THE SEASONALITY OF CONCEPTION*

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Individual data on menstrual cycles of noncontracepting women living in Western countries were used in order to verify whether the biological seasonality of conception persists after sexual behavior is controlled for. Episodes of intercourse were recorded daily, and the time of ovulation was detected by a marker. We find that the seasonality of conception changes with woman's age and frequency of episodes of sexual intercourse. In particular, for women aged 27–31 having only one act of intercourse during the six most fertile days of the menstrual cycle, the seasonality of fecundability is stronger. In this age group in the Northern Hemisphere, if seasonality of acts of sexual intercourse is controlled, the monthly distribution of probability of conception is bimodal, with two maxima (September and January) and two minima (December and March). When unobserved characteristics of the couples are considered, this seasonal pattern of conception persists.

In biodemographic research, the seasonality of conceptions and births is an intriguing and recurring topic. Traditionally, studies based on aggregate data describe the seasonal patterns of births or conceptions, together with those of other phenomena possibly affecting births or conceptions. The wide literature of aggregate studies on the seasonality of births was extensively reviewed by Leridon (1973) up until the late 1960s, and by Panther-Brick (1996) for the following period. This aggregate approach is not out of fashion: it has been revisited by Bobak and Gjonca (2001), Cagnacci et al. (2003), Chatterjee and Acharya (2000), Crisafulli, Dalla Zuanna, and Solero (2000), Danubio et al. (2003), Pascual et al. (2002), and Smits, Zielhuis, and Jongbloet (1998). Although some of these studies were merely exploratory, most of them tried to verify hypotheses concerning underlying seasonal patterns (see, e.g., Becker, 1984; Becker, Chowdhury, and Leridon 1986; Lam and Miron 1991; Lam, Miron, and Riley 1994; Leridon 1973; Luzzato Fegiz 1925; Pascual et al. 2002; and Rojansky, Brzezinski, and Schenker 1992). As Wood (1994:529–36) stressed, the main conceptual and statistical problem of these studies is the ecological fallacy. If two variables are affected by seasonality, it is always possible to find a statistical association between their seasonal distributions. Consequently, it is very difficult to distinguish the various components affecting the seasonality of conception or births.

In the last few years, knowledge about the seasonality of conception has been widely developed through individual data obtained by noninvasive techniques, which can determine whether a woman is fecund or subfecund (see Ellison 1997 for an extensive review of the medical, biological, and demographic literature). Thanks to some simple nonclinical tests on saliva, urine, or finger-prick blood samples, it is possible to determine—day by day—the level of hormones closely connected with the timing of ovulation in each monthly cycle. These methodological innovations have enabled individual-level studies of the seasonality of ability to conceive, testing some hypotheses that are practically impossible to test

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with aggregate data. In many cases, in different social contexts and latitudes, a significant association has been found between energy stress and a loss of ability to conceive, due both to seasonal nutritive deprivation (closely connected with harvesting cycles) and seasonal variations in job intensity (Bailey et al. 1992; Ellison 1997; Jasienska 1996; Panther-Brick 1996). The effect of energy stress on amenorrhea has also been shown in experimental studies on animals (see, e.g., Williams et al. 2001).

However, seasonal deprivation cannot be the only relevant aspect in the seasonality of conception, as data from past centuries show. A sudden fall in conception rates occurred in France and England during Lent in the 16th and 17th centuries (Houdaille 1988; Wrigley and Schofield 1989), most evidently in Catholic areas. Houdaille noted that it was forbidden to sell meat during Lent in many *départments* and towns in France. Because meat was an important component of French alimentation during the *ancien régime*, nutritive deprivation may have affected the population during every Lent, depressing ability to conceive. However, a great fall in conception during Lent also affected Southern Italy until the first half of the twentieth century, in regions where meat eaters were very rare all year round (Crisafulli et al. 2000; Danubio et al. 2003). In this case, the fall could be due to less frequent acts of sexual intercourse rates during Lent, as recommended in the past by the Catholic Church. These historical examples highlight the difficulty of distinguishing cultural (behavioral) factors from biological ones in explaining the seasonality of conception.

Some authors, when dealing with aggregate data, have tried to isolate the biological components of seasonality by selecting couples with similar sexual behavior. Luzzatto Fegiz (1925) studied the seasonality of conception for just the first two years following marriage, hypothesizing that all couples had similar and intensive sexual activity in this period. Becker (1984) asked women the time between the interview and the last episode of intercourse, using this information to reconstruct the frequency of intercourse. However, only if the episodes of intercourse are carefully recorded can the biological and cultural components of seasonality of conception be clearly distinguished.

In studies adopting the individual approach, data on the episodes of intercourse are not collected, probably to avoid an invasion of privacy. Moreover, even when sexual behavior is controlled for, nutritional stress might be just one of the biological components of seasonality (Ellison 1997; Panther-Brick 1996; Panther-Brick, Lotstein, and Ellison 1993). Some studies have shown that during wet, hot summers (in subequatorial areas) and long winters (in temperate and subpolar countries), the probability of conception is reduced (Bronson 1995; Lam and Miron 1996; Lam et al. 1994; Rosetta 1992), although a recent extended review on this topic suggested that there is not consistent evidence for a connection between seasonal variation of day length and seasonal changes in the reproductive activity of humans (Bronson 2004).

The reduction in conception probability during winter has also been detected in studies of in vitro fertilization (IVF; Rojansky et al. 2000). Researchers dealing with IVF have the great advantage of being able to distinguish between the seasonality of male and female components (Levine 1994). However, findings in the rapidly growing literature regarding the impact of seasonal variations on pregnancy rates during IVF are controversial (Dunphy et al. 1995; Ferber-Meiri et al. 2003; Fleming et al. 1994; Gindes et al. 2003; Mercan et al. 2003). As for the effect of summer, some clinical studies have shown that high temperatures cause diminishing mobility of sperm, which also become more perishable (Levine 1988; MacLeod and Gold 1953; Spira 1991), whereas a recent study appears to have demonstrated a significant benefit of increased daylight length on outcomes of IVF cycles (Wood et al. 2006).

Results on the seasonality of quality of sperm are controversial, however. Centola and Eberly (1999) concluded that the quality of sperm declines during spring, whereas Andolz, Bielsa, and Andolz (2001) and Chen et al. (2002) suggested that it improves. Carlsen et al. (2004) showed that there is no significant seasonal variation in sperm concentration, percentage of immotile spermatozoa, and percentage morphologically normal spermatozoa. Conflicting results also arose in two recent studies on seasonal variation of testosterone in human sperm specimens, both concerning men living in the northern part of Europe. Svartberg et al. (2003) found in a Norwegian study that the lowest testosterone levels occur in months with the highest temperatures and longest hours of daylight, whereas Andersson et al. (2003), examining Danish data, observed the peak level during June–July, with minimum levels occurring in winter–early spring.

Four conclusions can be drawn from the above brief overview. First, if the aim of the research is to find causes of seasonality of conception, individual studies should be performed. Second, in individual studies, the episodes of intercourse should be taken into account in order to control for the seasonality of sexual behavior. Third, the influence of season on the biological mechanisms managing conception is not clearly known. Finally, several studies share two results: (1) severe energy stress can induce seasonal depression of female fecundability; and (2) differing climatic characteristics (e.g., temperature, wetness, hours of light) can affect the probability of conception in a number of different ways, influencing both male and female ability to conceive. The aim of this paper is to verify and to try to explain some aspects of the biological seasonality of conception, controlling for sexual behavior.[1] For this purpose, we deal with a group of noncontracepting healthy couples living in Western countries, for which individual data on menstrual cycles and daily episodes of intercourse are available. Variables that are potentially connected with the seasonality of conception are controlled by the estimation of a multivariate logistic regression model on discrete-time data. A heterogeneous risk framework—accounting for unobserved heterogeneity of both partners—is assumed for inference.

MATERIALS AND METHODS

Data

In 1992, in the Statistical Department of the University of Padova, Italy, a large prospective study on Daily Fecundability, called “Fertili,” was conducted thanks to the collaboration of eight centers providing services on the symptom-thermal method of natural family planning (Colombo and Masarotto 2000). Following the same protocol, another study, called “Billings,” was conducted in the same department with the collaboration of four centers assisting couples in the Billings method of natural family planning (Colombo et al. 2004).

The two studies involved in total 11 European Natural Family Planning Centers, plus 1 center from Auckland, New Zealand.[2] The eight centers using symptom-thermal method were located in the following cities (the number of couples recruited appears in parentheses): Milan (272), Verona (214), Dusseldorf (105), Paris (104), Auckland (99), London (45), Brusselles (29), Lugano (13). The four centers that specialized in the Billings method were all from North-Central Italy: Parma (98), Milan (50), Rome (28), Saluzzo (17).

Couples recruited for the two studies were experienced in the use of methods of natural family planning, and it was a strict requirement that they use no contraceptive devices. Couples in the habit of mixing incidences of unprotected and protected acts of sexual

1. By “seasonality of conception,” we mean the “seasonality of probability of conception.” Moreover, in this article, we use the expressions “fecundability,” “probability of conception,” “risk of conception,” and “ability to conceive” interchangeably. “Fecundability” is defined by Gini (1923) as the probability of conceiving in a cycle for a couple not using contraceptives.

2. A woman’s place of residence may influence the seasonality of conception; that is, the seasonal profile of probability of conception could be different in one country than in another because of, for example, the different latitude. To make seasonal data in Auckland (in the temperate area of the Southern Hemisphere) comparable with other towns, we consider January as July, February as August, and so on. However, there are no statistically significant results for this variable in our models. See the introduction and the final paragraphs for a discussion of this topic.

intercourse were dropped from the analysis. Neither partner was permitted to be surgically permanently infertile and both had to be free from any illness that might cause subfertility. Women had to be between the ages of 18 and 40 years old, and the passage of a menstrual cycle was required after cessation of breast-feeding or after delivery or miscarriage. An abstinence of hormonal medication or drugs affecting fertility was also required. A total of 1,074 couples participated in the studies, leading to a data set comprising 10,508 menstrual cycles and yielding 752 detected conceptions.[3]

On a couple's entry to the study, information was collected on month and year of birth of the woman and of her partner, number of previous pregnancies, date of the last delivery or miscarriage, date of the end of breast-feeding, date of last contraceptive pill taken, and date of marriage. Both behavioral and biological data were collected longitudinally during the study. Each day, the women recorded the characteristics of their cycles, such as basal body temperature and/or quality of cervical mucus, in order to identify ovulation.[4] Women were also asked to record daily acts of intercourse, if any, and to indicate whether acts of sexual intercourse were protected or unprotected. Cycles in which even a single act of protected intercourse or of simple genital contact occurred were excluded from the analysis.

In the present analysis, the cervical mucus peak day is taken as a marker of ovulation.[5] Cycles in which the day of ovulation was not identified are dropped from the analysis. Also excluded are anomalous cycles with a very long preovulatory phase (more than 31 days). Finally, although data were collected from 1976 to 1998, we limit our analysis to information collected in the 1990s (more than 85% of cycles are dated 1994, 1995, or 1996).

The aim of our study is not to predict fecundability, but rather to study the connections between fecundability, season, and some biological and behavioral variables. Consequently, cycles with very low or no risk of conception are not included. More specifically, the cycles considered for analysis are those with at least one episode of intercourse within the most fertile window around ovulation (the "narrow window").[6]

Out of a total of 10,508 menstrual cycles, only 2,190 cycles from 656 women were retained to estimate the homogeneous risk model—that is, logistic regression on discrete-time data. Furthermore, as described below, to estimate the heterogeneous risk model—that is, the conditional logistic regression model on discrete-time data—we retain only cycles from couples obtaining at least one pregnancy: 1,416 cycles from 480 couples producing 511 pregnancies. (See Table 1 for general characteristics of the study population and for details on selected populations in the analysis.)

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3. A conception was assumed when a pregnancy was ongoing 60 days from the onset of the last menstrual cycle or when a miscarriage was clinically detected.

4. Charts were reviewed at each site by the local principal investigator, and cervical mucus symptoms were scored according to the common rules established for the study. Subsequently, the charts were sent to the coordinating investigators in Padova for processing and entry into the database.

5. Besides scoring the mucus symptoms, the local principal investigator also identified the peak mucus day, if any. It was defined as the last day of best-quality mucus (elastic, transparent, and wet) in a specific cycle of the woman, by sensation or appearance. There is evidence in the literature to suggest that cervical mucus is more useful than basal body temperature for identifying the time of ovulation (Dunson et al. 1999; Ecochard et al. 2001; Templeton, Penney, and Lees 1982).

6. The fertile window is the interval of consecutive days in a cycle that have a daily fecundability different from zero. Previous studies that used the same or similar data have shown that a consistent estimation of the fertile window is (–8,+3). This is an interval of 12 days, from the eighth day preceding the peak mucus day to the third day following it. The peak mucus day (as specified in footnote 5), which is a marker for ovulation, is day zero. Inside this fertile window, the most fertile six days, here called the "narrow window," are (–4,+1). For the estimation of daily fecundability, see Barrett and Marshall (1969) and Schwartz, MacDonald, and Heuchel (1980). In addition, concerning our present data set, see Colombo and Masarotto (2000), Colombo et al. (2004), Passarin (1998), and Rizzi (2000).

Table 1. Couples, Cycles, and Pregnancies Selected for Analysis

Selection	Number of Couples	Number of Cycles	Number of Pregnancies
Total	1,074	10,508	752
Only Cycles With Peak Mucus Day Identified	1,042	8,734	666
And collected in 1990–1998	944	8,366	568
And at high risk of conception[a]	675	2,231	523
And with preovulatory length less than 31 days	665	2,190	511
And from women conceiving	480	1,416	511

[a]At least one act of sexual intercourse in fertile window (–4,+1).

Dependent and Independent Variables

In our analysis, the dependent variable is the probability of conception, and the main independent variable is the month at the beginning of the menstrual cycle. The simpler description of seasonality of conception can be obtained by counting cycles that begin at a certain month *a* and conceptions achieved in these cycles *b*. The probability of conception by month is obtained by the ratio between cycles with conception and all cycles, *b* / *a*. As shown in Table 2 and Figure 1, the probability of conception falls in April, July, and November.[7] The likelihood ratio test (a global test of the null hypothesis of an equal fecundability for all months) and the chi-square test (a test of the null hypothesis of an equal fecundability for a specific month compared with a reference month) show that month differences in fecundability are not statistically significant. Nevertheless, seasonal fecundability could be influenced by the couple's behavioral and biological characteristics. Thus, in this study, we will try to control for them by using a multivariate analysis.

The other independent variables considered in our analysis are the woman's age at the beginning of a cycle, called *A* in our statistical models; the preovulatory (follicular) length, *L*, which is the distance from the beginning of menstrual cycle to the identified day of ovulation; the occurrence of at least one previous pregnancy, *P*; the number of acts of intercourse in the narrow fertile window, *In*; and the number of acts of intercourse in the interval of days (–8,–5) and (+2,+3), *I*. Identification of the two subwindows allows us to control for the frequency and, simultaneously, for the timing of acts of intercourse during the menstrual cycle.[8]

In order to verify that all these variables may be related to fecundability, we estimate in Table 2 the probabilities of conception (i.e., the ratio between cycles with conception and all the cycles) for the different categories of these variables. As expected, the higher the frequency of episodes of sexual intercourse, the higher the fecundability. Moreover, the risk of conception is higher for cycles in which follicular phases are very short or very long, probably making the application of natural method rules more difficult and conception for avoiders more likely. Also, the probability of conceiving diminishes with woman's

7. The magnitude of probabilities of conceptions in Table 2 is strictly related to the inclusion in the data of only cycles with at least one act of intercourse in the narrow window (i.e., cycles at high risk of conception). Consequently, these probabilities are not comparable with the estimates of fecundability in other studies for which information on acts of intercourse is not available. In some other contexts, episodes of unusually infrequent sexual intercourse may occur with seasonal regularity (e.g., because of religious taboos or seasonal migrations). In such cases, the distribution of conception may be more greatly affected by season than were the 656 couples considered here.

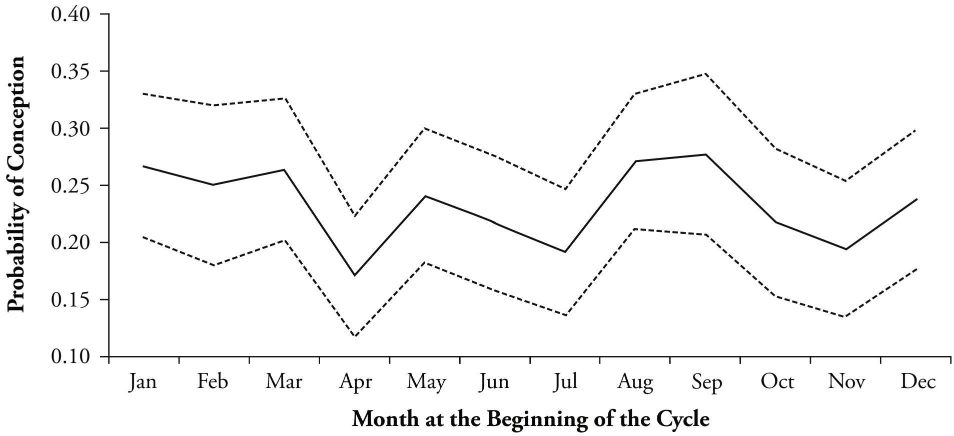
8. Days (+2,+3) have higher fecundability than days (–8,–5). Nevertheless, both of these subwindows have a negligible effect on fecundability.

Table 2. Probability of Conception, by the Levels of Independent Variables

	Probability of Conception		
Variable	Number of Cycles	Pr	*SE*
Month (at the beginning of the cycle)			
January	191	0.27	0.03
February	148	0.25	0.04
March	193	0.26	0.03
April	193	0.17	0.03
May	203	0.24	0.03
June	189	0.22	0.03
July	193	0.19	0.03
August	214	0.27	0.03
September	155	0.28	0.04
October	156	0.22	0.03
November	170	0.19	0.03
December	185	0.24	0.03
In = Frequency of Acts of Intercourse in the Narrow Window (–4,+1)			
1	837	0.18	0.01
2	758	0.26	0.02
3	425	0.25	0.02
4+	170	0.35	0.04
I = Frequency of Acts of Intercourse During Days (–8,–5) and (+2,+3)[a]			
0	549	0.22	0.02
1	759	0.22	0.01
2	572	0.24	0.02
3	231	0.25	0.03
4+	79	0.29	0.05
L = Preovulatory Length			
< 13 days	537	0.24	0.02
13–17 days	1,043	0.20	0.01
18–31 days	610	0.28	0.02
A = Age of Woman at the Beginning of Cycle			
≤ 26	339	0.32	0.02
27–31	1,199	0.23	0.01
> 31	652	0.20	0.02
P = Previous Pregnancies			
No	1,310	0.22	0.01
Yes	880	0.25	0.01
Total Number of Cycles	2,190	0.23	0.01

[a]Giving at least one act of intercourse in the fertile window (–4,+1).

Figure 1. Probability of Conception, by Month



Notes: 2,190 cycles and 665 couples. Dotted lines refer to upper and lower limits ($p \pm 1.96 \times SE$). See Table 2.

age—the influence of a woman's age on fecundability is well-documented (Dunson et al. 2002; Larsen and Vaupel 1993; McDonald et al. 2005). Lastly, as we expected, fecundability is higher for couples who were proven to be fecund with a previous pregnancy.

Episodes of sexual intercourse and preovulatory length may, in turn, be influenced by seasonality. In order to verify this, we describe a seasonal profile for each of these variables. The minimum frequency of episodes of sexual intercourse (5.5 acts of intercourse) is in January, and the maximum (6.75 acts of intercourse) is in June (see Figure 2). The *F* test (a global test of the null hypothesis of an equal number of acts of intercourse for all months) shows that at least in one month, the number of episodes of intercourse is significantly higher or lower than in all other months (significant at the 1% level). The chi-square test (a test of the null hypothesis of an equal number of acts of intercourse for a specific month compared with a reference month) shows that June, July, and August have a statistically significant effect compared with the December effect (significant at the 5% level). The August effect is no more statistically significant when computation of mean number of acts of intercourse by month is restricted to cycles at high risk of conception (with at least one episode of intercourse in the most fertile window) or to conceiving cycles; that is, when couples are trying to obtain a conception, this month effect on sexuality appears to be less important.

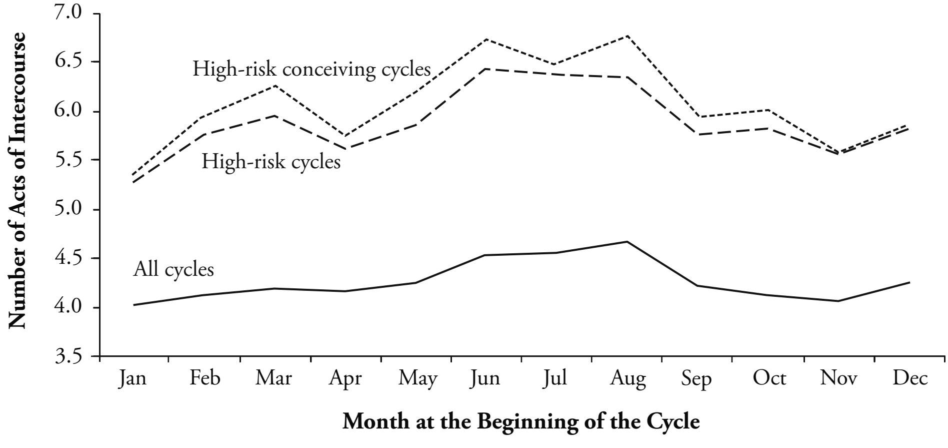
The preovulatory length also has a seasonal profile, with a maximum in March (see Figure 3). The *F* test and the chi-square test, however, show that month differences in preovulatory length are not statistically significant at the 5% level.

Because they may affect fecundability and may be affected by season, the frequency of acts of sexual intercourse and the preovulatory length may work as mediating variables on the association between season and fecundability (despite of the nonsignificant statistical effect of season on the latter, see the next paragraphs).

Causal Framework and Hypotheses

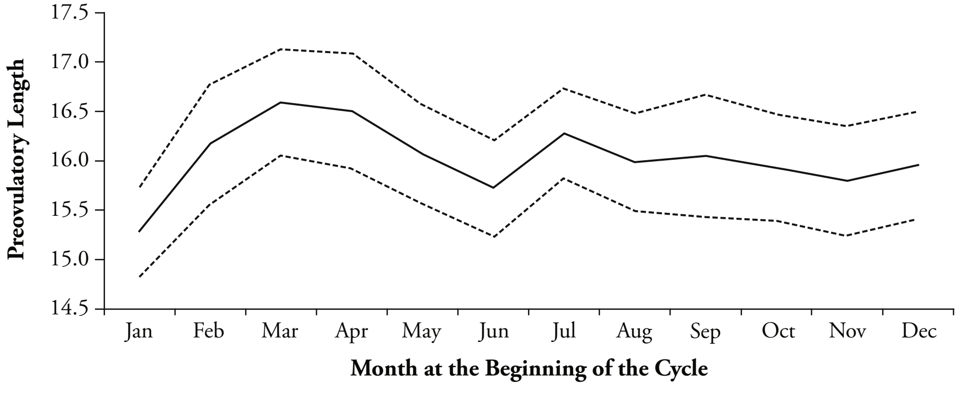
Some of the variables described above may have a mediating effect or a moderating effect on the association between season and fecundability. To better understand the meaning of

Figure 2. Mean Number of Acts of Intercourse, by Month



Notes: Cycles with more than 30 days are excluded. The number of cycles is 10,508 for all cycles, 2,190 for high-risk cycles, and 1,416 for high-risk conceiving cycles.

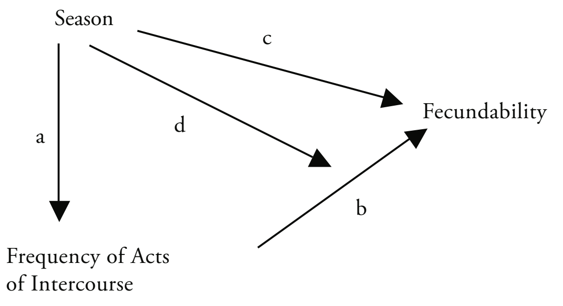
Figure 3. Mean Preovulatory Length, by Month



Notes: 2,190 cycles and 665 couples. Dotted lines refer to upper and lower limits ($x \pm 1.96 \times SE$).

a *mediating effect* in this particular context, let us first examine the relationship between season, fecundability, and the generic mediating variable *X*, which could be, for example, frequency of episodes of sexual intercourse (Figure 4). As shown in Figure 4, season may influence variable *X* (arrow "a"). Then, *X* influences fecundability (arrow "b"). If all seasonal effects on fecundability are captured by *X*, the residual effect of season on fecundability (arrow "c") should disappear. Conversely, if the residual effect "c" persists, mediating variables other than *X* may exist.

Figure 4. Mediating Effect and Interaction Effect



Season may have a different effect on fecundability according to the levels of X, and—symmetrically—the effect of X on fecundability may change with month. This is the *moderating effect* of X on the association between season and fecundability (arrow "d" in Figure 4), also called an *interaction effect* (Hosmer and Lemeshow 1989; Kleinbaum 1994).

Some of our explanatory variables may have both a mediating effect and an interaction effect (frequency of acts of sexual intercourse and preovulatory length). Others may have only an interaction effect (woman's age and previous pregnancies, for which arrow "a" of Figure 4, indicating a mediating effect, is obviously not present).

According to this causal framework, it is possible to specify two hypotheses: (1) that the seasonality of conception is mediated by the frequency of episodes of sexual intercourse and by the preovulatory length (mediating effect), and (2) that the seasonality of conception changes by changing frequency of episodes of sexual intercourse, preovulatory length, woman's age, and previous pregnancies (interaction effect).

Homogeneous Risk Model

In order to verify the causal nature of independent variables, we use a multivariate approach in our statistical analysis. Conception is our dichotomous dependent variable, assumed to follow a Bernoulli distribution with probability of success (conception) λ_c. We use a logistic model because our outcome is binary. The model assumes a discrete-time risk, given that conception occurs in a cycle "t" (see, e.g., Allison 1999), and it is a *homogeneous risk model*—that is, we assume that couples sharing the same values of observed characteristics have the same risk of conception and that no other unobserved characteristics of the couples affect conception. This is an unrealistic assumption because the observed variables do not represent the only heterogeneity of couples, but unobserved heterogeneity can also be taken into account by a suitable heterogeneous risk model, as discussed below. First, the following main-effect homogeneous risk model is fitted to our data:

$$\text{logit}(\lambda_i) = \alpha + \beta_k M_{ik} + \tau_s P_{is} + \pi_q L_{iq} + \rho_r A_{ir} + \delta In_i + \nu I_i, \tag{1}$$

where β, τ, π, ρ, δ, and ν are the main effects, respectively, for month (M), previous pregnancy (P), preovulatory length (L), woman's age (A), number of episodes of sexual intercourse in the narrow window (In), and number of episodes of sexual intercourse in the remaining days of fertile window (I). $k = 1, \ldots, 12$ are categories for month; $q = 1,2,3$ are categories for preovulatory length; and $r = 1,2,3$ are categories for woman's age. The

i index indicates the couple. The t index, indicating the specific cycle, is omitted here in order to simplify notation and because it is common to all variables (i.e., all variables are time-variant). The frequency of episodes of sexual intercourse in the narrow window, In, and the frequency of episodes of sexual intercourse in the remaining days of the fertile window, I, are continuous variables; month (M), preovulatory length (L), and woman's age (A) are categorical variables; and the previous pregnancies, measure P, is dichotomous (at least one previous pregnancy/no previous pregnancies). The homogeneous risk model is estimated by maximum likelihood using the GENMOD procedure in SAS.

To verify and measure the mediating effect of frequency of episodes of sexual intercourse and preovulatory length, we estimate Model 1 including all variables and then omitting each variable in turn, thus obtaining Models 2, 3, and 4. Model 2 excludes I, Model 3 omits In, and Model 4 omits preovulatory length (L). If the quality of fit of Models 2, 3, and 4 significantly decreases, and if—at the same time—month coefficients of Models 2, 3, or 4 differ from those of Model 1, it will mean that the frequency of acts of sexual intercourse or preovulatory length acts as a mediating variable of seasonality of conception.[9] Moreover, if month effects β_k in Model 1 differ from zero, it will mean that acts of sexual intercourse (In or I) and preovulatory length (L) cannot entirely explain the effect of season on the probability of conception. Note that no statistical test can help us verify a mediating effect. According to Kleinbaum, Kupper, and Morgenster (1982:254) ". . . confounding is a validity issue which addresses systematic rather than random error. Statistical testing is appropriate for considering random error rather than systematic error."

Homogeneous Risk Models With Interaction Terms

In the previous section, we presented the logistic model for probability of conception and discussed the method to ascertain the mediating nature of episodes of intercourse and preovulatory length, which are considered potential mediating variables. The other causal mechanism, interaction, potentially involves all explanatory variables: not only frequency of acts of intercourse and preovulatory length but also woman's age and the dummy variable for presence of previous pregnancies can interact with season to affect conception. In order to verify the existence of interaction effects, we fit the model indicated in Eq. (1) by adding the interactions between month and each of the other five independent variables ($M_k \times In$, $M_k \times I$, $M_k \times L_q$, $M_k \times A_r$, $M_k \times P_s$) and retain only interaction terms that are statistically significant at the 5% level by a chi-square test.

Homogeneous Risk Models With Interaction Terms for Dependent Observations

The homogeneous risk models presented above treat observations as independent. Actually, for the same woman, we observe one or more cycles, for which information is correlated. Ignoring this correlation produces standard errors that are underestimated and coefficient estimates that are inefficient. Thus, we also estimate a GEE model (generalized estimating equations): a homogeneous risk model that corrects for standard error bias and coefficient inefficiency (Allison 1999; Diggle, Liang, and Zeger 1994).

Heterogeneous Risk Model

So far we have assumed homogeneous risk models—discrete-time and GEE models—including only the observed variables. However, residual unobserved heterogeneity in couples can be taken into account by a suitable *heterogeneous risk model*.

One disadvantage of not including unobserved heterogeneity in nonlinear models is the "coefficient shrinkage" effect: heterogeneity tends to attenuate the estimated coefficients

9. Previous pregnancies and age are added to the model as important variables affecting fecundability, although they cannot be mediating variables.

toward 0 (Allison 1999; Trussel and Rodríguez 1990). Moreover, there may be some spuriousness (i.e., biases in coefficients resulting from unobserved characteristics of the couples, which might be correlated with observed variables; Allison 1999).

When estimating the nonlinear model on clustered data, it is possible to correct for these biases. Several solutions have been proposed in the literature (see Allison 1999). Consider the following general expression:

$$\text{logit}(\lambda_{it}) = \alpha_i + \beta X_{it}, \quad (2)$$

where λ_{it} is the probability of conception for couple i at cycle t, X is the generic explanatory variable, β measures the effect of the explanatory variable on probability of conception, and α_i represents all the stable characteristics, both measured and unmeasured, of couple i. One can decide to treat α_i as a random variable with specified probability distribution, which leads to a *random-effects model*. This method corrects for the attenuation of coefficient estimates caused by unobserved heterogeneity, but not for spuriousness caused by unobserved heterogeneity (see above for definitions and see Allison 1999 for detailed explanation).

Alternatively, α_i in expression (2) can be treated as a fixed constant, one for each individual in the sample. This is the approach considered in this work, sometimes referred to as a *fixed-effects model*, and solving both problems caused by unobserved heterogeneity—that is, shrinkage of coefficient estimates and spuriousness depending on stable unobserved characteristics of the couple. Nevertheless, time-varying unobserved characteristics continue to pose a risk of spuriousness in the month-conception relation.

When a logistic model with intercept α_i varying for each couple i is considered, a problem of biased parameter estimates arises. This is called the "incidental parameters problem" (Kalbfleisch and Sprott 1970, cited by Allison 1999), which refers to a violation of the assumption of asymptotic theory of maximum likelihood estimation such that the number of observations increases while the number of parameters remains constant. One solution is the conditional likelihood estimation method (Chamberlain 1980, cited by Allison 1999), in which coefficients are estimated by taking into account heterogeneity but avoiding estimating α_i. Thus, the model fitted here is called *fixed-effects model with conditional likelihood estimation* (Allison 1999:188–97). The PHREG procedure in SAS is used for fitting.

This method is particularly suitable when data are structured on two levels (in our analysis, couples and cycles) and the event measured by the dependent binary variable occurs only once for the first-level unit. This is the case in our analysis because almost all couples have at most one conception.

Three problems arise with this model. The first is when conception always occurs at the end of the sequence of observations (time series is of the type 0,0,0, . . . 1), since any variable that tends to increase or decrease over time will appear to increase (or decrease) the hazard of couple's conception (Allison and Christakis 2006). This could be the case for woman's age in our data. However, since the interaction between age and month is considered in the model, we limit this problem. Moreover, 10% of women have more than one entry in the study. For these women, the time series is not of the type 0,0,0, . . . 1; conception occurs not only at the end of the sequence of observations but also during the study.

Second, with this particular estimation method, only cycles of conceiving couples are taken into account, and we have an important loss of data (1,416 cycles instead of 2,190). Consequently, although our model is much less sensitive to unobserved heterogeneity biases (coefficient shrinkage and spuriousness), its efficiency is reduced (i.e., it has larger standard errors). Thus, the confidence intervals of estimates will be wider than those observed for the homogeneous risk model.

Third, this particular model is limited to determining which variables are influential on timing of conception. As a result, only variables whose values change from one cycle to another are estimated by the model. Fixed variables are accounted for by conditional likelihood estimation—since the term α_i in Eq. (2) represents all observed and unobserved characteristics of the couples—but their parameters are not assessed by this estimation method (see Allison 1999 and Kleinbaum 1994 for details on how conditional likelihood estimation works).

RESULTS

Evidence From Homogeneous Risk Model

The month at the beginning of the cycle (M), the frequency of acts of intercourse in the narrow window (In), and the preovulatory length (L) are significantly associated with probability of conception, whereas the frequency of episodes of intercourse in the remaining days of the fertile window (I) is not.[10] Are In, L, and I mediating variables of seasonality of conception? After we omit from Model 1 the variables In (Model 3) and L (Model 4), the odds ratios of August, September, and March slightly change (results not shown here). Thus, our findings give support for the first hypothesis of this work for In and L— that the seasonality of conception is mediated by the frequency of sexual intercourse and by preovulatory length—although the mediating effect is not strong.

A remaining seasonal effect in Model 1—after we control for acts of intercourse and preovulatory length—indicates that other unobserved characteristics of the couples do play a mediating role in the season-fecundability relation.

Evidence From Homogeneous Risk Models With Interaction Terms

Now we fit the model indicated in Eq. (1), adding all the possible interaction terms with month ($M_k \times In$, $M_k \times I$, $M_k \times L_q$, $M_k \times A_r$, $M_k \times P_s$). Only interactions $M_k \times In$ and $M_k \times A_r$ are statistically significant, both in the logistic model and in the GEE model; thus, we keep them for analysis (see Table 3 and the Appendix). This means that the seasonality of conception changes according to the frequency of episodes of intercourse inside the narrow window (–4,+1), In, and according to woman's age, A. Because interaction is a symmetrical concept, we can say as well that the effect of the frequency of intercourse on fecundability varies according to season and that the woman's age effect on fecundability differs according to season.

The model of Eq. (3) is finally estimated:

$$\text{logit}(\lambda_i) = \alpha + \beta_k M_{ik} + \tau_s P_{is} + \pi_q L_{iq} + \rho_r A_{ir} + \delta In_i + \nu I_i + \gamma_k (M_{ik} \times In_i) + \omega_{kr}(M_{ik} \times A_{ir}), \quad (3)$$

where γ is the interaction coefficient between the number of episodes of intercourse in the narrow window and month, and ω is the interaction coefficient between the woman's age and month. For detailed results, see the Appendix. As in Eq. (1), the t index, indicating the specific cycle, is omitted to simplify notation and because it is common to all variables (i.e., all variables are time-variant).

The variables In and I, respectively the number of episodes of intercourse in the narrow window and the number of episodes of intercourse in the remaining days of the fertile window, are considered to be continuous in our models. Nevertheless, once interaction terms are estimated, to exactly determine values for the monthly odds ratio, we have to fix values for In (Kleinbaum 1994). Particularly, odds ratios for each month are calculated by fixing In equal to 1, 2, and 3. The clearest shape of the seasonality of conception persists in the central age group (27–31) and when $In = 1$ (one episode of intercourse in the narrow fertile window). In this case, fecundability is higher in August–September and in January–February, when

10. Results not shown for chi-square test and likelihood ratio global test for month.

Table 3. Homogenous and Heterogeneous Risk Models Predicting Fecundability: Statistical Chi-Square Test for Month and Age Interaction and for Month and Number of Acts of Intercourse Interaction

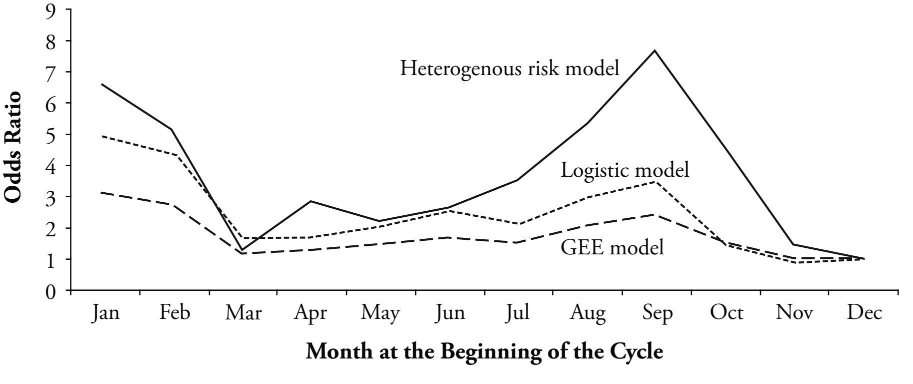
		Homogenous Risk Model					
		Logistic Model on Discrete-Time Data		GEE Model		Heterogeneous Risk Model	
Interaction Effects	*df*	χ^2	Pr > χ^2	χ^2	Pr > χ^2	χ^2	Pr > χ^2
Month × *In*	11	25.18	0.0086	34.51	0.0435	30.06	0.0039
Month × *A*	22	39.30	0.0130	23.10	0.0171	40.44	0.0053

Notes: The logistic and GEE models include 2,190 cycles and 665 couples; see Eq. (3) and the Appendix. The heterogeneous risk model includes 1,416 cycles and 480 couples; see the Appendix. *In* = the number of acts of intercourse in the narrow window (–4,+1). *A* = woman's age.

the odds ratios are respectively three and five times higher than in December (the reference month, with lowest fecundability; see Figure 5). The effects of August–September and January–February are statistically significant because the confidence intervals of the odds ratios do not include the null value of 1, both in the logistic model and in the GEE model (see Table 4). Moreover, with reference to the logistic model, the likelihood ratio global test for month shows a significant effect at the 5% level. Score statistics for the GEE analysis are also used to test for the significance of the month variable, showing a significant effect at the 1% level (see Table 5).

For a number of episodes of intercourse greater than 1, and for younger and older women, the seasonality of fecundability is lower; that is, the higher the sexual activity in the most fertile window of the cycle, the narrower the differences of probability of

Figure 5. Homogenous and Heterogeneous Risk Models With Interaction Terms (woman's age = 27–31 and *In* = 1): Odds Ratio of Fecundability, by Month



Notes: The logistic and GEE models include 2,190 cycles and 665 couples. The heterogeneous risk model includes 1,416 cycles and 480 couples. *In* = the number of acts of intercourse in the narrow window (–4,+1). See the Appendix and Table 4.

Table 4. Homogenous and Heterogeneous Risk Models Predicting Fecundability, by Month: Odds Ratio of Fecundability and Lower and Upper Limits of the 95% Confidence Interval[a]

	Homogenous Risk Model With Interaction Terms						Heterogeneous Risk Model Interaction Terms		
	Logistic Model on Discrete-Time Data			GEE Model					
Month	Lower Limit	Odds Ratio	Upper Limit	Lower Limit	Odds Ratio	Upper Limit	Lower Limit	Odds Ratio	Upper Limit
January	2.0	5.1	12.8	1.6	3.1	6.0	1.3	6.5	32.0
February	1.7	4.6	12.6	1.4	2.9	5.7	1.0	5.1	27.3
March	0.7	1.8	4.9	0.6	1.2	2.3	0.2	1.3	7.2
April	0.6	1.7	4.6	0.7	1.3	2.5	0.5	2.8	15.8
May	0.8	2.1	5.6	0.8	1.5	2.9	0.4	2.2	11.7
June	1.0	2.6	6.9	0.9	1.7	3.1	0.5	2.6	14.3
July	0.8	2.3	6.0	0.9	1.6	3.0	0.7	3.5	18.7
August	1.2	3.1	7.9	1.2	2.1	3.9	1.0	5.3	26.7
September	1.3	3.5	9.5	1.2	2.4	4.9	1.4	7.6	41.9
October	0.5	1.5	4.3	0.9	1.6	2.9	0.9	4.6	24.7
November	0.6	1.6	4.5	0.7	1.4	2.7	0.6	3.3	17.6
December	—	1.0	—	—	1.0	—	—	1.0	—

Notes: The logistic and GEE models include 2,190 cycles and 665 couples. The heterogeneous risk model includes 1,416 cycles and 480 couples. Age of woman is fixed at 27–31, and *In* = 1, where *In* is the number of acts of intercourse in the narrow window (–4,+1).

[a]See the Appendix and Figure 5.

conception between months. However, caution is needed in interpretation of the latter results, which are not statistically significant.

Evidence From Heterogeneous Risk Model With Interaction Terms

As we already pointed out, the heterogeneous risk model allows us to correct for bias, which results in an attenuation of coefficient estimates and for bias depending on the unobserved fixed characteristics of the couples correlated with the observed characteristics at the cluster level (that is, at the level of couples). We fit the same model as in the previous section (see Eq. (3)), replacing α with α_i (see Eq. (2)), considering only the 472 couples with at least a pregnancy, and estimating coefficients using the conditional likelihood method. Results for the heterogeneous risk model shown in Table 3 show that the interaction terms $M_k \times In$ and $M_k \times A_r$ are again statistically significant. Results of the homogeneous risk model (a more evident seasonal pattern of conception for women aged 27–31 with one act of intercourse in the narrow window) are confirmed even when we account for unobserved heterogeneity of couples. The bimodal form of seasonality of fecundability is further emphasized—monthly odds ratios increase due to correction of coefficient shrinkage. September's odds ratio is now larger than those of January and February (see Figure 5 and detailed results in the Appendix).[11] As expected, the confidence

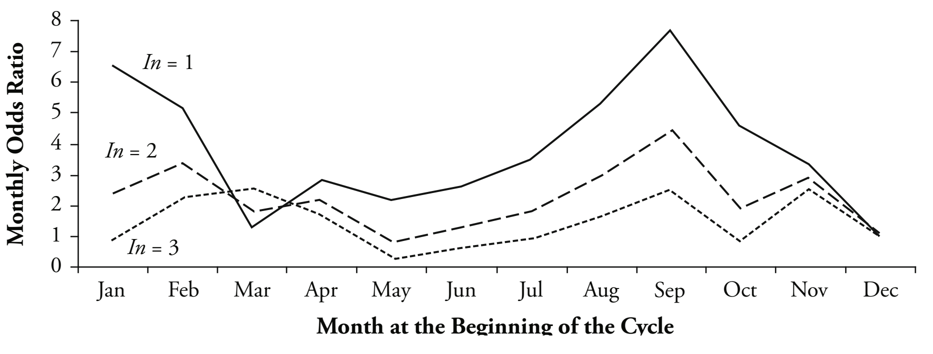
11. As stated earlier, in the heterogeneous risk model, only cycles from conceiving couples are selected in order to explain why, for the same couple, conception happens in a specific cycle and not in another. If the

Table 5. Homogenous and Heterogeneous Risk Models Predicting Fecundability: Statistical Chi-square Test for Month Effect

		Homogenous Risk Model With Interaction Terms				Heterogeneous Risk Model With Interaction Terms	
		Logistic Model on Discrete-Time Data		GEE Model			
Month Effect	*df*	χ^2	Pr > χ^2	χ^2	Pr > χ^2	χ^2	Pr > χ^2
Month	11	22.45	0.02	24.97	0.01	27.59	0.01

Notes: The logistic and GEE models include 2,190 cycles and 665 couples; see Eq. (3) and the Appendix. The heterogeneous risk model includes 1,416 cycles and 480 couples; see the Appendix.

Figure 6. Heterogeneous Risk Model With Interaction Terms (woman's age = 27–31 and different values of *In*): Odds Ratio of Fecundability, by Month



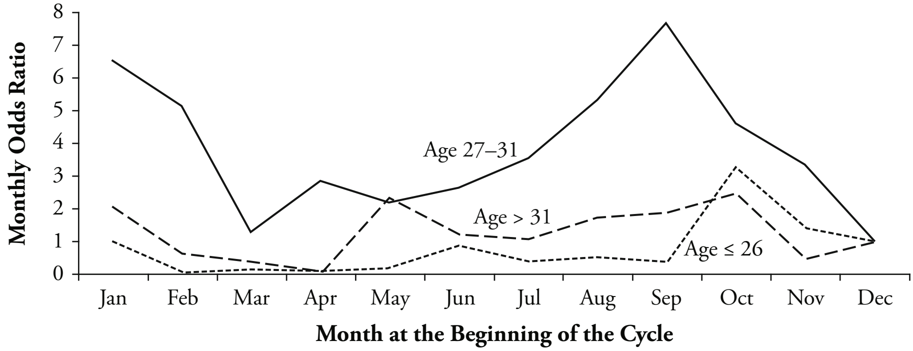
Notes: December is the reference month. 1,416 cycles and 480 couples. *In* = Number of acts of intercourse in the narrow window (–4,+1). See the Appendix.

interval becomes wider than for the homogeneous risk model, and the odds ratios for February and August are now not significant at the 5% level (see the last column of Table 4), but the likelihood ratio global test on month shows a significant effect at the 1% level (see Table 5).

As previously observed for both the homogeneous risk model and the heterogeneous risk hypothesis, when the frequency of episodes of intercourse is higher than 1 in the narrow fertile window or when women are younger or older than 27–31, the seasonality of fecundability is less evident (see Figures 6 and 7). Note that even if only 32 women (7% of 480 women) cross the age boundaries 27 or 31, the coefficient for the interaction of age and month is highly significant ($p < .01$). The three models in Figure 5 have similar profiles of seasonality of conception, which enhances the reliability of our results.

homogeneous risk model is fitted to this restricted group of 472 couples and 1,416 cycles, the results are similar to those obtained from the complete sample of 656 couples and 2,190 cycles (results not shown).

Figure 7. Heterogeneous Risk Model With Interaction Terms (different values of woman's age and *In* = 1): Odds Ratio of Fecundability, by Month



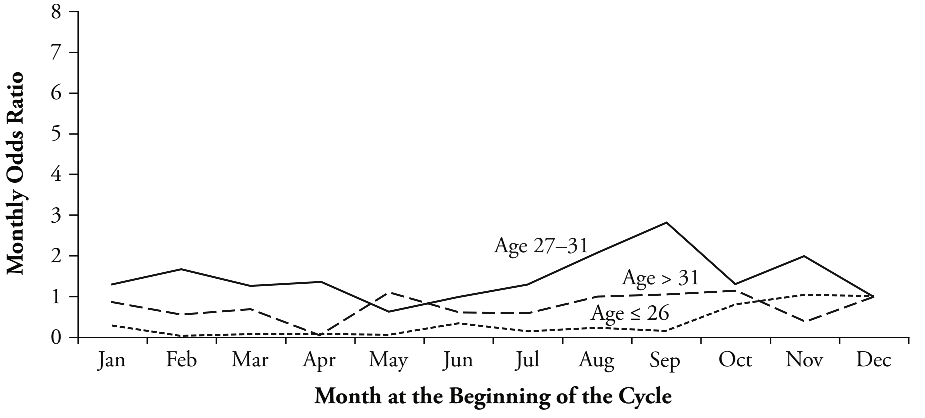
Notes: December is the reference month. 1,416 cycles and 480 couples. *In* = Number of acts of intercourse in the narrow window (–4,+1). See the Appendix.

Figure 7 shows a "residual seasonality" that results from controlling for fixed unobserved couples' characteristics, preovulatory length, and acts of sexual intercourse (fixed to be equal to 1). This residual seasonality depends on unobserved time-varying couples' characteristics, probably of biological nature. The residual unexplained seasonality is stronger for women of the age group 27–31 and weaker for younger and older women.

We can appreciate the importance of having information on episodes of sexual intercourse and of controlling for them in order to study biological seasonality when we do omit the variable *In* (the number of episodes of sexual intercourse in the narrow fertile window) in our final model. When the residual seasonality depends on episodes of sexual intercourse in the narrow fertile window—besides depending on unobserved time-varying couples' characteristics—the seasonal profile of the probability of conception becomes less pronounced (see Figure 8). This is due to the fact that the conceiving women selected for our final model have a high number of acts of intercourse during the whole year and not in any particular month (see Figure 2), causing the seasonal variation of fecundability determined by unobserved time-varying couples' characteristics to be less evident (and the seasonal peak at the beginning of the year that was observed in Figure 7 to disappear). In other terms, when sexual activity is intense, seasonality mediated by biology is a minor aspect of a couple's fecundability.

In our sample, the entries of women are not uniformly distributed throughout the year: the proportion of entrants is higher than expected in March, and lower than expected in October and November, and these differences are statistically significant ($p < .05$). As a consequence, women with a higher probability of conception could be more concentrated in March and April, as more fertile women soon obtain a conception, and less concentrated in October and November. This could bias the estimates obtained by the homogeneous model, but not the estimates obtained by the heterogeneous model. However, the pattern of seasonality is practically the same in homogeneous and heterogeneous models. Moreover, the probability of conception is neither particularly high in March nor low in October and November if episodes of intercourse are controlled, and the nonuniform distribution of

Figure 8. Heterogeneous Risk Model With Interaction Term Age × Month but Not Controlling for *In*: Odds Ratio of Fecundability, by Month



Notes: December is the reference month. 1,416 cycles and 480 couples. *In* = Number of acts of intercourse in the narrow window (–4,+1). See the Appendix.

entries does not explain the more important peaks in January and September (see Table 4 and Figures 5–7).

CONCLUSIONS

We use detailed data collected in the 12 Natural Family Planning Centers of the Daily Fecundability Study and measure relations between fecundability and season, controlling for woman's age, frequency of acts of intercourse, previous pregnancies, and preovulatory length. Other fixed unobserved characteristics specific for each couple were controlled in the final model.

The first result is that the seasonality of fecundability persists when we control for the seasonality of preovulatory length and for the seasonality of episodes of sexual intercourse. This means that the seasonal variability of conception is determined by other variables varying with season and not controlled by our model. Among these unknown mediating variables, the seasonal variation of energetic stress does not likely play an important role because the healthy women and couples involved in this research live mainly in western towns and are not poor.

The second result is that the seasonality of conception changes according to woman's age and frequency of acts of intercourse. Seasonality is reduced for couples in which women are younger (26 or younger) and older (older than 31). For women aged 27–31 with only one act of intercourse during the narrow fertile window, the seasonality of fecundability is particularly accentuated. In this group of women, the monthly distribution of probability of conception is bimodal, with two maxima (September and January) and two minima (December and March). Also, seasonality of conception diminishes when the frequency of episodes of intercourse in the fertile window (–4,+1) increases. These results on the connection between season, woman's age, and fecundability confirm those of Bobak and Gjonca (2001) for the Czech Republic. The maximum rate of conception at the beginning of autumn has also been found by Cagnacci et al. (2003) for contemporary Italy.

Our results do not mean that higher rates of episodes of sexual intercourse lead to lower risk of conception (the opposite is true, of course, as Table 2 shows). Rather, our models suggest that the more intense the sexual activity, the thinner the monthly differences in fecundability. In addition, our findings may help to explain the low conception rate during Lent in the European *ancien régime* (discussed earlier). If couples reduced their frequency of intercourse during Lent—following the suggestion of the Church—the probability of conception might decrease not only due to a reduced rate of episodes of intercourse but also due to an involuntary mechanism: the depressive effect of interaction between rate of episodes of intercourse and season, with a minimum conception rate in March (see Figure 6).

When unobserved characteristics of the couples are considered by a heterogeneous risk model, the causal structure described above does not change. The probability of conception, however, is accentuated at the beginning of autumn.

Our sample is not representative of the whole population because neither partner was permitted to be permanently infertile and both had to be free from any illness that might cause subfertility. Nevertheless, this should not influence seasonality of fertility if we assume that severe subfertility does not depend on season. Moreover, the sample is not representative of the whole population because enrolled couples use natural family planning and thus may have specific characteristics that affect the seasonality of conception. Most couples apply to a natural family planning center to avoid a pregnancy because of religious motivations. Some other couples, also trying to avoid a pregnancy, refer to a natural family planning center because of their preference for natural methods instead of more invasive methods of contraception. Still others desire to better know their fertile period in order to obtain a pregnancy. There is no reason to think these typologies of users have a seasonality of conception different than the whole population. Catholics could have a different sexual behavior during Lent, but any seasonality of acts of sexual intercourse is controlled for in our study. However, we can imagine some biasing mechanisms for those who use natural family planning. In some months, markers of ovulation could be, for example, more difficult to identify, so that some couples trying to avoid a pregnancy finally obtain it because they wrongly identified ovulation. Difficult identification of ovulation could occur because of seasonality of mucus characteristics; it could also be due to seasonality of early unrecognized embryonic losses, which can result in a longer-than-usual preovulatory length.

Seasonality of sperm characteristics can also influence fecundability of natural family planning users. Sperm perishability, for example, could change with season, which can enlarge or narrow the fertile window of the cycle, although this possibility contrasts with the results of a recent study (Carlsen et al. 2004). Thus, the final profile for seasonality of conception illustrated in Figures 5, 6, and 7 could depend on these mechanisms. Hence, future research should consider seasonality of mucus symptoms, early unrecognized embryonic losses, and sperm characteristics.

We give some other suggestions for future research. As we stated earlier, the collection of individual data on fecundability represents a very important step forward for the study of seasonality of conception. In this article, we show that the analysis is enriched if episodes of sexual intercourse are recorded daily, enabling the distinction between biological and behavioral seasonality. Moreover, additional results may be obtained if our data are further exploited. Other information is available in the Daily Fecundability Study, such as the characteristics of cervical mucus, the postovulatory length, and the age of partner. The first two variables could have both a mediating and an interaction effect on seasonality of fecundability, whereas the third could have only an interaction effect, similar to that observed for woman's age (which was, in the present analysis, a kind of approximation of the age of both partners). Adding the age of partner to the set of explanatory variables would be a first stage in distinguishing between the characteristics of men and women. In order to measure the effect of season on the probability of conception differentiating between men and women, the simplest choice could be to make experiments on IVF. However, as we discussed earlier, the results obtained so far are controversial.

It might be possible to add new variables to our data set. In our study on the effect of season, we implicitly assume an effect of light and temperature on fecundability. Actually, season is only a proxy of light and temperature conditions, and data on geographical latitude of each of the 12 European Natural Family Planning Centers could be easily obtained. For each menstrual cycle, it would be possible to estimate the daily hours of light, which some authors suggest may be related to the risk of conception (see the introduction). Other useful "external" information for each center might be measures of atmospheric temperature (e.g., calculating the mean, minimum, or maximum temperature during the most fertile six days of each cycle, using local daily temperature time series). Some scholars suggest that—mainly for men—conception probability decreases with higher or lower temperatures. Updating our data, it would be possible to study the effect of temperature and the hours of light on the probability of conception—controlling for frequency of sexual intercourse, biological characteristics of each cycle, characteristics of the woman, the age of her partner, and the unobserved heterogeneity of couples.

APPENDIX

The odds ratios presented in this paper are calculated as follows:

$$\mathrm{OR}(M_K) = \exp(\beta_k + \omega_{kr} A_r + \gamma_k In),$$

where M, A, and I are, respectively, the month of beginning of cycle, woman's age, and episodes of intercourse in (–4,+1); β is the main effect for month; γ is the coefficient of interaction between the number of episodes of intercourse in the narrow window and month; and ω is the coefficient of interaction between woman's age and month. $k = 1, \ldots, 12$ indicates categories for month; and $r = 1, 2, 3$ indicates categories for woman's age. We omit the t index and the i index to simplify notation because they are common to all variables.

In other words, the estimated odds ratio for this model can be written as e to l,

$$\mathrm{OR}(M_K) = \exp(l),$$

where l is the linear function given by the sum of β plus the sum of the ω_{kr} multiplied by A_r, and the sum of the γ_k multiplied by In. Thus, for January and for ages 27–31 and $In = 1$,

$$\mathrm{OR}\ (M_{Jan}) = \exp(1.230 + 1.083 \times 1 - 0.713 \times 1) = 5.$$

(See Appendix Table A1.)

The confidence interval formula for CI calculated in Table 4 is the following:

$$\mathrm{CI} = \exp\left[(l) \pm 1.96 \sqrt{\mathrm{var}\ (l)}\right],$$

where

$$\mathrm{var}\ (l) = \mathrm{var}(\beta_k) + (A_r)^2 \mathrm{var}(\omega_{kr}) + (In)^2 \mathrm{var}(\gamma_k) + 2A_r \mathrm{cov}(\beta_k, \omega_{kr}) + 2In\, \mathrm{cov}(\beta_k, \gamma_k) + 2A_r In\ \mathrm{cov}\ (\gamma_k, \omega_{kr}).$$

Appendix Table A1. Parameters of Logistic Model, GEE Model, and Heterogeneous Risk Model

	Homogenous Risk Model With Interaction Terms (cycles = 2,199)				Heterogeneous Risk Model With Interaction Terms (cycles = 1,416)	
	Logistic Model on Discrete-Time Data		GEE Model			
Parameter	Estimate	Pr > χ^2	Estimate	Pr > $\lvert Z \rvert$	Estimate	Pr > χ^2
Month, β (ref. = M_{Dec})						
M_{Jan}	1.230	0.062	0.943	0.046	1.722	0.087
M_{Feb}	0.852	0.235	0.370	0.431	–0.052	0.964
M_{Mar}	–0.878	0.236	–0.985	0.077	–1.288	0.261
M_{Apr}	–1.494	0.079	–1.403	0.003	–2.251	0.137
M_{May}	1.047	0.121	0.902	0.052	1.803	0.092
M_{Jun}	0.403	0.572	0.233	0.625	0.868	0.418
M_{Jul}	0.205	0.783	–0.014	0.974	0.726	0.522
M_{Aug}	0.489	0.480	0.302	0.524	1.131	0.286
M_{Sep}	–0.010	0.990	0.065	0.905	1.180	0.275
M_{Oct}	0.483	0.532	0.520	0.320	1.781	0.102
M_{Nov}	–1.136	0.210	–0.966	0.079	–0.653	0.568
Previous Pregnancy, τ (ref. = P_{1+})						
P_0	–0.357	0.002	–0.250	0.046	–1.448	0.011
Preovulatory Length (days), π (ref. = $L_{18–31}$)						
$L_{<13}$	–0.184	0.192	0.087	0.510	0.397	0.1863
$L_{13–17}$	–0.360	0.004	–0.072	0.500	0.272	0.2248
Woman's Age, ρ (ref. = $A_{>31}$)						
$A_{\leq 26}$	0.853	0.091	0.556	0.219	–4.706	0.001
$A_{27–31}$	–0.688	0.114	–0.538	0.089	–3.092	0.001
Frequency of Acts of Intercourse in the Narrow Window (–4,+1), δ						
In	0.579	0.004	0.454	0.002	0.965	0.006
Frequency of Acts of Intercourse in the Intervals of Days (–8,–5) and (+2,+3), ν						
I	0.020	0.690	0.065	0.117	0.175	0.056
Month × Woman's Age, ω (ref. = $M \times A_{>31}$)						
$M_\beta \times A_{\leq 26}$ (ref. = $M_{Dec} \times A_{\leq 26}$)						
$M_{Jan} \times A_{\leq 26}$	–0.495	0.510	–0.394	0.475	–0.705	0.564
$M_{Feb} \times A_{\leq 26}$	–1.218	0.159	–0.818	0.216	–2.281	0.187
$M_{Mar} \times A_{\leq 26}$	0.298	0.684	0.369	0.519	–1.022	0.457
$M_{Apr} \times A_{\leq 26}$	0.784	0.366	0.537	0.355	0.153	0.932
$M_{May} \times A_{\leq 26}$	–0.726	0.286	–0.832	0.140	–2.497	0.055
$M_{Jun} \times A_{\leq 26}$	0.216	0.767	0.261	0.662	–0.311	0.804
$M_{Jul} \times A_{\leq 26}$	–0.750	0.345	–0.426	0.437	–0.985	0.467

(continued)

(Appendix Table A1, continued)

	Homogenous Risk Model With Interaction Terms (cycles = 2,199)				Heterogeneous Risk Model With Interaction Terms (cycles = 1,416)	
	Logistic Model on Discrete-Time Data		GEE Model			
Parameter	Estimate	Pr > χ^2	Estimate	Pr > $\|Z\|$	Estimate	Pr > χ^2
Month × Woman's Age, ω (ref. = $M \times A_{>31}$)						
$M_\beta \times A_{\le 26}$ (ref. = $M_{Dec} \times A_{\le 26}$) (cont.)						
$M_{Aug} \times A_{\le 26}$	0.219	0.752	–0.005	0.993	–1.192	0.296
$M_{Sep} \times A_{\le 26}$	–0.424	0.589	–0.528	0.389	–1.541	0.223
$M_{Oct} \times A_{\le 26}$	0.278	0.703	0.253	0.692	0.272	0.803
$M_{Nov} \times A_{\le 26}$	1.262	0.146	0.934	0.113	1.130	0.315
$M_\beta \times A_{27–31}$ (ref. = $M_{Dec} \times A_{27–31}$)						
$M_{Jan} \times A_{27–31}$	1.083	0.055	0.674	0.096	1.145	0.171
$M_{Feb} \times A_{27–31}$	1.173	0.051	0.902	0.028	2.090	0.030
$M_{Mar} \times A_{27–31}$	1.197	0.046	0.748	0.090	1.171	0.208
$M_{Apr} \times A_{27–31}$	2.081	0.004	1.545	0.000	3.546	0.008
$M_{May} \times A_{27–31}$	0.064	0.911	–0.201	0.620	–0.074	0.937
$M_{Jun} \times A_{27–31}$	1.051	0.085	0.569	0.185	0.767	0.419
$M_{Jul} \times A_{27–31}$	0.951	0.123	0.598	0.136	1.175	0.232
$M_{Aug} \times A_{27–31}$	1.021	0.080	0.643	0.117	1.109	0.208
$M_{Sep} \times A_{27–31}$	1.479	0.017	0.938	0.050	1.409	0.121
$M_{Oct} \times A_{27–31}$	0.306	0.641	0.227	0.614	0.606	0.518
$M_{Nov} \times A_{27–31}$	1.778	0.024	1.243	0.006	1.978	0.037
Month × Intercourse in the Narrow Fertile Window, γ (ref. = $M_{Dec} \times In$)						
$M_{Jan} \times In$	–0.713	0.007	–0.495	0.008	–0.995	0.025
$M_{Feb} \times In$	–0.562	0.055	–0.282	0.196	–0.408	0.377
$M_{Mar} \times In$	0.220	0.428	0.343	0.128	0.354	0.440
$M_{Apr} \times In$	–0.068	0.815	0.085	0.671	–0.255	0.600
$M_{May} \times In$	–0.396	0.139	–0.331	0.092	–0.960	0.035
$M_{Jun} \times In$	–0.504	0.062	–0.302	0.109	–0.675	0.111
$M_{Jul} \times In$	–0.392	0.158	–0.182	0.326	–0.651	0.127
$M_{Aug} \times In$	–0.417	0.106	–0.233	0.211	–0.576	0.180
$M_{Sep} \times In$	–0.215	0.456	–0.122	0.586	–0.553	0.215
$M_{Oct} \times In$	–0.406	0.162	–0.339	0.093	–0.864	0.045
$M_{Nov} \times In$	–0.201	0.479	0.010	0.961	–0.123	0.778

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