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# Social chemosignals from breastfeeding women increase sexual motivation

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**Abstract**

Human pheromones, a type of social chemosignal, modulate endocrine function by regulating the timing of ovulation. In animals, pheromones not only regulate ovulation but also female reproductive motivation and behavior. There is no extant evidence that humans produce social chemosignals that affect human sexual motivation or reproductive behavior as occurs in other mammals. Here, we demonstrate that natural compounds collected from lactating women and their breastfeeding infants increased the sexual motivation of other women, measured as sexual desire and fantasies. Moreover, the manifestation of increased sexual motivation was different in women with a regular sexual partner. Those with a partner experienced enhanced sexual desire, whereas those without one had more sexual fantasies. These results are consistent with previous pheromonal effects on endocrine function, and warrant further study of these social chemosignals as candidates for pheromonal processes, including their effects on other aspects of motivation and behavior.


*Keywords:* Breastfeeding; Chemosignals; Lactation; Sexual motivation; Pheromone; Reproduction

Pheromones are defined as those natural compounds produced by one member of a social group that can regulate the neuroendocrine mechanisms underlying behavior, fertility, or development of another group member. Effective in minute quantities by definition, they are specialized types of social chemosignals used for communication within a species often functioning to indicate reliably the reproductive status of other social group members (Beauchamp, 2000; Karlson and Lüscher, 1959; definitions reviewed by McClintock (2002)). Utilized by many species, there has been great interest in discerning whether humans also utilize social chemosignals as pheromones (Jacob et al., 2001b; McClintock, 2000; Wysocki and Preti, 1998). To date, several studies have shown that natural compounds found in the axillary region of men and women can trigger in women neuroendocrine responses such as altered timing of the preovulatory surge of luteinizing hormone (LH) (McClintock, 2000; Stern and McClintock, 1998) and altered LH pulse frequency (Preti et al., 2003; Shinohara et al., 2001; Wysocki et al., 2001). Thus, such natural compounds are candidates for pheromonal systems that affect behavior.

Mammalian model studies have revealed that pheromones from lactating rats and their pups increase the variability of ovarian cycles in recipient females by lengthening the cycle (McClintock, 1984; Mennella, 1988; Mennella and Moltz, 1989). They also induce reproductive behaviors—specifically, maternal behaviors—in adult conspecifics (Mennella, 1988; Mennella and Moltz, 1989). Nonetheless, there has been little research on effects of lactating women and their infants on ovarian cycles and reproductive behavior of other women with whom they interact. We have reported that natural compounds collected from lactating women and breastfeeding infants tripled the variance in menstrual cycle length for an overlapping sample of women by acting on the timing of ovulation and the life span of the corpus luteum (Jacob et al., 2004). In addition to investigating effects on menstrual cycle length, another research focus was the psychosexual impact of

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breastfeeding chemosignals on fertile women. These data are presented here.

The effects of breastfeeding compounds on sexual behavior are of particular interest because most female mammals spend a greater portion of their reproductive life spans in birth cycles of conception, pregnancy, and lactation than in spontaneous unfertilized ovarian cycles (Altmann et al., 1978; Ellison, 2001; Gudermuth et al., 1984; Hedricks and McClintock, 1985). In fact, lactation is essential for successful reproduction in mammals. Females who can coordinate their pregnancy and lactation with other females are more likely to raise offspring that survive, and do so with less effort (Mennella et al., 1990; Silk et al., 2003). The presence of women who are breastfeeding may be an indicator for fertile women that the local environment can support the energetic demands of pregnancy and lactation, particularly in agrarian contexts where food resources are variable and fertility highly seasonal (Ellison, 2001; McClintock, 2000).

Hence, the present study tested the hypothesis that social chemosignals produced during breastfeeding would increase sexual motivation of other women, and therefore may potentially serve as behavioral, as well as, primer pheromones. We also hypothesized that the availability and motivation of a sexual partner might determine how the effect of these compounds on sexual motivation and behavior is expressed, as they do sexuality during the menstrual cycle (see Bullivant et al., 2004 for a broader study of women's sexual experience during the menstrual cycle). For example, breastfeeding compounds were expected to have a stronger effect on women's sexual desire and fantasies, measures of their motivation, rather than on sexual activity, which is obviously constrained by their sexual partner. Likewise, availability of a partner might also determine whether sexual motivation is experienced as desire or fantasies. If a woman has a regular sexual partner, then increased sexual motivation can be experienced as a desire for that particular partner. But if a woman has no partner, then we hypothesized that she would be more likely to create one through sexual fantasy. To this aim, we collected natural compounds produced by both members of the breastfeeding dyad—the lactating mother and her infant. The natural compounds, collected on pads worn in the maternal axillae and over the breasts were together deemed "breastfeeding compounds," representing the breastfeeding environment in this study. We utilized a double blind, between and within-subjects controlled experimental design to investigate these hypotheses.

## Methods

The current report was part of a larger investigation of the same population of women, focusing on the effects of breastfeeding compounds on the menstrual cycle (data are reported elsewhere (Jacob et al., 2004)). Here, we summarize effects of breastfeeding compounds on reproductive motivation. Nulliparous women were studied for three consecutive menstrual cycles. During the first cycle, hereafter called the baseline cycle, each woman was exposed to pads moistened with the carrier control of potassium phosphate buffered solution (control condition). During the two subsequent experimental cycles, half of the women continued to receive pads with potassium phosphate (control group; $n = 22$) whereas the remaining women (experimental group; $n = 25$) were exposed to pads worn next to the axillae and breasts of lactating women, hereafter called breastfeeding compounds. Because each mother nursed her infant several times during the collection periods, the breast secretions most likely also contained secretions from the infant (e.g., saliva). The following sections describe the study design and methods used to collect axillary and breast secretions and to expose other women to these breastfeeding compounds.

### *Collection of breastfeeding compounds*

#### *Donors*

Axillary and breast secretions were collected from 26 lactating women (8 African–American, 18 Caucasian) living in the Philadelphia area (32.2 ± 1.4 years of age), who were feeding their infants exclusively by nursing (13 girls; 13 boys; mean age = 3.5 ± 0.3 months) and had not yet resumed menstruation. Each donor participated in the study for 5 or 10 days. All procedures were approved by the Office of Regulatory Affairs at the University of Pennsylvania and informed consent was obtained before study participation.

Because previous research has shown that dietary flavors can be transmitted to human milk (Mennella, 1995), the mothers were instructed to eat a "bland" diet low in sulfur-containing foods. To encourage compliance, they were given a list of foods and spices to avoid (e.g., garlic, onion, curry) and were asked to record all foods and beverages consumed during this period. None of the mothers reported consuming such foods or spices during the collection period.

#### *Collection procedures*

Each day of the collection period, the donors bathed without perfumed products and wore 4 × 6 in. cotton Webril™ pads (The Kendall Company, Mansfield, MA) in their nursing brassiere for approximately 8 h, after which the pads were placed in glass vials (following modified methods used by Russell et al., 1980; Stern and McClintock, 1998). Donors also wore axillary pads that were secured in place by dress shields (J. C. Penny, Plano, TX) and placed them in a glass vial separate from the vial for breast pads collected at the same time. Nylon gloves (Scientific Instrument Services, Ringoes, NJ) were worn by the women and experimenters when handling the pads. Because each mother nursed her infant several times during the collection periods (8.6 ± 0.4 nursing sessions during the day (mean ± SEM); range = 4–

13 nursing sessions), the breast secretions most likely contained secretions from the infant as well (e.g., saliva).

Control pads with carrier solution were made to match the axillary and breast pads both in moisture and appearance. Potassium phosphate ($K_2HPO_4$) buffer solution was used as the control carrier solution since the components of this fluid are similar in kind, concentration and pH to that of female sweat and breast milk (I.C.R.P., 1975; Lentner, 1981). Because the breastfeeding pads naturally varied in moisture and appearance, we applied a range of buffer solution—between 500 and 1400 microliters—on the pad and breast shields. Each experimental and control pad was cut into four sections for future distribution and then frozen immediately at −80° Celsius in glass vials identical to those used to store pads with breastfeeding compounds.

### *Exposing women to breastfeeding compounds*

#### *Recipients*

Forty-seven non-smoking, nulliparous women (62% Caucasian, 10% African–American, 2% Hispanic and 25% Other) between the ages of 18 and 35 years of age (23.2 ± 1.1 years, 25.1 ± 1.2 years; Control, Breastfeeding, respectively; $df = 45$; $t$ value = −1.6, $P = 0.25$) were recruited and retained for a 3-month study through posters, newspapers, and fliers in a university community in Chicago. Each participant had a history of regular menstrual cycles, was not using birth control pills or an IUD, and successfully prevented pregnancy by using barrier contraception both during and immediately after the study (Bullivant et al., 2004). Women had to be within 30% of ideal body mass index (21.5 ± 7 kg/m$^2$) without a history of sinus problems, frequent colds, allergy symptoms, or nasal congestion, have no reported psychiatric symptoms, within normal range of olfaction as assessed by the University of Pennsylvania Smell Identification Test (20% > normal range ≤ 100%; subjects range was 72.2% to 97.2%; Sensonics, Inc., Haddon Heights, NJ; Doty et al., 1984), and not report high levels of premenstrual tension (Steiner et al., 1980). Participants also had to successfully provide a complete data set during normal cycles. Of the excluded enrollees, many (14 out of 30 women) withdrew or were disqualified either because of the time constraints of the study or because of atypical cycles and most (27 out of 30 excluded women) did not continue past the baseline cycle.

Because preconceived ideas about pheromones could potentially influence their responses, study participants were blind to the hypotheses and the sources of the compounds. The study was presented to subjects as an examination of odor perception during the menstrual cycle; the word "pheromone" was avoided in all communications. Participants were asked to avoid wearing all perfumes or scented products for the duration of the study. They were given a list of 30 possible odors that they might receive, which included infant or sweat odors or no odor at all. They were told that the odor condition might be different for each cycle. After application of the pads containing either control solution or breastfeeding compounds, subjects were asked six questions: Did you smell anything? If yes, describe the smell (an open ended question), How strong is the smell? (not at all (0) to extremely (4)), Do you like this smell? (not at all (0) to extremely (4)), Do you dislike this smell (not at all (0) to extremely (4)), Do you think this smell affected your mood (Yes or No)? Thus we focused their attention on the odor qualities of the pads in both experimental conditions. Informed consent was obtained from each woman before participation in the study and she was paid a sum upon completion of the 3-month study. All procedures were approved by the Institutional Review Board at The University of Chicago.

#### *Procedures*

All recipient women were studied for one baseline cycle during which they were given two vials daily both of which contained a control pad to apply under their nose (Stern and McClintock, 1998). During the two subsequent experimental cycles, half of the women continued to apply two control pads under their noses (Control Group; $n = 22$), whereas the remaining women applied two breastfeeding pads: one that had been worn in the axillae and the other over the breast of lactating women (Experimental Group; $n = 25$). Thus, the axillae and breast compounds were intermixed during application. Each woman in the Experimental Group received pads from at least three different lactating women donors during each experimental cycle. Investigators who were blind to the identity of the donors and treatment condition of the subjects coded the vials containing the pads and generated the study's block sequence for allocating women to study groups. At the end of a woman's baseline cycle, after their risk of study discontinuation had decreased, these investigators also randomly assigned recipient women to the study groups using an algorithm based on the date of a woman's next menses. A different set of investigators enrolled participants, distributed the pads to the subjects, and assessed the study outcomes. The latter investigators did not know the identity of the donor, the type of pad given to the participant (i.e., breastfeeding compounds or carrier control), the cycle status of the recipient, or the method of group assignment.

Methods established in our laboratory (Stern and McClintock, 1998) were used to promote constant exposure to the natural compounds. Specifically, recipient women were instructed to use clean hands to wipe the pads under their noses on the skin above their upper lips. They did this everyday throughout the course of their daily activities, during the 3-month study. Women were asked to apply the pads in the morning and before bed and record the time of application in her daily log, a practice designed to encourage subject compliance. They were also asked to reapply the pads after any activity in which the contents of the pads might be removed (e.g., wiping mouths after meals, after a shower, exercise). This practice reduced variability in ex-

posure to the compounds. Each woman returned to the lab twice a week to receive the next set of vials, monitor consistency in application procedures, and increase compliance. The investigators who interacted with the participants were blind to whether they belonged in the experimental or control group. Under the supervision of the investigator, each applied the pads directly under her nose on the skin above the upper lip and then filled out the odor perception questionnaire described above and the mood questionnaires described below. These twice-weekly applications were conducted in a small tiled windowless room (8 × 10 ft) with five room air changes per hour. Therefore, ambient room odors were weak and there was no cross-contamination between subjects.

*Sexual motivation assessment*

Subjects recorded levels of sexual desire and occurrence of sexual fantasies and activity during each day of the 3-month study. Sexual desire was rated using a 100-mm visual analog scale indicating "the degree...you felt desire today for sexual intimacy with other people" and sexual fantasy was measured by women reporting whether they had experienced "any fantasies/daydreams today...of a sexual or romantic nature." These are standard questionnaire methods to assess self-reported psychological states and correlate with physical measures of sexual arousal (Chivers et al., in press; Folstein and Luria, 1973; Luria, 1975; Stock and Geer, 1982). Daily, women recorded whether they had experienced sexual activity, and sexual partnership was confirmed from daily sexual activity and co-sleeping records. Data from several of the 47 women were excluded from particular analyses because their data were either incomplete, always rated at the maximum throughout the study, or was a statistical outlier (>2 SD from group mean). Hence, 44 women were included in the desire analyses, 45 women were included in the sexual fantasies analyses, and 46 women were included in the analyses of sexual activity. In addition to the analyses of raw values, we presented the magnitude of these effects in terms of percent change from baseline levels. In the case of sexual fantasies, six women reported having none during the baseline cycle. Two of these were excluded from the effect magnitude statistic because the denominator was zero, preventing calculation of a percent change from baseline. The other four were included in the average because they continued to report zero sexual fantasies and their percent change score was entered as zero.

*Mood assessment*

Mood was assessed twice weekly with the expanded Positive and Negative Affect Schedule (PANAS), a 60-item scale of emotion words. Before each session, participants were instructed, "Please fill out this sheet to describe how you are feeling now." Participants rated each emotion word from 1 to 5, with 1 as "very slightly or not at all" and 5 as "extremely". Study investigators later analyzed two subscales of the PANAS: a 10-item positive affect scale and a 10-item negative affect scale (Watson et al., 1988). The minimum and maximum possible scores on both scales is 10 and 50, respectively. A subset of the women met the study's inclusion criteria and had complete mood and sexual motivation data: 33 women (Control, 16; Experimental, 17) were included in the mood analyses that focused on sexual desire, and 34 women (Control, 15; Experimental, 19) were included in the mood analyses focused on sexual fantasies.

*Menstrual cycle assessment*

Procedures and hormonal measures for delineating the phases of the menstrual cycle are reported in detail elsewhere (Jacob et al., 2004; Bullivant et al., 2004). Briefly, participants were trained in data collection procedures before the start of the study, recorded morning basal body

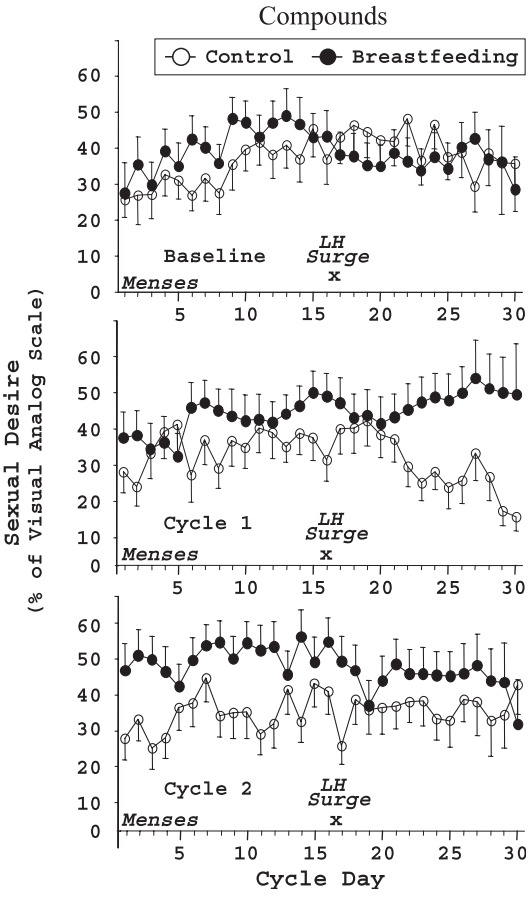


Fig. 1. Effects of breastfeeding pads and carrier control pads on daily ratings of sexual desire (measured as percent of 100-mm visual analog scale) during the baseline, cycle 1, and cycle 2. The data are shown as daily desire means ± SEM across women in each group ($n$ = 22, 22 women; Control, Experimental, respectively). The days of menses (Menses) and preovulatory LH surge onset (x) are indicated. Individual differences in lengths of the phases were handled for these graphs by justifying the data based on mean length of the follicular and luteal phases for each woman.

temperature, and evening cervical mucus throughout the 3 months of study participation. During the week before their expected day of ovulation, they tested their urine every evening (5–7 PM) for the preovulatory luteinizing hormone surge (LH; Ovukit Quidel Corporation, San Diego, CA), a singular hormonal event that triggers ovulation and demarcates the follicular from the ovulatory phase of the cycle. This method of interpreting hormonal data from a single daily urine sample enables accurate assessment of the timing of the LH surge within 12 h (Bullivant et al., 2004; Stern and McClintock, 1996). In addition, subjects collected first morning urine on the 5th, 7th, and 9th day following the LH surge, which we assayed for progesterone glucuronide, an indicator of ovulation and formation of a functional corpus luteum. These data were used together with data on vaginal secretions, menses, and basal body temperature to define the phases of the menstrual cycle (Bullivant et al., 2004). In general, the follicular phase begins the day after menses (days when the participant reported pink, brown, or red vaginal secretions) and ends the day before the LH surge onset. The luteal phase includes the days following ovulation and the day before onset of next menses.

*Data reduction and analysis*

A woman's average level of sexual desire for each of her cycles was calculated using the daily levels of desire that she recorded on the visual analog scale described above. A fantasy rate was also calculated for each of the three cycles a woman experienced during the study. Specifically, for every menstrual cycle, the total number of days that a woman reported at least one fantasy was divided by the total length (in days) of that menstrual cycle. This number was then multiplied by 30 (the length of a standard, hypothetical cycle) to yield a standardized number of fantasies per month. Parallel calculations were done to standardize the rate of sexual activity per month. Because the average rates fell above 0.1, normal statistics were used; F and T transformation for percentages yielded similar results. A woman's mean level of both positive affect and negative affect was calculated for each of her cycles using data from the twice-weekly PANAS scale described above.

In our experience, individual variation in ovarian and psychosexual variables significantly exceeds the effects of social chemosignals, odors, or menstrual cycle phase (Jacob et al., 2004; Stern and McClintock, 1998). Therefore, all effects were measured using each individual as her own control. To this end, each woman's changes from baseline were calculated for all three variables; specifically, the aforementioned baseline means or rates were subtracted from those of the experimental cycles and the difference used within the statistical models below.

To assess effects of breastfeeding compounds on sexual desire, fantasies, and activity and mood, repeated measures analysis of variance (ANOVA) was performed on the change from baseline cycles, with experimental group (breastfeeding compounds versus control) as a between-subjects factor and experimental cycle (cycle 1; cycle 2) as a within factor. In the text and tables, we present only the significant main effects and interactions. Within each experimental group, one-sample *t* tests also confirmed significant differences from baseline.

To determine whether effects of treatment on sexual motivation were independent of any effects of social chemosignals on mood, as has been reported in the literature (Jacob and McClintock, 2000), multiple regression was performed on the sexual motivation variable (mean change from baseline cycle), with experimental group (treatment versus control) and affect score (mean change from baseline) as independent variables. For this model, we focused on negative affect during cycle 2, given the near-significant effect of breastfeeding compounds on negative affect during this phase of the study (see results below). We also used simple regression models to assess any correlations between either negative affect or experimental group status (independent variable) and sexual desire or fantasies (dependent variable) during cycle 2. The effect on sexual motivation of

Table 1
Effect of experimental group on changes from baseline in sexual motivation and affect (mean (±SEM))

| Experimental group | | | | | |
|---|---|---|---|---|---|
| Psychological measures | Control | | Breastfeeding | | F-Value |
| | Cycle 1 | Cycle 2 | Cycle 1 | Cycle 2 | |
| *Sexual motivation* | | | | | |
| Desire (mm scale; $n$ = 44 women) | −4.4 (2.5) | −2.5 (2.2) | 2.5 (2.1) | 7.6 (2.4) | F(1,42) = 9.5** |
| Fantasies (# per month; $n$ = 45 women) | −2.0 (1.1) | −3.0 (0.9) | 0.6 (1.1) | 1.9 (1.0) | F(1,43) = 8.8** |
| Sexual activity (# per month; $n$ = 46 women) | −0.42 (0.78) | −0.03 (0.93) | 0.81 (0.81) | 0.99 (0.96) | F(1,44) = 1.0 |
| *Affect* | | | | | |
| Negative affect (mean score; $n$ = 34 women) | −0.8 (0.7) | −2.3 (0.8) | −0.3 (0.6) | −0.2 (0.7) | F(1,32) = 4.9*,# |
| Positive affect (mean score; $n$ = 34 women) | −1.5 (1.4) | −0.3 (1.7) | −2.0 (1.4) | −3.5 (1.5) | F(1,32) = 1.2 |

*Note*. Desire measure is rated on a visual analogue scale from 0 to 100 mm.
Fantasies and sexual activity scales are frequency rates (yes/no) in a cycle.
** $P < 0.01$, F-value of main effects of experimental group in repeated measures analysis of variance.
* $P \leq 0.05$, F-value of main effects of experimental group in repeated measures analysis of variance.
# Also the F-value and P-value for interaction between experimental group and cycle number.

having a regular partner was tested with unpaired two-tailed *t* tests. The 16 responses to questions "Did you smell anything?" and "If so, how strong was it?" were averaged for each subject during cycles 1 and 2. These scores were analyzed in the same manner described above.

## Results

### *Sexual motivation and sexual activity*

Although the groups did not differ during baseline (average desire scores were 39.6 mm; range = 0–100 mm; see Fig. 1), women exposed to breastfeeding compounds reported a significant increase in sexual desire ($F(1, 42)$ $df = 9.5$; $P = 0.004$; see Table 1). The size of this effect was a 9% and 24% increase above baseline, in cycles 1 and 2, respectively ($P \leq 0.05$ in cycle 2) in contrast to the control group who reported a non-significant decrease. A visual inspection of the continuous data also indicates that the effect grew with time; it was strongest after the preovulatory LH surge of the first cycle, overriding the normal waxing and waning that typically occurs during spontaneous menstrual cycles (see Fig. 1; also see Bullivant et al., 2004).

Women exposed to breastfeeding compounds also reported more sexual fantasies ($F(1,43)$ $df = 8.8$; $P = 0.005$; see Table 1, Fig. 2). They did not manifest the drop in ratings that the control group experienced over 3 months of filling out daily questionnaires and that has been reported in another controlled experimental study with repeated questioning (Jacob and McClintock, 2000). By cycle 2, women receiving breastfeeding compounds experienced a 17.4% increase from baseline ($P \leq 0.05$), while women in the control group experienced a 27.6% decrease in reported sexual fantasies ($P \leq 0.01$). In contrast, the frequency of sexual activity, which is most likely constrained by the availability and motivation of a sexual partner, did not significantly change during exposure to breastfeeding compounds ($F(1,44)$ $df = 1.01$; $P = 0.32$; see Table 1).

### *Mood*

During the baseline cycle, women in both study groups had similar levels of negative affect (mean = 13.5; range = 10.0–29.5) and positive affect (mean = 26.2; range = 12.5–39.7); however, exposure to breastfeeding compounds significantly modified negative affect in interaction with time being in the experiment (group × experimental cycle interaction in Repeated Measures ANOVA, $F(1,32)$ $df = 4.95$; $P = 0.03$; see Table 1). Specifically, women exposed to breastfeeding chemosignals reported no change in negative affect over the 2 months of exposure, while those exposed to carrier control reported decreased negative affect by cycle 2 (see Table 1 for results of simple regression on negative affect: [cycle 1: experimental group coefficient = 0.46 (Standard coefficient = 0.09), $P \leq 0.62$; cycle 2: experimental group coefficient = 2.10 (Standard coefficient = 0.33), $P \leq 0.06$]). Reported positive affect did not increase during the study, nor in response to breastfeeding compound exposure (main effect of type of compound in the repeated measures ANOVA, $F(1,32)$ $df = 1.2$; $P = 0.29$).

We explored the hypothesis that the effects of the breastfeeding compounds on desire and fantasies found by cycle 2 were mediated by the decrease of negative affect found in the control group during cycle 2. Initial explorations of cycle 2 data showed negative affect to correlate significantly with sexual fantasies [negative affect coefficient = 0.02 (Standard coefficient = 0.36), $P \leq 0.04$]), but not sexual desire [negative affect coefficient = −0.004 (Standard coefficient = −0.123), $P \leq 0.50$]. Exposure to breastfeeding compounds during cycle 2 also significantly effected both desire [experimental group coefficient = 0.10

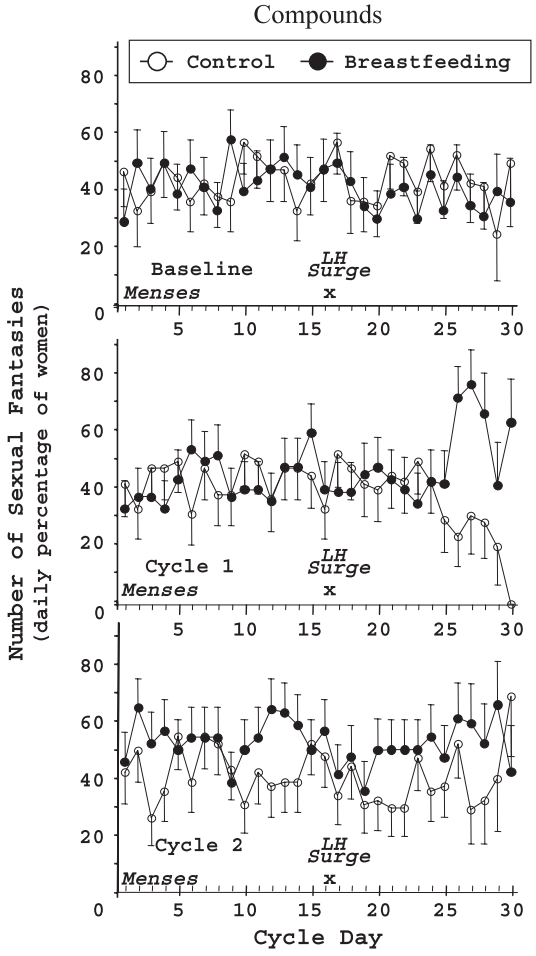


Fig. 2. Effects of breastfeeding pads and carrier control pads on daily incidence of sexual fantasies (measured as report of at least one fantasy on a daily questionnaire) during the baseline, cycle 1 and cycle 2. The data are shown as daily group percentage ± SEM of women in each group ($n = 21$, 24 women; Control, Experimental, respectively) who report a fantasy. The Menses (Menses) and preovulatory LH surge onset (x) are indicated. Individual differences in lengths of the phases were handled for these graphs by justifying the data based on mean length of the follicular and luteal phases for each woman.

Table 2
Effect of partnership status and experimental group on changes in sexual motivation from baseline (mean (±SEM))

| Sexual motivation measure | Change from baseline to Cycle 1 or 2 | Non-partnered women | | | Partnered women | | |
|---|---|---|---|---|---|---|---|
| | | Control | Breastfeeding | t-Value | Control | Breastfeeding | t-Value |
| Desire (mm scale; n = 44 women) | 1 | −4.2 (3.2) | 3.3 (3.2) | 1.49 | −4.9 (1.8) | 2.7 (2.8) | −1.58 |
| | 2 | −0.7 (2.5) | 7.2 (2.7) | 1.96 | −8.8 (3.8) | 7.9 (3.8) | 2.54* |
| Fantasies (# per month; n = 45 women) | 1 | −3.2 (1.2) | 3.2 (1.7) | 3.26* | 2.1 (1.4) | −1.7 (1.2) | 1.79 |
| | 2 | −3.8 (1.1) | 3.7 (1.6) | 4.11* | −0.3 (0.5) | 0.4 (1.1) | 0.38 |
| Sexual Activity (# per month; n = 46 women) | 1 | 0.3 (0.8) | 1.2 (1.2) | 0.68 | −2.8 (1.7) | 0.9 (1.2) | 1.65 |
| | 2 | 0.8 (1.0) | 0.9 (1.4) | 0.73 | −2.6 (2.0) | 1.1 (1.4) | 1.44 |

*Note.* Desire measures were rated on a visual analogue scale from 0 to 100 mm.
Fantasies and Sexual Activity scales are frequency rates (yes/no) in a cycle.
*F-value with $P < 0.05$ for main effect of experimental group in repeated measures analysis of variance.

(Standard coefficient = 0.41), $P \leq 0.02$] and fantasies [experimental group coefficient = 0.14 (Standard coefficient = 0.48), $P \leq 0.01$]. Negative affect, however, did not mediate the effect of the breastfeeding compounds on sexual desire or fantasies during cycle 2; when negative affect was added to the simple regression models, the previously observed effects of exposure to breastfeeding compounds during cycle 2 remained significant [desire: experimental group coefficient = 0.12 (Standard coefficient = 0.52), $P \leq 0.004$; fantasies: experimental group coefficient = 0.12 (Standard coefficient = 0.41), $P \leq 0.02$]. Moreover, negative affect did not behave as a potential mediator within this model, as it did not significantly correlate with desire [negative affect coefficient = −0.01 (Standard coefficient = −0.31), $P \leq 0.08$] or with fantasies [negative affect coefficient = 0.01 (Standard coefficient = 0.23), $P \leq 0.17$)].

### *Description of the pads*

When asked if they "smelled anything" after wiping the pads on their upper lip, subjects said "yes" with equal frequency in the control and experimental conditions (i.e., both at chance levels to a binary question). When a smell was reported, its strength was rated the same in the two conditions (1.0 ± 0.2 natural compounds vs. 0.8 ± 0.2 control, $P \leq 0.39$ on a 4-point strength scale). The frequency of responding that the pad had a smell during the experimental months (16 observations per participant) did not mediate the effects of the breastfeeding compounds on either sexual desire or fantasies (measured as change from baseline during the experimental cycles). First, breastfeeding compounds did not predict frequency of verbal reports in a simple regression model [experimental group coefficient = 0.18 (Standard coefficient = 0.25), $P \leq 0.10$]. Second, when frequency of odor reports was added to a different simple regression model (independent variable is experimental group status; dependent variable is sexual fantasies or desire), no significant relationship appeared between either sexual desire or fantasies and frequency of odor reports in the resulting multiple regression model [cycle 2 desire: odor report frequency coefficient = −0.02 (Standard coefficient = −0.05), $P \leq 0.76$; fantasies: odor report frequency coefficient = 0.02 (Standard coefficient = 0.05), $P \leq 0.72$)]. Moreover, any previously significant relationship between experimental group and either desire or fantasies remained significant [cycle 1 desire: experimental group coefficient = 0.08 (Standard coefficient = 0.34), $P \leq 0.03$; cycle 1 fantasies: experimental group coefficient = 0.06 (Standard coefficient = 0.18), $P \leq 0.24$; cycle 2 desire: experimental group coefficient = 0.11 (Standard coefficient = 0.44), $P \leq 0.005$; cycle 2 fantasies: experimental group coefficient = 0.16 (Standard coefficient = 0.48), $P \leq 0.002$]. We emphasize that further work is needed on the sensitivity to these breastfeeding compounds and the way they are experienced.

### *Effect of social context: sexual partner*

The availability of a sexual partner determined which facet of sexual motivation was affected most strongly. Women without regular sexual partners reported more sexual fantasies in response to breastfeeding compounds (cycle 1: unpaired $t$ (25) $df$ = 3.3; $P \leq 0.01$); cycle 2: unpaired $t$ (25) $df$ = 4.1; $P < 0.01$) compared with their respective controls; in contrast, those with sexual partners reported heightened desire for sexual intimacy with another person when exposed to the breastfeeding compounds, an effect that became significant by cycle 2 (cycle 1: unpaired $t$ (16) $df$ = 1.6; $P \leq 0.13$; cycle 2: unpaired $t$ (16) $df$ = 2.5; $P$ = 0.02), compared to their respective controls (see Table 2). Availability of a sexual partner did not change the non-significant relationship between exposure to breastfeeding compounds and sexual activity (see Table 2). Disregarding whether or not they had a sexual partner, women receiving the control pads had no significant increase in any measure of sexual motivation or behavior (all decreased, one group $t$ tests: $P$ values ranged from 0.98 to 0.002).

## Discussion

We report here that natural compounds collected from lactating women and their infants increased sexual desire

and sexual fantasies in other women relative to the effects of a potassium phosphate buffered control solution. The effects of these social chemosignals were independent of their effect on negative mood and verbal reports of odor perception at the time of application as assessed in this study. Visual inspection of the daily data indicates that the effect of breastfeeding compounds on desire was relatively weak during the follicular phase (the first half of a cycle, before the LH surge) and the periovulatory phases of the cycle, when sexual desire naturally rises (Bullivant et al., 2004; Slob et al., 1996). The effect became striking during the luteal phase (spanning the last half of a menstrual cycle after ovulation) when sexual motivation normally declines (Bullivant et al., 2004), and was sustained through the menstrual phase into the subsequent follicular phase. This may be because it takes at least 3 weeks of exposure for the effect to be observed. Alternatively, the effect might be specific to phases of the menstrual cycle when sexual motivation wanes, and would have manifested more quickly if exposure had started in the mid-luteal phase. This latter alternative, however, is less likely given that the effect remains throughout the 2nd month of exposure. Interestingly, although participants might have been expected to show fatigue after answering daily questionnaires for 3 months similar to women in other studies (Jacob and McClintock, 2000), neither the control nor the experimental group showed decreased positive affect or increased negative affect during the study. Nonetheless, the control group consistently reported less sexual behavior and motivation as the study progressed. This "fatigue effect" could well reflect underreporting as rating sexual experiences became less novel with repeated daily questions. Future studies are needed to determine if breastfeeding compounds can have long-term sustained effects on sexual motivation.

Having a sexual partner moderated how a woman expressed the effect of breastfeeding chemosignals on her sexual motivation. Specifically, the effect of breastfeeding chemicals on "desire...for other people" (as the question was worded) was greatest when a woman had a regular sexual partner. Among partnered women, there were no effects of treatment for fantasies or sexual activity. In contrast, when no partner was available, the chemosignal increased incidence of "fantasies...of a sexual nature..." (a question that did not refer to a person). That social context modulates the response to social chemosignals is supported by the finding that women experienced sympathetic arousal (skin conductance and temperature) when in the presence of a male tester but did not with female testers (Jacob et al., 2001a).

Although this is the first study documenting the effect of natural human compounds on sexuality, specifically compounds from nursing women and their infants on the sexual motivation of other women, our results are not surprising. Social chemosignals from lactating females and their infants modulate aspects of fertility of female conspecifics, including the estrous cycle and reproductive behavior in rats (McClintock, 1984; Mennella and Moltz, 1989) and homeostasis of menstrual cycle length in women (Jacob et al., 2004). Additional human research is needed to determine whether these compounds from the mother, infant, or both are detectable as odors when compared directly with buffer solutions or are implicitly associated with mothers and their babies and thereby mediate the observed effects on sexual desire and fantasies. Moreover, future investigations should assess the response specificity of the compounds and examine their effects on other forms of social behavior and motivational states as well as direct effects on the women's sexual partners or social group.

The neuroendocrine mechanisms underlying these psychological effects need to be identified. Current evidence indicates that other putative pheromones activate both hypothalamic and cortical areas (Jacob et al., 2001b; Savic et al., 2001) as well as alter hormonal responses triggering ovulation (Preti et al., 2003; Shinohara et al., 2001; Stern and McClintock, 1998). Identifying these neuroendocrine mechanisms will be facilitated by first determining the source of the active compounds (e.g., infants' saliva, maternal axillary compounds, breast milk, or their combination). Moreover, other natural compounds might be equally effective. Whichever the case, this is the first report in humans of natural social chemosignals that increase sexual motivation.

The effects described here did not occur in a normal social context—that is, the nulliparous women were not directly interacting with breastfeeding women. Instead, the compounds were transferred to the skin above the upper lip, as would occur after touching a breastfeeding woman, her infant, or something she had handled, and then resting a hand on the face. Definitively labeling breastfeeding chemosignals as human pheromones will require, among other things, demonstrating that they do indeed operate in the context of normal daily interactions with breastfeeding women and their infants. Ideally, such a study would also demonstrate how these effects would have increased the evolutionary fitness of individuals who used this system of social communication during human evolution (Meredith, 1991).

In the context of traditional societies, breastfeeding compounds may confer an evolutionary advantage, coordinating a woman's sexual motivation with a physical and social environment supportive of raising her children. Such social chemosignals might affect fitness in at least two ways. First, they may reduce the fertility of pubescent girls, perhaps daughters that would then remain with the family to help care for their siblings. This pheromonal effect is seen in house mice and primates (Epple, 1976; Vandenbergh, 1989). Second, in populations where variation in limited food resources make fertility highly seasonal (i.e., the Lesse farmers in Zaire (Ellison, 2001)), breastfeeding compounds may promote conceptions of other women in the community. Such an effect would increase the probability that undertaking the costs of

pregnancy and lactation would be coordinated with a physical and social environment that is already supporting the energetic demands of pregnancy and lactation in other women.

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## References

Altmann, J., Altmann, S.A., Hausfater, G., 1978. Primate infant's effects on mother's future reproduction. Science 201, 1028–1030.

Beauchamp, G.K., 2000. Defining pheromones. In: Stein, L.J. (Ed.), The Monell Connection Monell Chemical Senses Center, Philadelphia, PA, p. 2. Fall 2000.

Bullivant, S.B., Sellergren, S.A., Jacob, S., Spencer, N.S., Mennella, J.A., McClintock, M.K., 2004. Women's sexual experience during the menstrual cycle: identification of the sexual phase by noninvasive measurement of luteinizing hormone. J. Sex Res. 41, 82–93.

Chivers, M.L., Rieger, G., Latty, E., Bailey, J.M., in press. Sex difference in sexual arousal. Psychol Sci.

Doty, R.L., Shaman, P., Dann, M., 1984. Development of the University of Pennsylvania smell identification test: a standardized microencapsulated test of olfactory function. Physiol. Behav. 32, 489–502.

Ellison, P.T., 2001. On Fertile Ground: A Natural History of Human Reproduction Harvard University Press, Cambridge, MA.

Epple, G., 1976. Chemical communication and reproductive processes in nonhuman primates. In: Doty, R.L. (Ed.), Mammalian Olfaction, Reproductive Processes, and Behavior. Academic Press, London.

Folstein, M.F., Luria, R., 1973. Reliability, validity and clinical application of the visual analogue mood scale. Psychol. Med. 3, 479–486.

Gudermuth, D., McClintock, M.K., Moltz, H., 1984. Suppression of postpartum fertility in pairs of rats sharing the same nesting environment. Physiol. Behav. 33, 257–260.

Hedricks, C., McClintock, M.K., 1985. The timing of mating by postpartum estrous rats. Z. Tierpsychol. 67, 1–16.

International Commission on Radiological Protection: Task Group on Reference Man, 1975. Report of the Task Group on Reference Man: A report prepared by a task group of Committee 2 of the International Commission on Radiological Protection. ICRP Publication 23 Pergamon Press, New York.

Jacob, S., McClintock, M.K., 2000. Psychological state and mood effects of steroidal chemosignals in women and men. Horm. Behav. 37, 57–78.

Jacob, S., Hayreh, D.J., McClintock, M.K., 2001a. Context-dependent effects of steroid chemosignals on human physiology and mood. Physiol. Behav. 74, 15–27.

Jacob, S., Kinnunen, L.H., Metz, J., Cooper, M., McClintock, M.K., 2001b. Sustained human chemosignal unconsciously alters brain function. NeuroReport 12, 2391–2394.

Jacob, S., Spencer, N.A., Bullivant, S.B., Sellergren, S.A., Mennella, J.A., McClintock, M.K., 2004. Effects of breastfeeding chemosignals on the human menstrual cycle. Hum. Reprod. 19, 422–429.

Karlson, P., Lüscher, M., 1959. Pheromones: a new term for a class of biologically active substances. Nature 183, 55–56.

Lentner, C., 1981. Geigy Scientific Tables, vol. 1. Ciba-Geigy Limited, Basel.

Luria, R.E., 1975. The validity and reliability of the visual analogue mood scale. J. Psychiatr. Res. 1, 51–57.

McClintock, M.K., 1984. Estrous synchrony: modulation of ovarian cycle length by female pheromones. Physiol. Behav. 32, 701–705.

McClintock, M.K., 2000. Human pheromones: Primers, releasers, signalers or modulators?. In: Wallen, K., Schneider, J.E. (Eds.), Reproduction in Context. The MIT Press, Cambridge, pp. 355–420.

McClintock, M.K., 2002. The neuroendocrinology of social chemosignals in humans and animals: odors, pheromones and vasanas. In: Pfaff, D., Arnold, A., Etgen, A., Rubin, R., Fahrbach, S. (Eds.), Hormones, Brain and Behavior, vol. 1. Academic Press, San Diego, CA, pp. 797–870.

Mennella, J.A., 1988. Social control of infanticidal behavior in rats. Unpublished doctoral dissertation, University of Chicago.

Mennella, J.A., 1995. Mother's milk: a medium for early flavor experiences. J. Hum. Lact. 11, 39–45.

Mennella, J.A., Moltz, H., 1989. Pheromonal emission by pregnant rats protects against infanticide by nulliparous conspecifics. Physiol. Behav. 46, 591–595.

Mennella, J.A., Blumberg, M.S., McClintock, M.K., Moltz, H., 1990. Interlitter competition and communal nursing among Norway rats: advantages of birth synchrony. Behav. Ecol. Sociobiol. 27, 183–190.

Meredith, M., 1991. Sensory processing in the main and accessory olfactory systems: comparisons and contrasts. J. Steroid Biochem. Mol. Biol. 39, 601–614.

Preti, G., Wysocki, C.J., Barnhart, K., Sonheimer, S.J., Leyden, J.J., 2003. Male axillary extracts contain pheromones that affect pulsatile secretion of luteinizing hormone and mood in women recipients. Biol. Reprod. 68, 2107–2113.

Russell, M.J., Switz, G.M., Thompson, K., 1980. Olfactory influences on the human menstrual cycle. Pharmacol. Biochem. Behav. 13, 737–738.

Savic, I., Berglund, H., Gulyas, B., Roland, P., 2001. Smelling of odorous sex hormone-like compounds causes sex-differentiated hypothalamic activations in humans. Neuron 31, 661–668.

Shinohara, K., Morofushi, M., Funabashi, T., Kimura, F., 2001. Axillary pheromones modulate pulsatile LH secretion in humans. NeuroReport 17, 893–895.

Silk, J.B., Albers, S.C., Altmann, J., 2003. Social bonds of female baboons enhance infant survival. Science 302, 1231–1234.

Slob, A.K., Bax, C.M., Hop, W.C., Rowland, D.L., van der Werff ten Bosch, J.J., 1996. Sexual arousability and the menstrual cycle. Psychoneuroendocrinology 21, 545–558.

Steiner, M., Haskett, R., Carroll, B., 1980. Premenstrual tension syndrome: the development of research diagnostic criteria and new rating scales. Acta Psychiatr. Scand. 62, 177–190.

Stern, K.N., McClintock, M.K., 1996. Individual variation in biological rhythms. In: Jensvold, M.F., Halbreich, U., Hamilton, J.A. (Eds.), Psychopharmacology and Women, Sex, Gender, and Hormones. American Psychiatric Press, Washington DC, pp. 393–407.

Stern, K., McClintock, M.K., 1998. Regulation of ovulation by human pheromones. Nature 392, 177–179.

Stock, W.E., Geer, J.H., 1982. A study of fantasy-based sexual arousal in women. Arch. Sex. Behav. 11, 33–47.

Vandenbergh, J.G., 1989. Coordination of social signals and ovarian function during sexual development. J Anim. Sci. 67, 1841–1847.

Watson, D., Clark, L.A., Tellegen, A., 1988. Development and validation of brief measures of positive and negative affect: the PANAS scales. J. Pers. Soc. Psychol. 54, 1063–1070.

Wysocki, C.J., Preti, G., 1998. Pheromonal influences. Arch. Sex Behav. 27, 627–634.