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ABSTRACT

Establishment of lactation has important biological and emotional health consequences for the newborn. Even so, substantial variation within a culture and among different cultures is seen in the onset of breastfeeding. Parametric mixture models are used to explore this variation and to uncover general human patterns for the initiation of breastfeeding. The model components reflect two hypothesized patterns of behavior. The first component is a “natural” pattern of breastfeeding that has a rapid onset, and reflects, to some extent, a general mammalian behavior. The second component arises through culturally mediated delays in the initiation of breastfeeding. Candidate models were fit to observations from 25 previously published studies of breastfeeding behavior, giving interval- or right-censored observations of early breastfeeding behavior on 26,220 mother-infant pairs. Maximum likelihood estimation revealed that models with both components are clearly statistically identified. Effects of cultural and geographic covariates were found to have significant effects in the models, including the first component. Although there is clear evidence for two distinct patterns of behavior associated with the initiation of breastfeeding, the results indicate that learned behaviors play an important role in mediating even the “early onset” behavior. We conclude that the increased reliance on learned rather than preprogrammed behaviors characterize the evolution of early maternal behaviors that must have accompanied the re-emergence of altricial infants over the course of human evolution.

INTRODUCTION

Following parturition, a child's relationship with its mother changes from one of physiological dependence to include behavioral dependencies as well. Breastfeeding is a significant component of this dependency, so that the initiation of breastfeeding must rank as one of the earliest and most important postpartum decisions made by both the mother and her child in their newly modified, postpartum relationship. Throughout our species' evolutionary past, and in most contemporary non-industrial settings, breastfeeding has been universal and necessary for the survival of the newborn. It is widely recognized that infant breastfeeding has many health benefits both for the newborn and for the mother. Breastfeeding not only provides for the fundamental nutritional and emotional needs of the infant, but breast milk provides growth factors, hormones, and maternal antibodies. At the same time, breastfeeding limits an infant's exposure to food-borne diseases that may be present with alternative feeding methods (Cunningham et al., 1991; Popkins et al.; 1990; Hanson, 2000).

Establishment of lactation within hours after birth may have important consequences for the health and development of the newborn. During this time colostrum, a yellowish precursor to mature breastmilk, is secreted (Humenick et al., 1994). Colostrum has a higher protein and lower fat content as compared to more mature breastmilk (Hartmann et al., 1985; Emmett and Rogers, 1997). The protein component of colostrum consists primarily of enzymes, anti-infective agents, hormones, and growth factors, many of which serve to support neonatal growth and development (Xu, 1996; Kunz et al., 1999). Of these bioactive agents, immune cells, such as antibodies (e.g., secretory IgA, IgG, IgM) make up the largest fraction of total protein content of colostrum (Garg et al., 1989; Hartmann et al., 1985). Other compounds include still more anti-microbial factors (e.g., oligosaccharides, fatty acids); anti-inflammatory agents; transporters (e.g., lactoferrin); digestive enzymes; and peptide hormones (Baumrucker and Blum, 1993; review by Kunz et al. 1999).¹

The conversion of colostrum to mature milk in breastfeeding women typically takes place during the second or third day postpartum, although there is variation among individuals, which is thought to arise as a result of individual differences in the timing of initiation and the intensity of breastfeeding (Hartmann et al., 1985; Humenick, 1987; Humenick et al., 1994). Initiation of breastfeeding while colostrum is still being produced is thought to decrease infant morbidity, especially in non-industrialized populations, by reducing the risk of gastroenteritis (Carlsson et al., 1976; Cruz et al., 1982), diarrheal disease (Feachem and Koblinsky, 1984; Popkin et al., 1990), respiratory infections, ear infections and influenza (Shortlidge et al., 1990). These benefits are thought to arise from both the passive immunity conferred through colostrum (Hanson et al., 1994b; Hanson, 2000), and by reducing pathogen exposure from prelacteal feeding practices (Hanson et al., 1985a, 1985b). Also, colostrum serves to supply the developing gastrointestinal (GI) tract with growth factors that promote the maturation of GI epithelia cells, which facilitates not only the absorption of nutrients but also the construction of physical barriers to invasion by pathogens (Xu, 1996).

Breastfeeding within an hour or two of delivery is associated with the establishment of longer and more successful breastfeeding (Salariya et al., 1978; Trevathan, 1984; Hill, 1991), and of exclusive breastfeeding (Kurinj and Shiono, 1991). Other than the nutritional value, prolonged breastfeeding benefits the newborn by ensuring an extended period for the transfer of passive immunity from mother to child as well as producing a longer birth interval, which is associated with reduced infant mortality (Hanson et al., 1994a). The mother also receives positive benefits from breastfeeding within hours of giving birth. Breastfeeding initiates the release of oxytocin into the circulation (Ojeda, 1996), which causes uterine contractions and may help to expel the placenta in the immediate postpartum period (Carr, 1996), and reduce maternal blood loss (Trevathan, 1984; Carr, 1996).

The early initiation of breastfeeding hastens mother-infant interactions, which are an important

¹ Colostrum provides a much lower daily energy supply to the newborn than mature milk, primarily because the quantity of colostrum produced is from 1/6th to 1/10th that of mature milk (Saint et al., 1984; Hartman and Prosser, 1984; Hartman et al., 1985). For example a typical milk yield on postpartum day 1 is about 40 g, on day 3 about 400 g, and on day 28 about 900 g (Saint et al., 1984).

component in the early development of a strong and healthy relationship between mother and child (reviewed by Maestripieri, 2001). Close physical contact, such as breastfeeding, in the hours after birth allows a mother and infant to learn the olfactory and tactile characteristics needed for the recognition of each other (Porter and Winberg, 1999). The ability of the mother and infant to recognize each other is a precursor to any enduring social attachment. The extent to which such cues influence maternal behavior is not clear. Non-human primate mothers are highly motivated to provide care to newborns during the postpartum period, which when coupled with early recognition ensures parental investment is directed to biological offspring (Maestripieri, 2001). For the altricial human newborn this early period of physical contact allows the infant to learn about maternal olfactory cues and use these to guide her to the nipple (reviewed by Porter and Winberg, 1999).

Regardless of these benefits, much variation is found among cultures in the onset of breastfeeding. Cultural attitudes about the acceptability of colostrum are one important component that affects a mother's decision about when to begin breastfeeding (Lipsky et al., 1994; Yusof et al., 1995; Littler, 1997). In many settings, colostrum is viewed as harmful to the health of newborns; some women routinely delay breastfeeding for several days postpartum until mature breast milk is expressed (Morse et al., 1990). Other culturally mediated factors that play a role in determining when a child is first breastfed include: the availability and acceptability of bottle feeding (Rogers et al., 1997), an imposed period of separation of the mother and her child as seen in some hospital settings (Hull et al., 1990; Subbulakshmi et al., 1990; Lipsky et al., 1994); advice from health-care workers (Hull et al., 1990); and prelacteal feeding rituals (Saxena and Garg, 1968; Davies-Adetugbo, 1996).

As important as cultural beliefs and learned behaviors are in determining the time to initiation of breastfeeding, it may not be the entire story. One could argue that both actors, the mother and her newborn child, are expected to be driven by some of the same biobehavioral responses that unfold among mothers and offspring of all mammals. The initiation of breastfeeding must, to some extent, be a response that arises from deeply seated mammalian instinct in both a mother and her child. Nevertheless, responses to individual circumstances, the mother's experience, and cultural norms that shape her beliefs may modify or completely circumvent these primitive mammalian behaviors. Thus, initiation of breastfeeding is an intriguing biocultural behavioral and life-history trait that establishes a new phase of the reproductive cycle, one characterized by intense energetic investment in the child by the mother.

In this paper we examine cross-cultural behavior in the initiation of breastfeeding. An attempt is made to uncover general patterns for the initiation of breastfeeding that are common to all humans. This approach of examining "natural breastfeeding" is modeled after Kathryn Dettwyler's concept of "natural weaning" (Dettwyler, 1995). In short, this approach asks the following question: If we could eliminate the effects of culturally mediated delays in the initiation of breastfeeding, how much time would elapse between parturition and initiation of suckling? We expect that there exists an underlying distribution of times to initiation of breastfeeding that is shared by all *Homo sapiens*. Culturally mediated decisions on initiation of breastfeeding may ordinarily mask the pattern of natural breastfeeding.

Our purpose is not to minimize the effects of learned behaviors, beliefs, and culture on the initiation of breastfeeding. Instead, we feel that an understanding of early breastfeeding behavior as a life history trait of *H. sapiens*, a behavior shaped by natural selection since the earliest mammals and most recently by the particular life history trade-offs encountered during the evolution of *H. sapiens*, can provide additional insight into this part of the human reproductive cycle. Partitioning behaviors into natural and cultural components may contribute to a better understanding of the factors responsible for differences among cultures in early breastfeeding behavior. One of the hallmarks of human evolution is the emergence of flexible behavioral systems that have evolved within, and in response to, prevailing social contexts, so that a straightforward dichotomy between natural and cultural components of early breastfeeding behavior may be much too simplistic. Still, it provides a starting point for the study of this critical stage of the human reproductive cycle.

Biobehavioral models of initiation of breastfeeding

In order to examine early breastfeeding behavior in a comparative way, a biobehavioral model is developed for the onset of breastfeeding over a variety of human cultural and ecological contexts. The

model is embodied as a family of parametric probability functions that describe times to initiation of breastfeeding. The model is constructed so that the parameters, to the extent possible, have intrinsic behavioral or biological interpretations. The parameters of the model can then be found by statistical estimation from cross-cultural observations on the time to initiation of breastfeeding. The approach adopted here, modeling a biobehavioral process as probability distributions and estimating parameters from observations, has been used in previous investigations, including studies of postpartum amenorrhea (Ford and Kim, 1987), postpartum resumption of ovulation (Ginsberg, 1973), distribution of coital events across the menstrual cycle (Dobbins, 1980), age at first marriage (Coale and McNeil, 1972), son preference (Haughton and Haughton, 1996), and fecundability and sterility (Wood et al., 1994; Larsen and Vaupel 1993).

Three candidate models of the process are initially constructed. Each candidate is tested for how well it fits to observations of the time to initiation of breastfeeding (latching times). This is done by statistically estimating parameters of the model from 26,220 observations of early breastfeeding behavior taken from 25 previously published studies for which we could ascertain individual latching times. Each candidate model has two components that embody the two hypothesized subgroups of mothers-infant dyad behavior. The first subgroup is made up of dyads that initiate breastfeeding very shortly after parturition, corresponding to "natural" breastfeeding. We propose a particular shape for the distribution among this subgroup based on previous observation and based on some simple theoretical arguments about the attributes of a natural pattern of breastfeeding. The second subgroup represents dyads that postpone breastfeeding for one reason or another—rejection of colostrum, illness of the mother or child, etc. The behavior for this second subgroup is largely mediated by cultural practices or other decisions of the mother that compete with the natural pattern.

The statistical model is made up of probability density functions (PDFs) and probability weights for each subgroup. Call $f_1(t; \theta)$ the probability density functions for latching times (t) for dyads in the first subgroup, and $f_2(t; \phi)$ the distribution of times to latching for dyads in the second subgroup, where θ is an array of parameters that define the PDF for first subgroup, and ϕ is an array of parameters for the second subgroup. In general, we cannot measure with certainty into which subgroup any given dyad belongs. But for a sample of dyads, we can probabilistically model the overall distribution of times to initiation of breastfeeding as a composite of the two types of behavior. The combined distribution of times to initiation of breastfeeding is $f(t; \theta, \phi, p) = pf_1(t; \theta) + (1 - p)f_2(t; \phi)$, where p is the proportion of dyads whose behavior falls within the first subgroup and $1 - p$ is the proportion whose behavior falls in the second subgroup.

The first component. In a previous paper, we examined the empirical distribution of latching times in rural Bangladesh in 1993 and found a short mean time to initiation of breastfeeding (Holman and Grimes, 2001). That empirical distribution appeared to approximate a negative exponential distribution, which led us to use the negative exponential distribution for the parametric analysis. The negative exponential distribution arises frequently in natural phenomena as a model that describes constant "risk" (or hazard, as it is termed in the statistical literature) of the event occurring over time.² The negative exponential implies that dyads have a constant hazard of initiating breastfeeding at all times following parturition. In other words, dyads that have not yet initiated breastfeeding have a constant probability of initiating breastfeeding over a small time interval. Under the constant hazard model, most dyads are expected to initiate breastfeeding immediately following delivery, and a decreasing percentage of mothers will initiate breastfeeding at later times. The model fit well to the observations of Bangladeshi dyads where about one half the dyads initiated breastfeeding within 7 1/2 hours and three quarters of the sample began breastfeeding within 15 hours (Holman and Grimes, 2001).

The negative exponential probability density function is defined as $f_1(t; \theta) = \theta \exp(-\theta t)$, and the corresponding hazard function is $h_1(t; \theta) = \theta$. Under this model, the mean time to initiation of breastfeeding is $1/\theta$. The corresponding survival function is $S_1(t; \theta) = \exp(-\theta t)$. Examples of exponential distributions are given in the top panel of Figure 1.

This first component of the model is supposed to most closely represent those mothers who follow a natural pattern for the initiation of breastfeeding. We generalize this component by modifying the negative exponential component in two ways. First an additional parameter is added that defines a

² When discussing initiation of breastfeeding, we use the terms *hazard* and *risk* in a technical sense and without the negative connotations of ordinary usage. The technical definition of the hazard in this context is the age-specific instantaneous probability of initiating breastfeeding for a dyad that has not yet initiated breastfeeding. Age is taken from the time of birth.

distribution among women in the rate (hazard) parameter of the negative exponential. The hazard of initiating breastfeeding is still constant over time for a given dyad, but now the hazard of initiating breastfeeding differs among dyads according to a gamma distribution. The resulting distribution, called a gamma-frailty model, has been used to model other biological or behavioral phenomena like rates of nucleotide substitutions (Nei, 1987), variation in mortality (Vaupel, 1990), and fecundability (Larsen and Vaupel, 1993). The probability density function for the gamma frailty model is

$$(1) \quad f_1(t; \theta_1, \theta_2) = \frac{\theta_1 \theta_2^{\theta_2+1}}{(\theta_1 t + \theta_2)^{\theta_2+1}},$$

where θ_1 describes the constant hazard within dyads and θ_2 defines the variance in θ_1 among dyads. The mean time to initiation of breastfeeding is $\theta_2/(\theta_1\theta_2 - \theta_1)$. The combined hazard for all dyads within the first subgroup is $h_1(t; \theta_1, \theta_2) = \theta_1\theta_2/(\theta_1 t + \theta_2)$. The corresponding survival function is

$$(2) \quad S_1(t; \theta_1, \theta_2) = \left(\frac{\theta_2}{\theta_2 + \theta_1 t} \right)^{\theta_2}.$$

Examples of the gamma-frailty distribution are given in middle panel of Figure 1. Compared to the exponential distribution, the gamma-frailty distribution has more dyads initiating breastfeeding at later ages, corresponding to a heavier tail seen for the distribution.

We consider one other variation on the negative exponential model for the first subgroup. The modification provides for a low risk of breastfeeding immediately after parturition, but then the risk rises following birth. The distribution of times to initiation of breastfeeding under this model will show an initial increase in frequency to some maximum value very shortly after parturition, and then is followed by a nearly negative exponential decline in frequency thereafter. We chose the Weibull distribution as the probability model because it allows for departures from a constant risk of initiation of breastfeeding to more complex cases where risk increases with time, decreases with time, or remains constant with time (Kalbfleisch and Prentice, 1980). This Weibull probability density function is given by

$$(3) \quad f_1(t; \theta_1, \theta_2) = \theta_2 t^{\theta_2-1} \theta_1^{\theta_2} \exp[-(t\theta_1)^{\theta_2}],$$

where $\theta_1 (> 0)$ is a scale parameter, and $\theta_2 (> 0)$ is a shape parameter. The reciprocal of θ_1 defines the characteristic time (63rd percentile) to initiation of breastfeeding. The mean time to initiation of breastfeeding is $\Gamma(1+1/\theta_1)/\theta_2$, where $\Gamma(x)$ is the gamma function. The corresponding hazard function is $h_1(t; \theta_1, \theta_2) = \theta_2 t^{\theta_2-1} \theta_1^{\theta_2}$ and the survival function is

$$(4) \quad S_1(t; \theta_1, \theta_2) = \exp[-\theta_1 t^{\theta_2}]$$

(Lee, 1992; Nelson 1983).

From a behavioral standpoint, we can expect that there will usually be a delay of some minutes to hours following parturition until breastfeeding is even possible. Indeed, both the mother and infant must be "ready" before breastfeeding can begin. At the very minimum, some time is required for severing the umbilical cord, handling, and perhaps grooming the infant prior to the start of breastfeeding. Therefore, the risk of initiating breastfeeding might begin low and increase with time, corresponding to a Weibull distribution with parameter $\theta_2 > 1$. The Weibull distribution includes the exponential model as a special case when the $\theta_2 = 1$. Thus, the Weibull θ_2 parameter, in some sense, measures departure from the basic model with an exponential first component. An increasing hazard model arises when $\theta_2 > 1$. As θ_2 gets larger than 1, the mode of the distribution gradually moves away from 0. Examples of the distribution are given in the lower panel of Figure 1.

The second component. The second component of the model reflects the subgroup for which

breastfeeding is delayed. The reasons for delays are determined by cultural and health factors. The health-related delays might be determined in any particular case by illness of the mother or child, a long postpartum recovery period for the mother, difficulty of establishing breastfeeding, or insufficient milk production. Delays that are culturally mediated include withholding of colostrum from the infant while the breastmilk matures and ritual prelacteal feeding of the child. This second subgroup is modeled as a lognormal distribution (for all three candidate models). We chose the lognormal distribution for this subgroup for several reasons. First, this second subgroup is heterogeneous—there are potentially many causes or reasons for delaying breastfeeding. Under the assumption that there are numerous small factors, each one acting multiplicatively on the delays to initiation of breastfeeding, then the lognormal distribution arises by the central limit theorem of statistics. We chose the lognormal over the normal distribution because the normal distribution has the incongruous property of admitting some probability of breastfeeding at negative times.

The lognormal probability density function is given by

$$(5) \quad f_2(t; \phi_1, \phi_2) = \frac{1}{t\phi_2\sqrt{2\pi}} \exp\left\{-\frac{[\ln(t/\phi_1)]^2}{2\phi_2^2}\right\}$$

The mean time to breastfeeding under the lognormal distribution is $\phi_1 \exp(\phi_2^2/2)$ and the variance is given as $\phi_1^2 \exp(\phi_2^2/2) [\exp(\phi_2^2/2) - 1]$. Examples of lognormal distributions with several parameters are given Figure 2.

Although we have specified two behaviorally determined subgroups, in general it is not possible to determine subgroup membership for any mother-infant pair. For purposes of statistical estimation, however, we need not identify subgroup membership for individual dyads. Instead, we treat the entire distribution of times to initiation of breastfeeding as a mixture of the two components. Within the statistical literature, these are called finite mixture models or commingling analysis. The models have previously been used for a number of applications in anthropology and reproductive ecology (Pearson et al., 1992; Ford and Kim, 1987; Haughton and Haughton, 1996; and Wood et al., 1992).

Some of the shapes for each composite candidate model are given in Figure 3. All three can produce bimodal distributions of times to initiation of breastfeeding. The first mode of the negative exponential-lognormal and gamma-frailty-lognormal models occurs at time zero (top and center panel). Both modes of the Weibull-lognormal models may occur at later times when θ_2 (bottom panel).

The resulting two component models will fit a variety of bimodal distributions, the models are usefully simple, and the parameters of the models lend themselves to the following simple interpretations. If dyads use only learned behaviors to determine when to begin breastfeeding, then only one of the model components should be statistically identifiable. If initiation of breastfeeding has one component that is largely instinctual behavior, then both components of the model will be identifiable. If both components of the model can be statistically identified, the effects of behavioral, cultural, and biological covariates can be modeled as affecting each of the model components (we discuss how to do this in the statistical methods section). Under a pure dichotomy where the first component is instinctual behaviors and the second is learned behaviors, cultural factors should have little affect on the first component of the model. If covariates show a strong effect on the first component of a two-component model, we would interpret this to suggest that the first component is itself a mixture of instinctual and learned behaviors.

SUBJECTS AND METHODS

Subjects

Observations of early breastfeeding behavior were taken from 25 previously published studies of breastfeeding behavior identified in a literature search (Table 1). In order to be included in the current analysis, a study had to include at least 100 subjects. Additionally, the study had to include a distribution of times to initiation of breastfeeding. The distribution had to be subdivided into three or more categories of time.

From studies that met these criteria, we determined individual observations from tables, graphs, or text describing the empirical distribution of times to initiation of breastfeeding. The counts of dyads in each interval were taken as a series of individual observations of time to initiation of breastfeeding. Each observation falls within an interval defined to bracket the minimum possible time (in hours) until initiation of breastfeeding and the maximum possible time until initiation of breastfeeding for that dyad. The resulting observations are treated as interval-censored observations. For one study, ungrouped, and generally smaller intervals within which breastfeeding started were known for all individuals (Holman and Grimes, 2001).

In addition to the interval-censored observations, several special classes of observations were found. For some studies, the last time interval was defined for children known to begin breastfeeding after some number of hours. We treated these as statistically right-censored observations at the minimum time of initiation. Additionally, some studies included observations of the number of children who were never breastfed. For example, in Gupta et al. (1992), time to initiation of breastfeeding was divided into five categories: 0 to 6 hr, 6 to 12 hr, 12 to 24 hr, over 24 hr and never. There were 2,660 mothers-infant pairs who initiated breastfeeding in the interval of 0 and 6 hours. In our analysis, these make up 2,660 observations interval-censored between 0 and 6 hours. The 4,267 observations in the last interval (e.g. over 24 hr in the Gupta example above) are treated as 4,267 observations right censored at 24 hr. The category, "never breastfed", included 262 children who never breastfed, and these children are excluded from the analysis. In this way, we were able to include observations on 26,220 mother-infant pairs, including interval and right-censored observations.

Figure 4 shows typical empirical distributions of time to breastfeeding from four of the studies in our meta-analysis. Panel a. shows a distribution that has one major mode on day three, whereas panel b. shows one mode on day one with a pattern of times that look like a negative exponential distribution. The distributions must be interpreted carefully as the interval sizes are not consistent within graphs, and the intervals are defined differently among studies.

A number of variables were coded for each sample or subsample, based on characteristics reported by the original authors. For example, authors usually defined their samples as urban or rural. In cases where basic information such as dates of data collection or primary religious affiliation of the study population was not included in the original source, we asked the original authors. In a few cases where the information was not made available by the original authors, we used indirect evidence provided from the original source or summary statistics for the region to infer a value. For statistical analysis, we recoded all variables as a set of indicator covariates. The covariates, their characteristics, and the reference categories for each set of variables are given in Table 2.

Model estimation

The general form for the model is $f(t; \theta, \phi, p) = pf_1(t; \theta) + (1-p)f_2(t; \phi)$ for dyads who will breastfeed. As discussed previously, the form of $f_1(t; \theta)$ is under investigation; we begin with an

exponential distribution, and test two different modifications of the exponential PDF: the gamma frailty model and the Weibull model. The form of $f_2(t; \boldsymbol{\phi})$ is assumed to be a lognormal distribution. The mixing parameter p (where, $0 \leq p \leq 1$) is the fraction of mothers that breastfeed according to the exponential (and variant) component; whereas, $1 - p$ breastfeed according to the lognormal distribution.

Likelihoods. Times to breastfeeding are given as interval-censored observations, meaning that instead of observing an exact time, we know the earliest possible time and latest possible time at which breastfeeding was initiated. Thus, each observation is a pair of times $[t_o, t_c)$ that defines an interval within which breastfeeding was initiated. The term t_o is the opening time of the interval, and t_c denotes the closing time of the interval. For example, we might know that breastfeeding was initiated at or after 12 hours and prior to 24 hours, so that for this observation $t_o=12$ and $t_c=24$.

Estimation of the model parameters from interval and right-censored observations is easily accommodated using likelihood methods. A right-censored observation can simply be considered an interval-censored observation in which t_c is infinity (Wood et al., 1992). The individual likelihood for an interval or right-censored observation is taken as the area under the probability densities between t_o and t_c . The likelihood for a sample of N such observations is constructed as the product of the individual likelihoods:

$$(6) \quad L = \prod_{i=1}^N \int_{t_{o_i}}^{t_{c_i}} f(t; \boldsymbol{\theta}, \boldsymbol{\phi}, p) dt$$

$$= \prod_{i=1}^N [S(t_{o_i}; \boldsymbol{\theta}, \boldsymbol{\phi}, p) - S(t_{c_i}; \boldsymbol{\theta}, \boldsymbol{\phi}, p)]$$

where $S(t; \boldsymbol{\theta}, \boldsymbol{\phi}, p)$ is the survival function for the mixture model, which can be found from the survival distribution of each of the two components as, $S(t; \boldsymbol{\theta}, \boldsymbol{\phi}, p) = pS_1(t; \boldsymbol{\theta}) + (1-p)S_2(t; \boldsymbol{\phi})$. The parameter p is the mixing proportion that is interpreted as the probability that a dyad behaves according to the first subgroup rather than the second. The maximum likelihood estimates are those values of $\boldsymbol{\theta}$, $\boldsymbol{\phi}$, and p that maximize likelihood (6).

Covariates. The effects of covariates on p are specified as a logistic regression. An $M + 1$ array of parameters, $\boldsymbol{\beta}_p = (\beta_{p0}, \beta_{p1}, \beta_{p2}, \dots, \beta_{pM})$, quantifies the effects of M covariates, $\mathbf{x}_i = (x_{1i}, x_{2i}, \dots, x_{Mi})^T$, for the i -th dyad as

$$(7) \quad p_i = \frac{1}{1 + \exp(\mathbf{x}_i \boldsymbol{\beta}_p)} = \frac{1}{1 + \exp(\beta_{p0} + x_{1i}\beta_{p1} + x_{2i}\beta_{p2} + \dots + x_{Mi}\beta_{pM})}$$

and p_i replaces p in likelihood (6).

The effects of covariates is also modeled as affecting the hazard of initiation of breastfeeding for each subgroup. Effects of covariates for the first subgroup are modeled with M parameters, $\boldsymbol{\beta}_1 = (\beta_{11}, \beta_{12}, \dots, \beta_{1M})$, as $\mathbf{x}_i \boldsymbol{\beta}_1 = x_{1i}\beta_{11} + x_{2i}\beta_{12} + \dots + x_{Mi}\beta_{1M}$ and a vector formed by M covariates \mathbf{x}_i for the i -th dyad and. Likewise, parameters for the second subgroup are modeled as $\mathbf{x}_i \boldsymbol{\beta}_2 = x_{1i}\beta_{21} + x_{2i}\beta_{22} + \dots + x_{Mi}\beta_{2M}$. A proportional hazards specification is used to model $\mathbf{x}_i \boldsymbol{\beta}_1$ on the first component and $\mathbf{x}_i \boldsymbol{\beta}_2$ on the second component. Under the proportional hazards model, the survival function is specified as $S_i(t_i; \mathbf{x}_i, \boldsymbol{\theta}, \boldsymbol{\phi}, \boldsymbol{\beta}_p, \boldsymbol{\beta}_1, \boldsymbol{\beta}_2) = p_i S_1(t_i; \boldsymbol{\theta})^{\exp(\mathbf{x}_i \boldsymbol{\beta}_1)} + (1-p_i) S_2(t_i; \boldsymbol{\phi})^{\exp(\mathbf{x}_i \boldsymbol{\beta}_2)}$ (Kalbfleisch and Prentice, 1980). Parameter estimates were found numerically using the software program *mle* 2.0 (Holman, 2000).

Model selection. We examined a number of different models and parameterizations of the models. The Akaike Information Criterion (AIC) was used to select which of the models most parsimoniously approximates the true (but unknown) model from which the data were drawn (Akaike, 1973, 1992; Burnham and Anderson, 1998). The AIC for a model is computed as $-2\ln(\hat{L}) - 2M$, where M is the number of parameters estimated for the model, and \hat{L} is the maximized likelihood for that model. The model with the lowest AIC is taken as the most parsimonious model among the candidates.

RESULTS

Three models for the initiation of breastfeeding (Weibull-Lognormal, Gamma-Frailty-Lognormal, Exponential-Lognormal) were evaluated for their fit to cross-cultural observations of the initiation of breastfeeding. The Gamma-Frailty-Lognormal distribution was the most parsimonious of the three candidate models according to the AIC values (Table 3). Reduced versions of all three models, in which the first or second component was removed, fit the data significantly more poorly (results not shown).

For the logistic mixing proportion, all but two covariates dropped out of the best-fitting of the candidate models (Table 3). The proportion estimated for the reference group suggests that a baseline 50.6% of women breastfed almost immediately. This proportion increased over this reference category to 72.5% for urban dyads, and increased over the reference group to 56.5% for subjects from studies in the Middle East.

The first component of the model, the gamma-frailty distribution, was affected by seven different covariates (Table 3). Dyads that behaved according to the first component and whose covariates corresponded to the reference groups had a baseline mean time to initiation of breastfeeding of just over 2.5 (S.D. 3.5) hours. The negative covariate coefficients act to reduce the hazard, effectively increasing time to onset of breastfeeding. Urban women and women from slums had a later onset of breastfeeding than did rural mothers. Hindu dyads, and dyads of “other” religions delayed breastfeeding compared to the reference Islamic dyads. Compared to reference S. Asian dyads, African dyads delayed initiation of breastfeeding and dyads from the Middle East had an earlier onset of breastfeeding. Effects of covariates are additive, so that Hindus living in S. Asian urban slums, for example, are expected to have an initiation time of nearly 36 (S.D. 79) hours if they breastfeed according to the first component. The decade in which studies were conducted (1970's-1990's) had no effect on time to initiation of breastfeeding.

Dyads that behaved according to the second model component had a later baseline time to initiation of breastfeeding (mean 65 hours, standard deviation 67 hours). A number of covariates affected the time to initiation of breastfeeding, including living in a slum which delayed initiation of breastfeeding, and living in an urban setting, or being Hindu, which led to later breastfeeding times.

A graphical description of the findings, produced by plotting $f(t; \theta, \phi, p)$ using different hypothetical combinations of parameters estimates in Table 3 are given in Figure 5. The corresponding mean and standard deviation of each model component and the total model are given in Table 4. Clearly, the effect of the covariates can have a strong effect on both components of the model, as well as the proportion in each component.

DISCUSSION

We have estimated parameters of a biobehavioral model of initiation of breastfeeding using observations from 25 previously published studies, and including over 26,000 observation of early breastfeeding behavior. For each of the three candidate models, versions with two components fit significantly better than reduced versions with one component. This indicates that the distribution of times to initiation of breastfeeding is composed of two distinct behavioral patterns. Investigation of the first component reveals that the gamma frailty distribution provided a better fit than did the exponential or Weibull candidate components. The interpretation of the gamma frailty portion of the model is that dyads who are “early” feeders experience a constant risk of initiating breastfeeding following parturition, but that the risk varies *among* dyads. This can be taken as evidence that there is some deviation from a strong “preprogrammed” initiation behavior for this “rapid onset” subgroup, whether for biological or behavioral reasons.

The second subgroup consists of dyads whose initiation of breastfeeding began at later postpartum times. The mean time to initiation of breastfeeding for this subgroup was 66 hours (S.D. 19 hours) for the reference category of covariates. Dyads who behave according to this second component are proposed to be heterogeneous with regard to latching times; individuals are expected to behave according to their specific cultural norms and beliefs concerning proper and healthy infant feeding practices. These norms

include things like restrictions on infant feeding for the first two days seen in many cultures throughout the world, especially in South Asia, Pacific Islands, and parts of sub-Saharan Africa (Morse et al., 1995). Other factors, such as illness or delivery complications may also be important, but data were not available to examine these issues in any detail.

Initiation of breastfeeding is an obstacle faced by the mother and offspring of all mammals. The behavior is of sufficient importance to the survival of offspring that lineage-specific and species-specific solutions may have been shaped by natural selection. One-day-old rat pups, for example, actively participate in the initiation of breastfeeding through a series of trunk movements, and a specific type of crawling along the ventral surface of the mother (Eilam and Smotherman 1998). The general reproductive pattern seen in primates is a lengthened gestation interval and relatively precocious offspring. Many non-human primate newborns are actively involved in the initiation of breastfeeding by using grasping, clambering, and rooting behaviors to make their way toward the nipple and begin breastfeeding. Thus, the relatively precocial non-human primate newborn is an active participant in establishing the physical connection of breastfeeding (Jolly, 1985:325). In a small sample, Rhesus macaque newborns that are rejected or mistreated by mothers with psychopathologies are successful about half the time in establishing lactation even though the mothers continued to ignore or thwart their breastfeeding attempts (Harlow and Harlow, 1962). It appears that in most non-human primates breastfeeding is initiated within minutes or hours after parturition, although there is little systematic research on the topic.

Of all the primates, the large-bodied hominoids (*Pan*, *Gorilla*, *Pongo*, and *Homo*) are the least precocial, with *Homo sapiens* carrying out the trend to an extreme. Humans have evolved secondarily altricial characteristics as a result of brain expansion under the constraints of bipedality (Portmann, 1990; Martin, 1983; Martin and MacLarnon, 1990). This limitation on prenatal brain growth means that many behaviors expressed by more precocial primates at birth are not possible in the human newborn because the neural structures responsible for facilitating such behaviors are not fully developed at birth (Martin and MacLarnon, 1990). Human infants at birth have a limited repertoire of motor capabilities compared to newborn rhesus monkeys that can crawl and pull themselves over their mother's fur at birth (Jolly, 1985:376). A normal human newborn can achieve sucking, grasping, crying and a rudimentary series of body movements referred to as rooting, but does not develop more involved motor behaviors such as crawling and reaching and grasping objects for several weeks. Even so, a human infant left to its own devices on its mother's abdomen immediately after birth will initiate rooting behaviors after 20 min, and will begin to make movements towards the breast, reaching the nipple in about 50 minutes; at this point, the infant may initiate suckling unaided (Righard and Alade, 1990). Olfactory stimuli from nipple secretions appear to be the primary sensory cue that elicit rooting behavior and nipple localization (Varendi and Porter, 2001; Porter and Winberg, 1999). Crying is another programmed behavior practiced by the human infant to establish breastfeeding presumably by triggering a response from the mother. Compared to other primates, though, human newborns are relatively passive in some aspects of initiating breastfeeding, like transporting themselves to the nipple.

Does maternal instinct play a role in the initiation of breastfeeding in humans, or do human mothers rely exclusively on learned maternal behaviors? All mammals engage in species-specific stereotypic behaviors after parturition that culminate in breastfeeding. Nevertheless, it is clear that mammalian maternal behaviors are to a great extent learned behaviors (reviewed in Fleming et al., 1999). For some mammals, hormonal changes that occur around or during parturition, especially in estradiol, progesterone, prolactin, and oxytocin, are associated with the onset of maternal behaviors (Uvnäs-Moberg, 1996; Fleming et al., 1999; Maestripieri, 1999). In non-human primates, pregnancy hormones have been found to have associations with maternal behaviors or social behaviors related to motherhood (Fite and French, 2000; Maestripieri and Megna, 2000). In women, changes in pregnancy hormones have been linked with "postpartum attachment feelings" (Fleming et al., 1997), yet no studies have investigated endocrine effects on immediate postpartum behaviors including the initiation of breastfeeding in humans.

Human infants are relatively altricial organisms in a precocial phylogenetic lineage.³ Unlike other primates, responsibility for initiation of breastfeeding falls almost entirely to the mother. New or enhanced secondary mechanisms of maternal behavior in *Homo* may have co-evolved with the morphological and neurological suite of traits leading to brain expansion and secondarily altricial human infants. One such

³ The suggestion has been made that the human infant is only altricial for neuromotor behaviors, and is cognitively precocial (Clancy et al. 2001). Our point still holds in light of this refined understanding of relative maturity since it is neuromotor skills that are used by newborn mammals to participate the establishment of nursing.

secondary mechanism—perhaps the most important—may be a reliance on learned behaviors rather than programmed behaviors, an idea consistent with increased importance of learned behaviors in the genus *Homo*. If so, a straightforward implication is that maternal behavior in the immediate postpartum period has been successfully and continuously transmitted by cultural mechanisms over the course of human evolution.

There is ample evidence to support the importance of social learning as a primary mechanism in the initiation of breastfeeding in humans. Classic research in psychology has empirically demonstrated the importance of early contact between a primate mother and her infant in determining the female infant's success when she becomes a mother (Harlow and Harlow, 1965). Although, from these studies it is not clear if primates learn about breastfeeding from being breastfed, or if the normal maternal-infant contact does not take place the young animal develops abnormally and is incapable of all, or several maternal behaviors such as breastfeeding. Anecdotal evidence suggests that orphaned female gorillas with no experience in breastfeeding can learn this behavior by observing human mother-infant dyad breastfeeding.

In contemporary humans, cultural norms can dictate if and when a mother initiates breastfeeding. In societies where breastfeeding is publicly practiced, females may learn by observing the practices of other mothers. Behaviors learned through observation may be more important in shaping a mother's behavior for her first child than is formal training or written material (Hoddinott and Pill, 1999; Ekwo et al., 1983).

The results presented in this paper strongly suggest that there are two distinct behavioral patterns in the timing for the initiation of breastfeeding. We proposed that the first subgroup represents a "natural" behavioral pattern, and that it might reflect a more general primate latching behavior expected to occur in the absence of culturally mediated delays in breastfeeding. If this first component were purely instinctual, then we would expect that it would not be affected by cultural covariates. Yet, many of the covariates had some effects on this first component—some covariates caused substantial delays in time to onset of breastfeeding (Table 4). We interpret this to mean that the behavior captured in the first component of the model is more complex than simply instinct.

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Table 1. Sources of information on times to initiation of breastfeeding.

<u>Study location</u>	<u>N</u>	<u>Setting</u>	<u>Study date</u>	<u>Recall</u>	<u>Source</u>
Bangalore, India	539	Urban slums	1983	Long	Prabhakara et al. (1987)
Varanasi, India	273	Urban	1970s	< 5 y	Katiyar et al. (1981)
Varanasi, India	284	Urban slums	1970s	< 5 y	Katiyar et al. (1981)
Varanasi, India	336	Rural	1970s	< 5 y	Katiyar et al. (1981)
Patna, India	950	Urban	1990s	?	Srivastava et al. (1994)
India, major cities	10032	Urban	1991	?	Gupta et al. (1992)
Bhalwal & Raya, India	250	Urban	1975	6 – 24 m	Sharma & Lahori (1977)
Bhalwal & Raya, India	300	Rural	1975	6 – 24 m	Sharma & Lahori (1977)
India, Himachal Pradesh	975	Rural	1985-1986	?	Bahl & Kushal (1987)
Chengdu & Sichuan, China	357	Urban	1993	4 – 12 m	Guldan et al. (1995)
Bissau, Guinea-Bissau	330	Urban slums	1984-1986	3 d median	Gunnlaugsson et al. (1995)
Kota, India	120	Urban	1980s	< 3 y	Singhania et al. (1990)
Nagpur, India	217	Urban slums	1995	< 2 y	Bhosale et al. (1997)
Indonesia, 8 major cities	450	Urban	1985	2.1 d mean	Hull et al. (1990)
Karnataka, India	1052	Rural	1991-1992	< 2 y	Banapurmath et al. (1996)
India	161	Urban	1991-1992	?	Banapurmath & Selvamuthukumarasamy (1995)
Chandigarh, India	351	Urban	1974	10-14 m	Walia et al. (1987)
Chandigarh, India	694	Urban	1984	10-14 m	Walia et al. (1987)
South Delhi, India	547	Urban slums	1980s	< 3 y	Kumar et al. (1989)
Ile Ife, Nigeria	50	Urban slums	1989-1991	?	Davies-Adetugbo & Ojofeitimi (1996)
Ile Ife, Nigeria	62	Urban	1989-1991	?	Davies-Adetugbo & Ojofeitimi

(1996)					
Bangladesh	4538	Rural	1993-1994	< 4 y	Chowdhury et al. (1997)
Tangail district, Bangladesh	248	Rural	1982-1985	< 2 y	Rizvi (1993)
Pennoken, Liberia	72	Rural	1980	10 m mean	Jarosz (1993)
Monrovia, Liberia	49	Urban	1980	10 m mean	Jarosz (1993)
Al-Ain, United Arab Emirates	221	Urban	1995	< 28 d	Al-Mazouri et al. (1997)
Bahrain	499	Urban	1980s	?	Musaiger (1995)
Oman	1028	Urban	1980s	?	Musaiger (1995)
Saudi Arabia	990	Urban	1980s	?	Madani et al. (1990)
Karachi, Pakistan	102	Urban slums	1992-1994	< 3 m	Badruddin et al. (1997)
Matlab, Bangladesh	143	Rural	1993	3 d median	Holman & Grimes (2001)

Table 2. Mean and standard deviation for indicator variables used as covariates.

<u>Variable</u>	<u>Mean</u>	<u>Std dev</u>
Environment		
1		
Is_slum	0.079	0.270
Is_notslum ^a	0.921	0.270
Environment		
2		
Is_urban	0.708	0.455
Is_rural ^a	0.292	0.455
Religion		
Is_Hindu	0.651	0.477
Is_Islamic ^a	0.318	0.466
Is_other	0.031	0.173
Region		
Is_SAsia ^a	0.843	0.364
Is_SEAsia	0.031	0.173
Is_Mideast	0.058	0.234
Is_Africa	0.021	0.145
Decade		
Is_70s ^a	0.068	0.252
Is_80s	0.254	0.435
is_90s	0.678	0.467

^a Reference category

Table 3. Parameter estimates for the best fitting models

	Exponential		Gamma frailty		Weibull	
	Estimate	SE	Estimate	SE	Estimate	SE
p	0.020	0.026	-0.026	0.026	-0.050	0.027
β_{purban}	-0.731	0.042	-0.846	0.042	-0.943	0.045
$\beta_{pMideast}$	-0.501	0.070	-0.345	0.070	-0.236	0.073
θ_1	0.423	0.009	0.431	0.010	2.32	0.062
θ_2			20.5	2.0	0.878	0.008
$\beta_{\theta slum}$	-0.499	0.042	-0.324	0.041	-0.352	0.040
$\beta_{\theta urban}$	-0.350	0.035	-0.354	0.036	-0.369	0.038
$\beta_{\theta Hindu}$	-1.56	0.036	-1.52	0.036	-1.51	0.038
$\beta_{\theta other}$	-1.32	0.099	-1.27	0.103	-1.30	0.102
$\beta_{\theta SEAsia}$	-0.949	0.081	-0.870	0.084	-0.807	0.086
$\beta_{\theta Mideast}$	0.588	0.046	0.606	0.048	0.582	0.052
$\beta_{\theta Africa}$	-0.319	0.100	-0.316	0.107	-0.223	0.107
ϕ_1	4.15	0.015	4.14	0.013	4.14	0.013
ϕ_2	0.282	0.008	0.256	0.008	0.248	0.008
$\beta_{\phi slum}$	-0.286	0.092	-0.385	0.124	-0.365	0.139
$\beta_{\phi urban}$	0.345	0.047	0.660	0.062	0.669	0.067
$\beta_{\phi Hindu}$	0.239	0.066	0.207	0.065	0.136	0.068
Loglikelihood	-37175		-37082		-37093	
AIC	74383		74197		74220	

Table 4. Mean and standard deviation (S.D.) of time to initiation of breastfeeding for the total distribution and for each component for the gamma frailty-lognormal mixture model with three different hypothetical combinations of covariates (see Figure 3).

Covariates	Proportion	Total		Subgroup 1		Subgroup 2	
	Subgroup 1	Mean	S.D.	Mean	S.D.	Mean	S.D.
Urban, Mideast, Hindu	0.772	20.0	29.6	10.0	15.7	53.9	54.9
Rural S. Asia, Islamic	0.506	33.3	47.2	2.4	3.5	65.0	67.1
Slum, S.E. Asia, other religions	0.506	58.5	76.9	45.3	78.5	72.1	75.2

FIGURE CAPTIONS

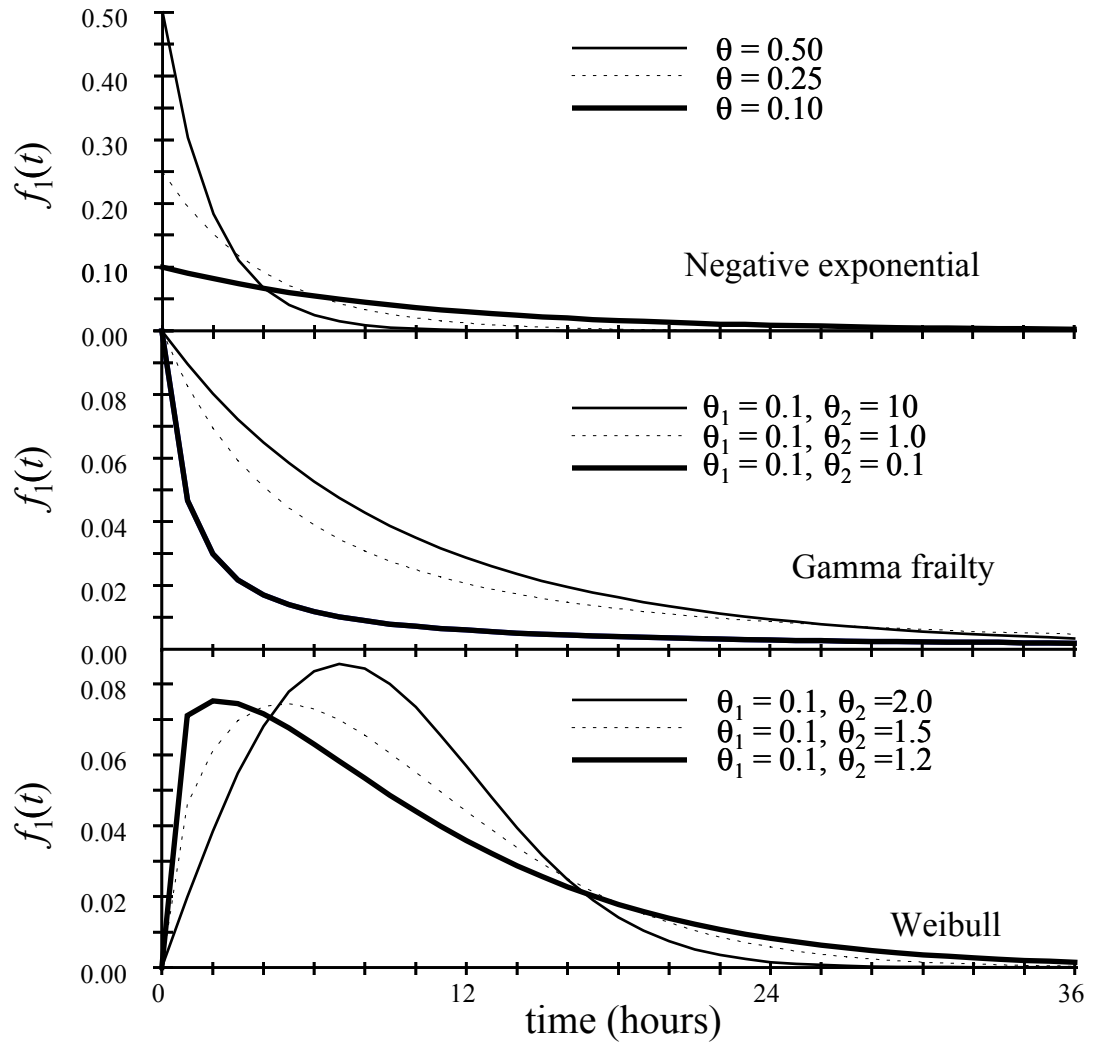


Figure 1. Examples of three candidate distributions for the first component of the model of time to initiation of breastfeeding.

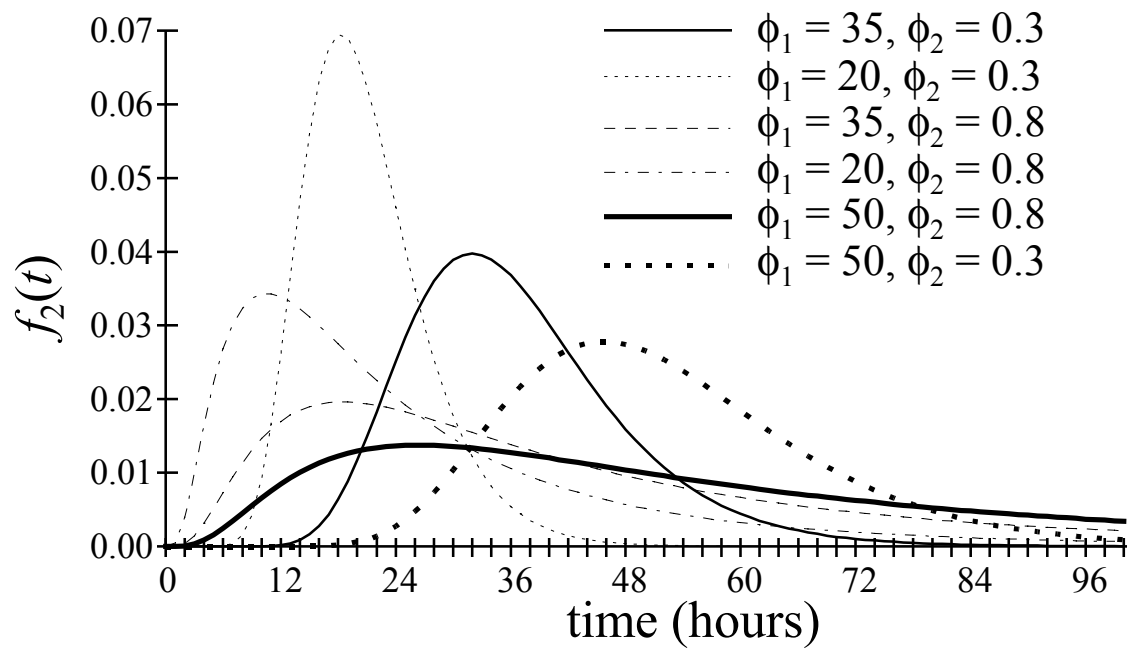


Figure 2. Examples of lognormal distributions for the second component of the model of time to initiation of breastfeeding.

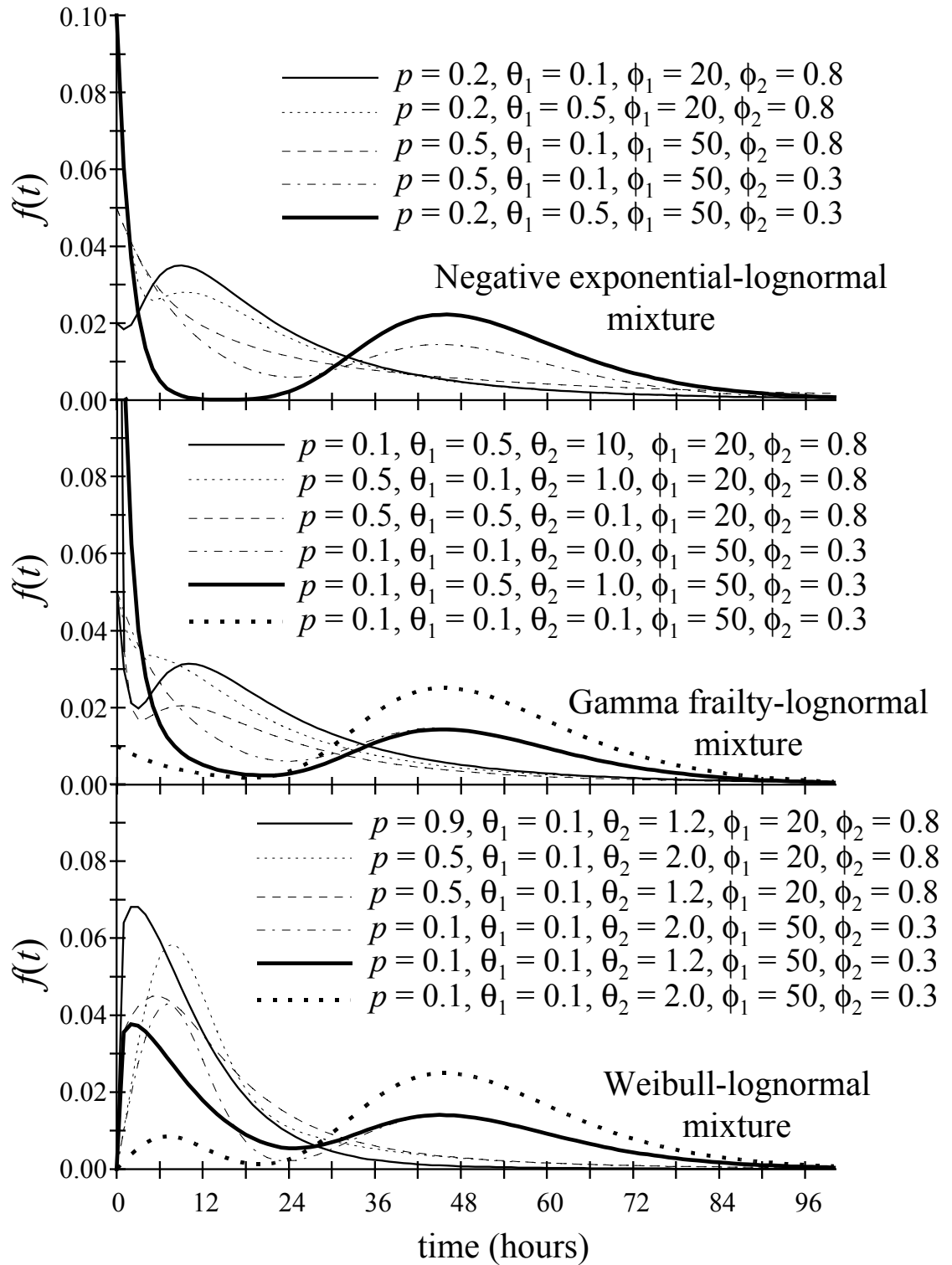


Figure 3. Examples of three candidate models, with both components of the mixtures.

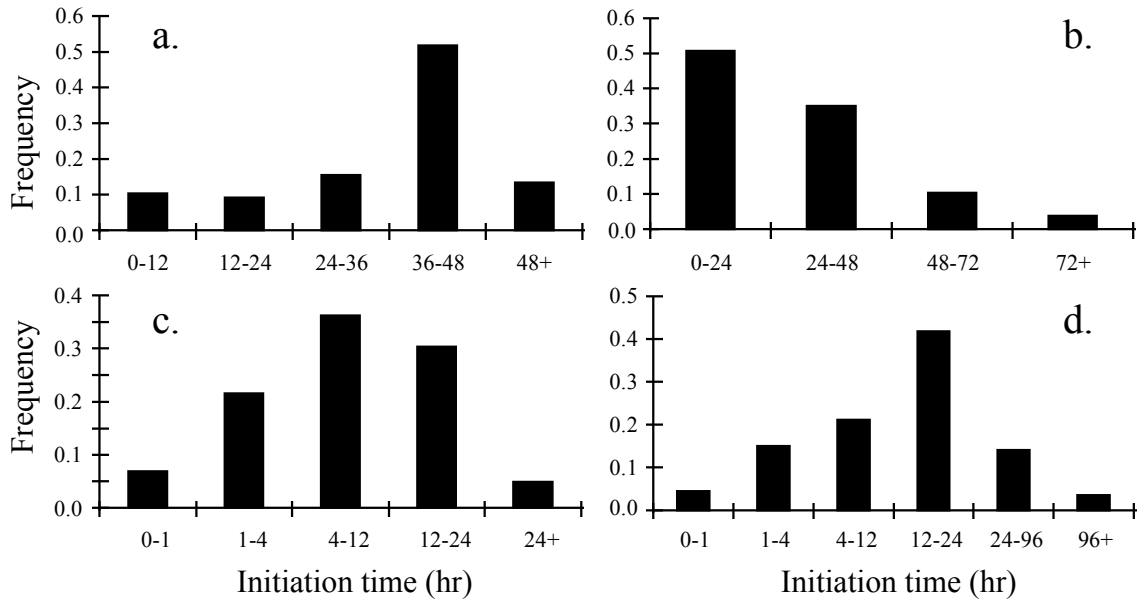


Figure 4. Empirical distributions of latching times reported in four studies. Studies are from a. India (Kumar et al., 1989), b. United Arab Emirates (Al-Mazouri et al., 1997), c. Pakistan (Badruddin et al., 1997), d. India (Prabhakara et al. 1987).

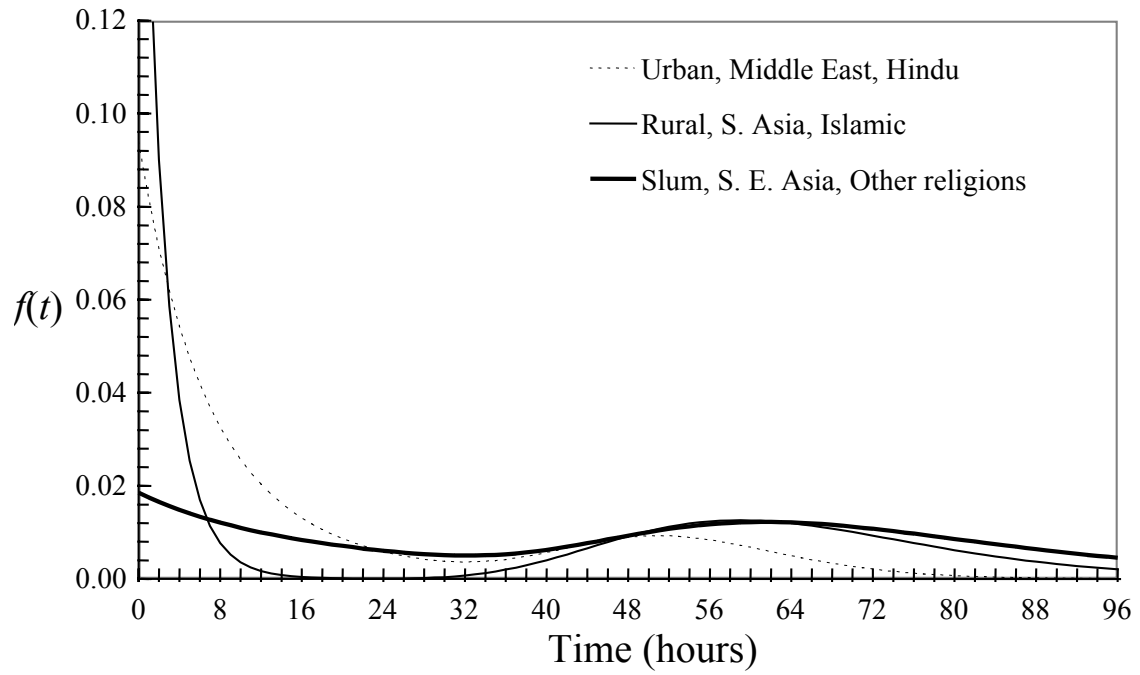


Figure 5. Three expected distributions of latching based on the parameter estimates for the two-point gamma frailty-lognormal model given in Table 3 using three hypothetical combinations of covariates.