological measurements were only recorded during the baseline measurement and the attention task.

1.6. Procedure and experimental design

The study had a double-blind, within-groups design, and was counterbalanced for treatment. All participants ($n = 37$) were tested in two seemingly identical sessions by either a female ($n = 20$), age 28, or a male experimenter ($n = 17$), age 30. In order to limit the deviation in treatment of the participants between the experimenters, a detailed experimental protocol was followed, interaction with the participants kept to a minimum, and four pilot subjects were tested with both experimenters present. To eliminate potential carry over effects between days or deviation between sessions due to circadian rhythm, all participants were tested on two different days, at the same time of day, with 1 day between sessions. Before their first session, experimental or control, each participant reported her

demographic information by filling out a computerized questionnaire alone in the testing room to ensure privacy. Each session started with administration of the baseline mood test. Electrodes for the psychophysiological recordings were then attached followed by a 2 min psychophysiological baseline recording phase. Since previous studies have demonstrated a bimodal distribution in sensitivity to androstadienone with a subpopulation of supersmellers (Lundstrom et al., 2003b), nine repetitions of a three-alternative forced-choice discrimination test with a pre-randomized target position was administered (for a more thorough description, see Lundstrom et al., 2003a). This enabled us to screen for those with a heightened sensitivity and to assess whether control and experimental substances were indeed indiscriminable. The discrimination test started with two training trials during which the experimenter explained the task. To avoid that participants' performance revealed the substance coding to the experimenter, the participants indicated their answer in each trial by clicking with the mouse on the corresponding box on a computer screen. Following the discrimination test, the attention task was demonstrated and explained to the participant, and each participant was allowed to train on the task for 2 min. Directly after the training, the solution was applied above the upper lip with a cotton swab. The participant then performed the 20 min attention task that was accompanied by the psychophysiological recordings. After completion of the attention task, attractiveness ratings of the male faces together with response times for these ratings were then collected. The session ended with the second mood test. After their last session, participants were briefed about the true aims of the experiment. Each session took approximately 60 min with the experimenter present in the room throughout the whole session.

1.7. Data treatment and reduction

Two individuals were excluded from the experiment due to their ability to discriminate between the experimental and control solutions and were not included in the final 37 participants. The difference between the post-exposure measurement and pre-exposure measurement was calculated for each mood scale, indicating the effects of exposure to the solution within each session, and then *Z*-value transformed. Aggregated scales have in the past been repeatedly used in this context (Jacob et al., 2002, 2001a; Jacob and McClintock, 2000). To determine appropriate aggregation, the ten VAS adjectives were subjected to a hierarchical cluster analyses with squared Euclidian distance. The analyses yielded one cluster with the seven positive directed scales (*social*, *open*, *relaxed*, *focused*, *sensual*, *energetic*, and *happy*), denoted 'positive mood' and one with the three negative directed scales (*heavy*, *irritated*, and *down*), denoted 'negative mood'.

Each participant's performance on the attention task was expressed as a percentage of the total time the target was kept within the randomly moving square. Due to malfunction of the computerized attention task in the control session for one participant tested by the male experimenter, attention task scores for only 36 participants were included in the analyses. Attraction rating scores were transformed into an 11 grade scale and averaged into a mean rating. Response times were averaged into mean response time values (in seconds) and transformed into logarithmic values to control for the positive skewness associated with the distribution of reaction time responses (Miller, 1988).

All psychophysiological recordings were analyzed off-line with the integrated data analysis program PSYLAB 7. Absolute values for FP in each minute of recording in the attention task phase were averaged into average per minute values and expressed as differences from the averaged baseline recording. The difference from the first to the last minutes of the attention task recording was finally calculated to represent total change. Values for ST were reduced to reflect magnitude of temperature change over the recording period in comparison with the average for the baseline recording. In order to be able to compare between participants and to statistically neutralize the law of initial value error, both ST and FP scores were transformed into *Z*-scores (Stern et al., 2001). Moreover, in order to be able to assess effects on general psychophysiological arousal, FP and ST were equally weighted in respect to each variable's direction of effect and combined into a general psychophysiological index as previously described by others (Bensafi et al., 2003; Stern et al., 2001). We here define general psychophysiological arousal as the accumulated physiological effects of androstadienone exposure on participant's autonomic nervous system (Cacioppo et al., 1991).

General effects due to treatment on each variable were assessed with repeated measurements analysis of variance (ANOVA) with effect of treatment used as a within-subject variable and experimenter as a between-subjects variable. Results from the discrimination test were analyzed as the difference from chance performance (three correct choices) with a one-tailed Student's *t*-test. Further, main effect of treatment on the attention task was assessed with a Student's *t*-test.

2. Results

A Student's *t*-test revealed that there was no difference from the expected chance level in performance in the discrimination tests for participants in either the androstadienone ($2.9 \pm .22$) or control session ($3.1 \pm .24$), all Ps $> .64$. The participants could not discriminate between the experimental and control solutions. We therefore conclude that the demonstrated effects reported below are caused without conscious awareness of the androstadienone present in the experimental solution.

2.1. Psychological variables

ANOVAs of the general positive and negative mood variables revealed that the participating women reported significantly stronger overall positive mood, F (1, 35) = 10.07, $P < .01$, and a tendency to experience a decrease in overall negative mood, F (1, 35) = 3.50, $P < .10$, when exposed to androstadienone in comparison to the control substance. Although only marginally significant but in line with our directed hypothesis, effects for the single mood scale *focused* indicated that women also in this experiment felt more focused during exposure to androstadienone than during the control odor, t (36) = 1.69, $P = .05$.

Another hypothesis of this study was that an experimenter of opposite sex (i.e., male) would facilitate effects due to androstadienone exposure. There was a main effect of sex of experimenter for both 'positive mood', F (1, 35) = 8.13, $P < .01$, and 'negative mood', F (1, 35) = 4.77, $P < .05$. Moreover, a significant interaction between sex of experimenter and exposure type in the 'positive mood' variable shows that androstadienone exposure induced a stronger positive mood when tested by a male experimenter than a female experimenter, F (1, 35) = 14.82, $P < .01$. In fact, when tested by a female experimenter, exposure to androstadienone had virtually no effect at all (see Fig. 1a). Similarly, in the presence of a male, but not a female experimenter, the women experienced a decrease in negative mood in comparison with the control session, F (1, 35) = 10.44, $P < .01$ (see Fig. 1b). With respect to our previously reported finding that exposure to androstadienone made women feel more focused, a repeated measures ANOVA indicated that there was a marginally significant interaction between sex of experimenter and treatment on the mood variable *focused*, F (1, 35) = 4.05, $P = .05$. Moreover, two-tailed Student's t-tests between treatments on the variable *focused* for each experimenter revealed that a male experimenter was indeed a necessity for that response. Women felt significantly more focused due to treatment when a male experimenter was in the room, t (16) = 2.21, $P < .05$, but there were no effects in the presence of a female experimenter, t (19) = .09, P = ns.

2.2. Measures of attention and attraction

Even though women in this study reported feeling more focused during exposure to androstadienone than during a control odor, a Student's t-test revealed no significant performance difference in the attention task between the androstadienone and control sessions, t (35) = .36, $P = .65$. On average, during exposure to either androstadienone or control, the participants were able to keep the smaller square inside the larger at 36.83% (S.E. ± 2.89) and 35.99% (S.E. ± 2.84) of the time, respectively (see Fig. 2). Contradictory to our hypotheses, there were no significant main, or interaction effects, due to exposure or sex of experimenter (all Fs < .29; all Ps > .42) on performance in the attention task.

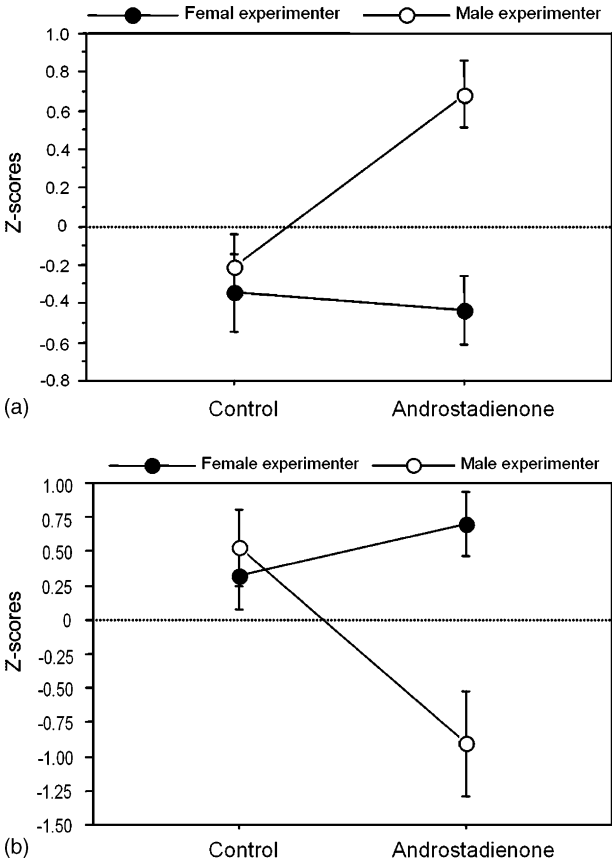

Fig. 1. (a) Effect of exposure to androstadienone on the positive VAS adjectives expressed as Z-scores. (b) Effect of exposure to androstadienone on the negative VAS adjectives expressed as Z-scores. Filled circles indicate participants tested by a female experimenter and open circles indicate participants tested by a male experimenter. Error bars denotes S.E.M.

Fig. 2. Participant's performance in the sustained attention task as percentage of time inside the target square, subdivided by condition and sex of experimenter. The black bar indicates participants tested by a female experimenter and striped bar indicates participants tested by a male experimenter. Error bars denotes S.E.M.

The relatively low performance level together with the high inter-individual variation of participant's results in the attention task raises the possibility that individual skills might have an impact on treatment effects in the attention task. In order to assess if personal skills had such an influence, participants were divided into low and high performers depending on their attention task results in the control session. However, an ANOVA with performance on the attention task and sex of experimenter as a between-subjects variable and effect of treatment as a within-subject variable showed that there was no significant main or interaction effects (all $Fs < .94$; all $Ps > .33$).

Lastly, there were no significant main or interaction effects of exposure on either attractiveness ratings (all $Fs < 1.06$; all $Ps > .31$) or their log-response times (all $Fs < 1.97$; all $Ps > .17$) of the presented pictures.

2.3. Psychophysiological recordings

An ANOVA showed that there were no significant main effects of either exposure or sex of experimenter on participant's general psychophysiological arousal index (all $Fs < 1$). However, there was a significant interaction effect between treatment and sex of the experimenter on the arousal index expressed in *Z*-scores, $F(1, 35) = 6{,}27$, $P < .01$. In the presence of a male, women experienced a decrease in psychophysiological arousal consisting of 0.68 units (S.E. ± .38) due to androstadienone exposure if tested by a female experimenter (see Fig. 3). In contrast, women tested by a male experimenter expressed an increase in psychophysiological arousal consisting of 0.99 units (S.E. ± .39).

3. Discussion

The current study suggests that exposure to a non-detectable amount of the steroid androstadienone affects women's mood. Women reported an increase in overall positive mood and a decrease in overall negative mood while exposed to androstadienone. There is now an increasing amount of evidence indicating that androstadienone has the ability to modulate primarily, but not exclusively, women's self-reported mood. However, to fit a more conservative definition of a human pheromone, exposure of a pheromone candidate substance should not only alter discrete measures such as those of mood and physiology but also enhance behavioral responses as measured by test performance or actions.

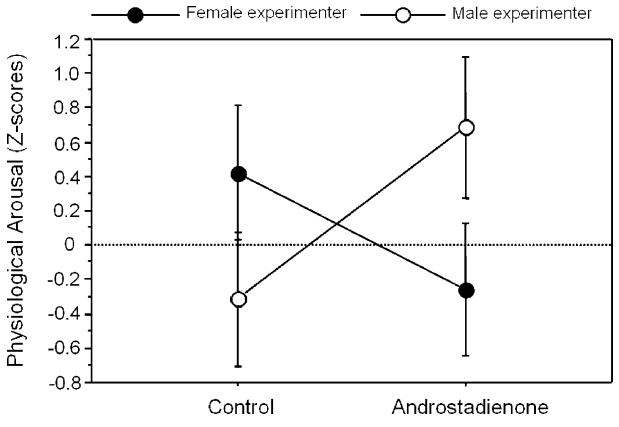

Fig. 3. Interactions effect between sex of experimenter and exposure type on the general psychophysiological index expressed in *Z*-scores. Filled circles indicate participants tested by a female experimenter and open circles indicate participants tested by a male experimenter. Error bars denotes S.E.M.

Previous studies have discussed modulator pheromones (Jacob and McClintock, 2000). As noted, one study showed interactions between steroid exposure and experimenter sex (Jacob et al., 2001a). The current study showed that exposure to androstadienone did indeed interact with experimenter sex even when conscious odor experience of the experimental substances was rigorously controlled. Changes in women's self reported mood and general arousal were evident only when there was a man present in the room during testing. Only one experimenter of each sex was used to test the participants, which limits somewhat the conclusions we can draw from this study alone. Any differences between experimenters could be derived from their differences in personality rather than their sex, per se. Also, the presence of a male may have affected the concentration of androstadienone in the room for both control and experimental session. However, since the concentration found in the skin is much lower than that of the experimental solution and a within-groups design was employed, this may be of marginal importance. Other studies employing different methods have found similar results and the data are consistent in that effects in women are only evident with a male experimenter, the conclusion that an experimenter of the opposite sex is an important contextual cue therefore seems quite plausible.

We have previously demonstrated that exposure to a non-discriminable amount of androstadienone can increase the feeling of being focused (Lundstrom et al., 2003a). For the third time in our lab, we found that mood variables were enhanced by androstadienone exposure. In line with the persistent observation that women feel more focused when exposed to androstadienone, we investigated whether sustained attention would increase as well. There was no impact on measures of attention or otherwise any effects on attraction ratings. Although the attention task has been used extensively in electroencephalogram (EEG) recordings as a mean of measuring participants attention (Hummel and Kobal, 2001), and results of the participants were in mid range without any effects of individual skills in performing the task, one might ask whether the attention task was optimal for our purposes. Moreover, it is plausible that ecologically more suitable tasks such as judgments of characteristic related to mate preferences or more social variables are needed to demonstrate modulation of behavioral performance. However, even though several

studies, including this one, have indicated that exposure to androstadienone alters predominantly women's mood (Bensafi et al., 2003; Grosser et al., 2000; Jacob et al., 2002, 2001a; Jacob and McClintock, 2000), autonomic nervous responses (Bensafi et al., 2004; Bensafi et al., 2003; Jacob et al., 2001a), and brain activity (Jacob et al., 2001b; Savic et al., 2001), there is very little evidence of changes in actual behavior. This study was unable to demonstrate any exposure-induced changes in behavioral performance, as assessed in an attention task as well as by attraction ratings.

It has been argued that it is the context or meaning of the situation that determines if a person responds to pheromone exposure (Jacob and McClintock, 2000; McClintock, 2000; McClintock et al., 2001). More specifically, modulator pheromones are said to modulate ongoing behavior or psychological reactions to a particular context, without triggering a specific behavior or thought (McClintock, 2000). In this study, exposure to non-detectable amounts of androstadienone was indeed able to modulate the participating women's mood and psychophysiology, but only in the presence of a male experimenter; a pattern of results that corresponds well with the definition of a modulator pheromone. It may therefore be more reasonable to argue that potential human pheromones act through an interaction with basic physiological and mood processes paired with more subtle changes of higher cognitive processes, such as attention or social cognition, which guide our behavior in certain contexts. In our view, future studies on potential pheromone-like effects of androstadienone exposure should therefore also include measures of higher cognitive functions.

To summarize, exposure to a non-detectable amount of androstadienone modulated women's mood and psychophysiological arousal. However, measures of different behaviors tapping sustained focused attention as well as ratings of facial attractions did not change accordingly. Interestingly, effects were only evident when an experimenter of the opposite sex was present during testing. This suggests that social context can modulate effects of androstadienone exposure in women.

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