

Breastfeeding and Smoking: Short-term Effects on Infant Feeding and Sleep

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ABSTRACT

OBJECTIVE. The present experimental study was designed to determine how breastfeeding from a mother who smokes affects infants in the short-term.

METHODS. Fifteen mother-infant dyads were tested on 2 days separated by 1 week. Mothers smoked (not in the presence of their infants) on one test day and refrained from smoking on the other. For the next 3.5 hours, infants breastfed on demand. Sleep and activity patterns were monitored by placing an actigraph on the infants' leg, and milk intake was determined by weighing the infants before and after each feeding. The nicotine content of the milk was measured to determine the dose of nicotine delivered to the infants.

RESULTS. Although there was no significant difference in breast milk intake, despite the taste changes in the milk, infants spent significantly less time sleeping during the hours immediately after their mothers smoked (53.4 minutes), compared with the session when their mothers abstained from smoking (84.5 minutes). This reduction was attributable to shortening of the longest sleep bout and reductions in the amounts of time spent in both active sleep and quiet sleep. With greater doses of nicotine delivered to the infant, less time was spent in active sleep.

CONCLUSIONS. An acute episode of smoking by lactating mothers altered infants' sleep/wake patterning. Perhaps concerns that their milk would taste like cigarettes and their infants' sleep patterning would be disrupted would motivate lactating mothers to abstain from smoking and to breastfeed longer.

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Key Words

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MORE THAN 250 million women throughout the world inhale one of the most strongly addicting drugs.¹ Those who smoke tobacco while pregnant present a serious threat to their own health and their children's health.² These health threats continue after birth when infants are exposed passively to nicotine and other toxic constituents of cigarette smoke in ambient air, breast milk, or both.^{2,3}

Although the amount of nicotine transferred into breast milk is more than double that transferred to maternal serum,⁴ there is evidence that breastfeeding offers protection; the incidence of acute respiratory illness among infants whose mothers smoked was diminished for those who were breastfed, compared with formula fed.⁵ Because the benefits of breastfeeding outweigh the risks of nicotine exposure, nicotine is no longer listed as a drug that is contraindicated during breastfeeding.⁶ Although lactating women who smoke are advised to stop smoking, breast milk remains the ideal food even if the mother does not stop smoking, because there is little evidence to suggest that breastfeeding from a mother who smokes has adverse effects on the infant (although there are risks related to smoking-induced reductions in milk iodine content⁷). It should be emphasized that the lack of evidence may be attributable to the paucity of research. Moreover, as described previously,⁸ many existing studies on the effects on infant development of maternal smoking during pregnancy failed to quantify the duration and extent of breastfeeding and the smoking practices of the mothers after birth or to take into account the amount and recentness of exposure to tobacco via mother's milk.

Despite recommendations that encourage breastfeeding, women who smoke are less likely to breastfeed and those who breastfeed wean their infants from the breast earlier than those who do not smoke.⁸ Several explanations (not mutually exclusive) may explain the early weaning. First, smoking ≥ 10 cigarettes daily affected the lactational process adversely by decreasing milk production and altering milk composition.⁹ The hormonal mechanisms underlying such changes and the effects of more-moderate levels of smoking on the lactational process remain unknown. Second, smokers were more likely to think that their milk supply was inadequate¹⁰ and to be less motivated to breastfeed.¹¹ Third, breastfed infants whose mothers smoked ≥ 5 cigarettes daily exhibited behaviors (eg, colic and crying) that may promote early weaning.¹²

The present experimental study was designed to determine how breastfeeding from a mother who smokes affects infants in the short-term. The infants' feeding and sleep behaviors were monitored, because smoking is associated with sleep disturbances in adolescents¹³ and adults.¹⁴

METHODS

Subjects

Fifteen healthy lactating women (33.3% black, 53.3% white, 6.7% Hispanic, and 6.7% other) who were current smokers were recruited through advertisements in local newspapers and breastfeeding support groups. The mothers (80.0% multiparous) ranged in age from 20 to 41 years (mean age: 30.3 ± 1.6 years) and their infants (7 girls and 8 boys) ranged in age from 2.3 to 6.7 months (mean age: 4.0 ± 0.3 months). None of the mothers was taking any medications or using any illicit drugs. Three additional mother-infant dyads were tested but were excluded because of noncompliance with study procedures ($n = 1$) or because the infant was sick on one of the testing days ($n = 2$). All procedures were approved by the Office of Regulatory Affairs at the University of Pennsylvania, and informed consent was obtained from each woman.

Procedures

Using methods established in our laboratory for a previous study on the effects of exposure to alcohol via mothers' milk,^{15,16} we conducted a study with a within-subjects design, in which mother-infant pairs were tested on 2 days separated by 1 week. Mothers were asked to refrain from smoking for at least 12 hours before each testing session. Baseline milk samples were obtained with an electric breast pump (Medela, Crystal Lake, IL), to confirm that levels of nicotine and cotinine (a major metabolite of nicotine) were low (see below) and comparable to levels reported in previous studies.¹⁷ Mothers also refrained from drinking any alcoholic beverages during the 3 days preceding each test day, because our previous research demonstrated alterations in sleep and activity levels after exposure to alcohol in mothers' milk.^{16,18}

Each mother-infant dyad arrived at the Monell Center at $\sim 9:30$ AM. Infants were last breastfed $\sim 2.5 \pm 0.2$ hours before testing; there was no significant difference in the time since the infants were last fed on the 2 testing days. Mothers did not consume any caffeinated foods or beverages during the test sessions, which occurred in a private carpeted room that contained a portable crib. After acclimatization to the room and personnel, an actigraph (AMA-32; Ambulatory Monitoring, Ardsley, NY) was placed on each infant's left leg. The mother, shielded with a disposable laboratory coat and wearing gloves, then went into a 700-ft³, stainless steel environmental chamber (Acoustic Systems, Austin, TX; airflow rate: 450 ft/min) without the infant for a 20-minute period. In counterbalanced order, mothers smoked during one test session and refrained from smoking during the other. All except 2 of the women smoked 1 cigarette in the chamber; the remaining 2 women could not stop at 1 cigarette and smoked either 2 or 3 cigarettes of their regular brand. The order of testing was randomized

among subjects. No effect of order was observed for any of the variables investigated.

After removing the laboratory coat and gloves, mothers washed their hands with unscented soap and returned to the testing room, where they breastfed on demand. Immediately before each feeding, we obtained a 10-mL sample of the milk so that we could measure the nicotine and cotinine contents of the milk at the time of feeding and determine the dose of nicotine delivered to the infant during testing. Samples, which were sent to National Medical Services (Willow Grove, PA) for nicotine determination, were analyzed by gas chromatography with alkali flame ionization (nitrogen-phosphorus) detection; levels could not be determined for the milk samples from 1 mother because of a laboratory error.

Infants were weighed on an Acme medical scale (San Leandro, CA), which was accurate to 5 g, immediately before and after each feeding to determine milk intake. After feeding, infants were always placed supine in a crib or on the floor, so that the actigraph-monitored infant activity was independent of the mothers' activity and because body position influences sleep patterning in infants.¹⁹

Sleep and Activity Measures

The actigraph, a self-contained microcomputer that consists of a piezoelectric accelerometer, generates a voltage in proportion to the mechanical deflection of the free end as it is moved.²⁰ Motility levels were sampled in the 0-crossing mode at a constant rate of 10 Hz. In this mode, an activity count was scored each time the infant's leg movement fell above the unit's sensitivity threshold. The number of 0 crossings was stored in memory in 1-minute epochs and was later analyzed with a computer program (Ambulatory Monitoring, Ardsley, NY) that had been validated previously with behavioral observational state taxonomic assessment of sleep stages in infants in this age range.²¹ From the raw activity data, the program determined the number of minutes spent in active sleep and quiet sleep, latency to sleep, number of sleep bouts, length of the longest sleep bout, and mean activity count during wakefulness during each 3.5-hour test session for each infant.

Data Analyses

Repeated-measures analyses of variance were conducted to determine whether there were significant differences in sleep and feeding measures as a function of experimental condition (nonsmoking versus smoking). Significant effects in the analyses of variance were probed with paired *t* tests. Pearson's product-moment correlations were used to examine relationships between the dose of nicotine delivered via milk and the relative changes in various sleeping measures, as well as the relationship between parental smoking and infant birth weight. All summary statistics are expressed as means \pm SEM.

RESULTS

Maternal Drinking and Smoking Practices

Smoking rates decreased significantly from 13.2 ± 2.2 cigarettes per day before conception (range: 1.5–30 cigarettes per day) to 7.6 ± 1.7 cigarettes per day during pregnancy (range: 0–20 cigarettes per day; $P = .01$). Ten women reported that they began cutting back during the first trimester; 4 of those women reported that they quit smoking completely while pregnant. Nine of the children's fathers also smoked; they smoked 10.2 ± 2.9 cigarettes per day. Although all infants except 1 were born at an average weight for gestational age, the number of cigarettes smoked during pregnancy by either the mother alone ($r = -0.67$, $df = 13$; $P = .007$) or both parents combined ($r = -0.52$, $df = 13$; $P = .05$) was correlated significantly with infant birth weight. Parental smoking was also related significantly to infants' BMI at birth ($r = -0.67$, $df = 12$; $P = .009$). With greater numbers of cigarettes smoked daily during pregnancy, the birth weight and BMI at birth were lower.

Although smoking rates had increased to 9.7 ± 1.9 cigarettes per day (range: 1–30 cigarettes per day) at the time of testing, there was a tendency for women to be smoking less than reported before conception ($P = .09$). None of the mothers reported that they modified where and when they smoked (eg, smoking in the presence of the infant or timing of smoking in relation to breastfeeding) because they were lactating. Similar to findings observed for cigarette smoking, women reported drinking less alcohol during pregnancy. The women drank very little during pregnancy (range: 0–6.5 alcoholic drinks per month; mean: 0.7 ± 0.4 drinks per month) and then slightly but significantly increased alcohol intake to 2.9 ± 1.0 drinks per month during lactation ($P = .04$). Nine of the women abstained from drinking during pregnancy, but only 6 abstained from drinking during lactation.

Dose Delivered to Infants

Baseline levels of nicotine (nonsmoking day: 10.2 ± 4.4 ng/mL; smoking day: 12.4 ± 4.0 ng/mL) and cotinine (nonsmoking day: 154.3 ± 31.8 ng/mL; smoking day: 141.3 ± 31.4 ng/mL) in mothers' milk at the beginning of each testing session were similar. Nicotine was absent from the baseline milk samples of 8 mothers. For all infants, the amounts of nicotine ingested via breast milk (estimated by multiplying the volume of milk by the concentration of nicotine in the milk at the time of feeding) were higher on the days their mothers smoked. Taking into account the body weight of each infant, the estimated dose of nicotine delivered to the infants increased significantly from 127.1 ± 59.8 ng/kg during the nonsmoking test session to 548.9 ± 233.0 ng/kg during the test session in which the mothers had smoked recently ($P = .03$).

Breastfeeding Behaviors

As shown in Table 1, infants breastfed the same number of times and ingested the same amounts of milk on the 2 testing days.

Sleep and Activity Behaviors

Infants spent significantly less time sleeping during the hours immediately after breastfeeding when their mothers had smoked recently, compared with when their mothers had refrained from smoking ($P < .001$). The reduction in sleep was attributable to shortening of the longest sleep bout ($P = .01$) and reductions in the amounts of time spent in both active sleep ($P = .002$) and quiet sleep ($P = .05$). As shown in Fig 1, the decrease in active sleep was observed for all except 2 of the infants ($P = .002$). With greater relative doses of nicotine delivered to the infants via milk, less time was spent in active sleep ($r = -0.60$, $df = 12$; $P = .02$).

DISCUSSION

An acute episode of smoking by lactating mothers altered their infants' sleep/wake patterning. Infants spent significantly less time in active and quiet sleep and woke from their naps sooner. These changes being attributable to nicotine exposure is suggested by the finding that, with greater relative doses of nicotine delivered to infants in their mothers' milk, sleep disruption was greater.

Whether the observed differences in sleep patterning were also attributable to compensatory increases in sleep during the nonsmoking session requires additional research. In the present study, infants had been exposed to breast milk with little, if any, nicotine for several hours before the session in which mothers refrained from smoking. Improvements in sleep have been reported during abstinence from cigarette smoking in adults, despite the daytime discomfort associated with tobacco withdrawal.²² Moreover, compensatory increases in

sleep have been reported for the sleep deficits induced by alcohol exposure in mothers' milk.¹⁸ Because children who sleep longer are perceived as having more desirable temperaments,²³ we hypothesize that the increase in sleep and possibly the decreased display of other undesirable behaviors such as excessive crying and colic¹² that occur when smoking mothers stop breastfeeding reinforce their decisions to wean.

Sleep, the most frequent state of consciousness of infants, can be influenced by a variety of environmental and physiologic factors. The present study aimed to control experimentally for a variety of such factors. Each test session occurred at the same time of day, in a private room. Infants were not present in the chamber when mothers smoked; therefore, any effects observed were not due to passive exposure via the ambient air. Infants were placed supine in the crib or on the carpet, so that the actigraph-monitored measures were independent of the mothers' activity.¹⁹ The finding that they consumed the same amounts of breast milk in the 2 test sessions provides additional evidence that infants do not reject the tobacco flavors in mothers' milk.³ Although it is possible, it seems unlikely that the alterations in the patterning of sleep were attributable to some reason besides feeding with the milk of a mother who had smoked recently.

Although the mechanisms underlying these changes in sleep patterning remain to be elucidated, it is not surprising that sleep architecture was altered, given the known stimulant effects of nicotine, which is the primary pharmacologically active component of tobacco smoke.¹⁴ Nicotine directly suppresses pontogeniculoocipital spike activity, a factor important in initiating and maintaining active sleep,²⁴ and indirectly inhibits sleep-promoting neurons in the ventrolateral preoptic area.²⁵ Whether changes in sleep integrity and altered arousal mechanisms observed after infants are exposed to tobacco smoke, which is the leading risk factor for sudden infant death syndrome,²⁶ or other neurotoxicants (such as alcohol) contribute to sudden infant death syndrome in susceptible infants is an important area for future research.^{27,28}

Because the adverse effects of nicotine exposure involve multiple transmitter pathways and influence programming of synaptic competence,²⁹ the consequences of early nicotine exposure often appear after long periods of apparent normality. Similar to findings observed for fetuses²⁹ and adults after chronic exposure, nicotine exposure via maternal milk upregulated nicotinic receptor expression in neonates.³⁰ Such neonatal nicotine exposure during sensitive periods of development can produce long-term behavioral and learning deficits.² We hypothesize that the nicotine-induced disruptions in sleep may contribute to the deficits, because sleep promotes learning in infants³¹ and deprivation of active

TABLE 1 Infants' Breastfeeding and Sleep Behaviors During Two 3.5-Hour Testing Sessions

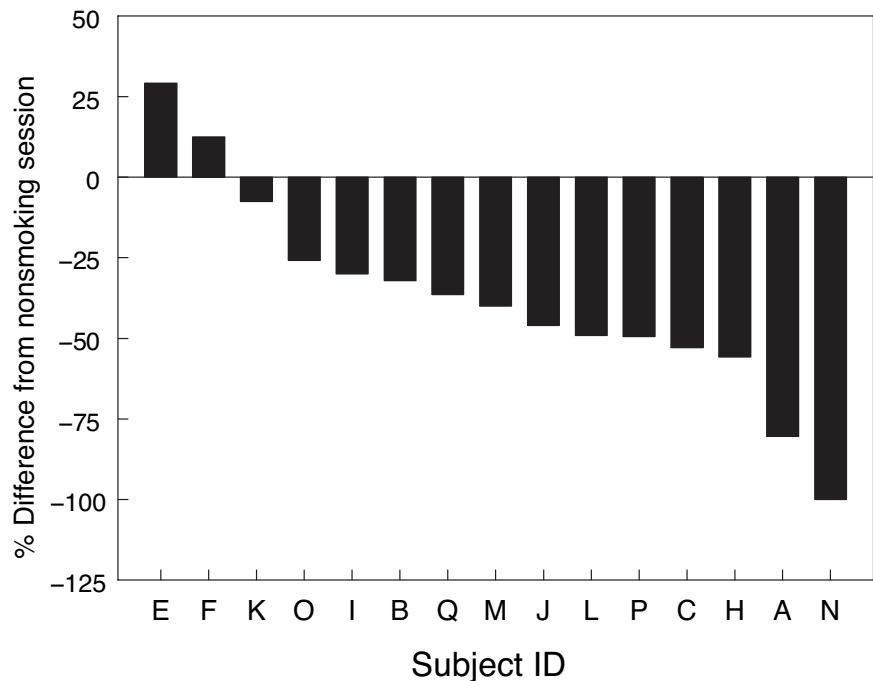
	Nonsmoking Session	Smoking Session
Breastfeeding behaviors		
Time since last breastfeeding, h	2.4 ± 0.2	2.5 ± 0.2
No. of breastfeedings	2.7 ± 0.2	2.9 ± 0.3
Milk intake, mL	161.6 ± 16.5	175.5 ± 19.4
Sleep/wake patterning		
Total sleep, min	84.5 ± 10.6	53.4 ± 8.8 ^a
Active sleep, min	44.6 ± 6.9	27.7 ± 4.8 ^a
Quiet sleep, min	39.9 ± 7.1	25.7 ± 6.6 ^a
No. of sleep bouts	2.1 ± 0.4	2.7 ± 0.4
Length of longest bout, min	60.1 ± 10.1	36.9 ± 6.5 ^a
Latency to sleep, min	47.9 ± 11.8	49.1 ± 10.8
Mean activity count during wakefulness	223.5 ± 4.7	216.6 ± 8.9

Values are presented as mean ± SEM. The infants ($N = 15$) breastfed on demand immediately after their mothers abstained from smoking during one testing session (nonsmoking session) and smoked ≥ 1 cigarette during the other (smoking session).

^a $P \leq .05$, compared with nonsmoking session.

FIGURE 1

Differences in the time the infants spent in active sleep during the 3.5-hour testing session when their mothers smoked as compared with the time spent in active sleep when their mothers abstained from smoking. The 15 infants were rank-ordered according to the amplitudes of their responses. The mean difference was $-37.6\% \pm 8.4\%$ ($P = .002$).



sleep impairs learning and the formation of new memories in animal models.³²

Maternal smoking during early childhood increases the risk that the child will smoke during adolescence.³³ Animal model studies revealed that nicotine exposure in amniotic fluid and mother's milk upregulated brain nicotinic receptors to levels observed in adults who smoke.³⁰ Mothers' milk³ and presumably amniotic fluid are flavored with tobacco if women smoke, raising the possibility that, in addition to the effects of nicotine on the developing brain, early experiences with the flavor of tobacco influence the likelihood that exposed children will find these flavors appealing later in life. Indeed, research has shown that infants develop preferences for flavors experienced in milk.^{34,35} Moreover, children whose parents smoke respond differently to the odor of tobacco; they associate tobacco odors with the emotional context in which their mothers smoke.³⁶

The removal of nicotine from the list of drugs contraindicated during lactation⁶ does not diminish the need for more research on the effects of smoking during lactation. Unlike during pregnancy, a nursing woman who smokes occasionally can time breastfeeding in relation to smoking, because nicotine is not stored in breast milk and levels parallel those found in maternal plasma, peaking ~30 to 60 minutes after the cessation of smoking and decreasing thereafter.³ It should be emphasized, however, that cigarette smoke is a complex mixture of chemicals with ~4000 compounds,³⁷ including >60 carcinogens. Whether compounds other than nicotine and cotinine are transferred to human milk with similar time courses and, if so, what levels are transmitted remain unknown.

Although many women, like those in the present study, are motivated to stop or reduce smoking during pregnancy, they often relapse after the infant is born, for a variety of reasons (eg, having a partner who smokes, concerns about weight gain, and greater alcohol consumption in the postpartum period).^{38,39} Whether the encouragement to breastfeed, along with lack of awareness and counseling by some health professionals that nicotine is transferred into breast milk and that smoking in the postpartum period poses a health risk to the infant,^{8,40} promotes smoking relapse is not known.

Clearly, there is a need for targeted smoking cessation programs that address issues relevant to lactating women.⁴¹ Women who are successful and do not relapse after their infants' birth have significantly higher levels of intrinsic motivation to quit, such as anticipated health improvements.⁴² Perhaps concerns that their milk will taste like cigarettes³ and their infants' sleep patterning will be altered could be used in a relapse prevention strategy to motivate lactating mothers to abstain from smoking and to breastfeed longer. More research on the benefits and consequences of breastfeeding from mothers who smoke, as well as the efficacy of smoking cessation treatments for lactating women, is needed to develop evidence-based strategies that have long-term consequences for both infant and maternal health.

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sponsibility for any analyses, interpretations, or conclusions.

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