A Comparison of Popular Fertility Awareness Methods to a DBN Model of the Woman's Monthly Cycle

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Abstract

Fertility Awareness Methods are effective, safe, and low-cost techniques for identifying the fertile days of a menstrual cycle. In this paper, we compare the effectiveness of predicting the fertile days by a Dynamic Bayesian Network model of the monthly cycle to 11 existing Fertility Awareness Methods. We base our comparison on a real data set of 7,017 cycles collected by 881 women. We demonstrate that the DBN model is more accurate than the best modern Fertility Awareness Methods, based on the observation of mucus, marking reasonably high percentage of days of the cycle as infertile. We argue that the DBN approach offers other advantages, such as predicting the ovulation day and being able to adjust its predictions to each woman's individual cycle.

1 Introduction

Fertility Awareness Methods (FAMs) are a collection of practices that help a woman know during which days of the menstrual cycle she is most likely to conceive. They are based on the observation of physiological signs of the fertile and infertile phases of the woman's menstrual cycle. They identify the fertile window based on tracking the menstrual cycle length and/or observation of changes in one or more of the primary fertility signs, such as basal body temperature, cervical mucus, and cervix position. This knowledge can be used both to increase the chance of or to avoid pregnancy. The efficacy of FAMs to avoid pregnancy has been critically reviewed by several authors (e.g., (Arevalo et al., 2002; Frank-Herrmann et al., 2007; Howard and Stanford, 1999; Jennings and Sinai, 2001)). Additionally, FAMs can also be helpful in monitoring gynecological health and in identifying some reasons of infertility or early miscarriages.

In this paper, we examine the effectiveness of a Dynamic Bayesian Networks (DBN) model in identifying the fertile days of a woman's monthly cycle. Given primary fertility signs, the model predicts the time around ovulation when the probability of conception is high. Because each woman is different, the parameters of our model are based on individual characteristic of a woman's menstrual cycle. Because every cycle can be different, we reevaluate both the structure and the parameters after each cycle. We present the results of a comparison of our DBN model to 11 popular fertility awareness methods. The data that we used in our study originate from an Italian study of daily fecundability (Colombo and Masarotto, 2000), which enrolled women from seven European centers (Milan, Verona, Lugano, Düsseldorf, Paris, London and Brussels) and from Auckland, New Zealand. From 1992 through 1996 in Europe and from 1979 through 1985 in New Zealand, 881 women collected 7,017 cycles. In our experiment, of all compared FAMs, methods based on observation of the cervical mucus (i.e., the Billings Ovulation Method and the Creighton Model) perform best in the sense of indicating the shortest fertile window. Our DBN model is more accurate than the best modern Fertility Awareness Methods, based on the observation of mucus, marking reasonably high percentage of days of the cycle as infertile.

2 Woman's monthly cycle

The woman's monthly cycle is driven by a highly complex interaction among hormones produced by three organs of the body: the hypothalamus, the pituitary gland and the ovaries. There are four main hormones involved in the menstrual cycle process: estrogen, progesterone, follicle stimulating hormone (FSH), and lutenizing hormone (LH). The woman's monthly cycle can be divided into four phases (Figure 1): (1) menstruation, (2) the follicular phase, (3) ovulation, and (4) the luteal phase. The length of each phase may vary from woman to woman and from cycle to cycle.

In addition to measurable blood hormone levels, there are several easily accessible indicators of the phase of the cycle: raise of the basal body temperature (BBT) after ovulation, presence of the cervical mucus, and changes in position and consistency of the cervix. BBT is defined as the body temperature measured immediately after awakening and before any physical activity has been undertaken. To increase the reliability of this indicator, temperature should be measured every day at the same time. BBT follows a cyclical biphasic pattern, shifting near the ovulation from a low to a high phase. Metabolism is slower in the pre–ovulatory phase of the cycle, which results in a slightly lower body temperature. Following the ovulation, as a result of an increased level of progesterone in the body, women typically experience an increase in the BBT of at least 0.2°C. BBT remains higher until menstruation occurs or, if a woman becomes pregnant, until the end of the pregnancy. Sometimes BBT can rise due to causes other than ovulation. This atypical rise is treated as disturbance and can be caused by a change in conditions around the measurement, such as later measurement time, lack of sleep, high stress, travel, or illness.

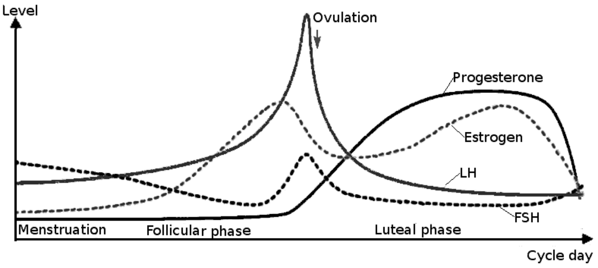

Figure 1: Levels of hormones during the phases of the woman's monthly cycle (Weschler, 2006).

As the cycle progresses, due to hormonal fluctuations, the cervical mucus increases in volume and changes its texture. Usually it is too thick for sperm to pass through. Around the time of ovulation, it becomes more elastic and less acidic, easier for sperm to penetrate. When there is no mucus or the mucus discharge is small, the day is considered infertile. There can be also a feeling of dryness around the vulva. In the luteal phase, mucus returns to its sticky stage.

3 Fertility Awareness Methods

Fertility Awareness Methods (FAMs) are techniques for identification of the fertile days of the monthly cycle. FAMs rely on the fact that a woman ovulates only once per menstrual cycle and she is fertile from a few days before ovulation (due to sperm life span) until after ovulation has occurred. Most menstrual cycles start with infertile days (pre–ovulatory infertility), a period of fertility and then several infertile days until the next menstruation (post–ovulatory infertility). Systems of fertility awareness identify the fertile window based on tracking menstrual cycle length and/or observation of changes in one or more of the primary fertility signs, i.e., BBT, cervical mucus, and cervix position (Weschler, 2006).

Depending on the information that they use, FAMs can be divided into three groups: (1) calendar–based methods, (2) symptoms–based methods, and (3) sympto–thermal methods.

3.1 Calendar–based Methods

Calendar–based methods determine both pre–ovulatory and post–ovulatory infertility taking into consideration only the length of previous menstrual cycles.

Rhythm method (Szymański, 2004) finds the estimated length of the pre–ovulatory infertile phase by substracting 19 from the length of the woman's shortest cycle. Beginning of the post–ovulatory phase is determined by substracting ten from the length of the woman's longest cycle. These calculations are updated every month using the six most recent cycles.

3.2 Symptoms–based Methods

Symptoms–based methods depend on the observation of changes in one or more of the primary fertility signs.

The *basal body temperature* (BBT) method rests on the fact that a woman's temperature drops 12 to 24 hours before an egg is released from her ovary. In this method, days from the first day of menstrual cycle until the third day after the BBT shift are considered fertile (Royston, 1982).

Doering system (DS) sets the length of the pre–ovulatory infertile phase to a woman's earliest historical day of temperature rise (in at least the previous six cycles and at most the previous 12 cycles) minus seven days. BBT shift marks the onset of post–ovulatory infertility. The BBT shift is defined as the first day in the menstrual cycle when three consecutive temperatures are above the average temperature of the last six preceding days (Barron and Fehring, 2005).

The *Billings Ovulation* (BO) method (Muzzerall, 1984) and the *Creighton Model* (CM) (Howard and Stanford, 1999) are methods recognizing and using the cervical mucus as the principal bio-marker of fertility. The first appearance of the cervical mucus is used to determine the end of the pre–ovulatory infertile phase, and its disappearance is used to determine the start of the post–ovulatory infertile phase. They differ in the method of collecting observations. The CM requires use of toilet tissue to make observations, which are subsequently compared to a standardized mucus descriptions. The BO method instructs the woman to be aware of vulval sensations over the whole day just as she goes about her ordinary activities.

The *Two–Day* (2D) algorithm (Dunson et al., 2001; Jennings and Sinai, 2001) classifies a day as fertile if cervical secretions are present on that day or were present on the day before.

3.3 Sympto–thermal Methods

The sympto–thermal methods combine the calendar, the basal body temperature, and the mucus inspection methods. They can also take into consideration indicators such as breast tenderness or ovulation pains. In these methods, every primary sign of fertility is used to cross–check each other to determine the fertile and infertile days of each cycle. Any appearance of the mucus or moist sensation marks the start of the fertile period.

In the *Couple to Couple League* (CCL) method, the end of the pre–ovulatory phase is calculated by using the following formula: shortest cycle minus 21 days over the last six cycles or shortest cycle minus 20 days over the last twelve cycles, provided that there is no mucus. The first appearance of mucus marks a positive start of the fertile time. The post–ovulatory phase begins when, after the day with the most fertile mucus (mucus peak day), three consecutive temperatures are above the average temperature of the last six preceding days (Kippley and Kippley, 1996).

Roetzer's method (RM) considers the first six days of each cycle infertile, provided that none of the previous 12 cycles was shorter than 26 days. It finds the estimated length of the pre–ovulatory infertile phase by subtracting 20 from the length of the woman's shortest cycle. These calculations are updated every month using the 12 most recent cycles. Three days of elevated temperature after the mucus peak day mark the beginning of the post–ovulatory phase (Roetzer, 1968).

Flynn proposed the following formula (called the *English method*, EM) to determine the end of the pre-ovulatory phase for women having knowledge about the length of their last 12 cycles: the shortest of the last 12 cycles minus 20, provided that there is no mucus. The appearance of the cervical mucus secretion starts the fertile phase. A woman who does not have records of her 12 most recent cycles, proceeds as follows: (1) in the first three cycles, the woman does not designate the pre-ovulatory infertility phase, (2) from the 4^{th} to the 12^{th} cycle, if none of the observed cycles is shorter than 26 days, the first 5 days of the cycle are considered infertile. For cycles shorter than 26 days, the woman should subtract 21 from the shortest cycle, (3) after the 13^{th} cycle, the woman subtracts 20 from the shortest of the last 12 cycles. The fertile phase begins when the woman observes cervical mucus secretion (Szymański, 2004).

According to *Sensiplan* (called also the *German method*, GM), the method promoted by Arbeitsgruppe Natürliche Familienplanung in Germany (Raith et al., 1999), a woman who has just started self-observation and does not have records on the timing of her periods can consider the first five days of her menstrual cycle infertile. A woman with records of the length of her cycles determines the length of the pre–ovulatory infertility phase by subtracting 20 from the shortest cycle. A woman who has collected 12 consecutive cycles with correctly interpreted temperature curves can used the following formula: the earliest measurement of the first higher temperature minus eight gives the number of infertile days at the beginning of the cycle. The pre–ovulatory infertile phase lasts as long as the woman feels dry or does not feel anything and does not observe cervical mucus. To determine the beginning of the post–ovulatory infertility phase, women need to find the day of the BBT shift and the mucus peak day. Having marked the peak mucus and higher temperatures and adding to them three days, the end of the fertile period is determined by the symptom that appeared later.

In the method of Kramarek (called also the *Polish method*, PM) (Szymański, 2004), the end of the post–ovulatory infertility is marked by two indicators: the length of the shortest cycle and the shortest phase of the lower temperature for the last 6-12 cycles. 6 days from the shortest phase of lower temperature should be subtracted. Between 19 and 22 days should be subtracted from the shortest cycle, depending on the length of cycles. The smaller result sets the number of days of relative infertility, provided twelve or more observed cycles. With only 6 collected cycles (up to a twelve), the result is reduced by 2 days. Appearance of feeling of moisture or any mucus begins a period of fertility. The end of the fertile period is determined by three days of elevated temperature after the mucus peak day.

4 Our Experiment

The term fertility awareness means that a woman knows when the fertile time of her monthly cycle starts and ends. This knowledge helps a couple in both achieving and avoiding pregnancy but can also be useful in diagnosing possible disturbances in the monthly cycle. FAMs are safe, natural, and inexpensive ways of monitoring reproductive health. They have no medical counter-indications. Their disadvantage is that they require self–discipline and can be time consuming. In our experiment, we tested the effectiveness of the existing FAMs in predicting fertile and infertile days of the monthly cycle. For this, we had a sizeable data set of real monthly cycles available and for individual records in this data set we predicted fertile and infertile days using each of the methods. While the individual records are perfect for testing, they are also used for training each of the models.

4.1 The Data

Our data were drawn from an Italian study of daily fecundability (Colombo and Masarotto, 2000), which enrolled women from seven European centers (Milan, Verona, Lugano, Düsseldorf, Paris, London and Brussels) and from Auckland, New Zealand. From 1992 through 1996 in Europe and from 1979 through 1985 in New Zeland, 881 women collected 7,017 cycles. To our knowledge, this is one of the most comprehensive data sets describing woman's monthly cycle.

In each menstrual cycle, the subject was asked to record the days of her period, her basal body temperature and any disturbances such as illness, disruption of sleep or travel. She was also asked to observe and chart her cervical mucus symptoms daily during the cycle and to record every episode of coitus, and whether the couple used contraceptives or not.

The original data set include 7,017 monthly cycles collected by 881 women. However, in our analysis we included only 3,432 cycles from 236 women. We excluded all women who collected fewer than seven cycles, because a woman needs at least six cycles to become familiar with a chosen fertility awareness method. And while we wanted to compare all fertility awareness methods described in Section 3, we also excluded cycles with not uniquely identified mucus peak or the BBT shift days, because FAMs are dependent at least on one of these indicators and it is impossible to identify the fertile days of the cycle for the purpose of this analysis in cycles where the peak day is not uniquely identified. Because of current software performance limitation, we excluded women with very long cycles (longer than 40 days).

4.2 The Model

Our dynamic Bayesian model of woman's monthly cycle (Figure 2), combines information retrieved from BBT charting with observations of the cervical mucus secretions. It contains a variable *Phase* with four states: menstruation, follicular, ovulation, and luteal. We included three discrete observation variables: *Basal Body Temperature*, *Bleeding* and *Mucus observation*, which are readily available to any woman and also included in our data set. BBT has two possible values: lower range and higher range, representing temperature before and after the BBT shift respectively. *Bleeding* describes whether on a particular day the woman had menses or not. *Mucus observation* can be in one of four states (s1 through s4), described in detail in (Dunson et al., 2001). We modeled time explicitly as n time steps, where n is the number of days of the longest monthly cycle of the particular woman. The model is of k-order, i.e., it contains temporal influences between 1 and k. An example of a third-order DBN is shown in Figure 2. Furthermore, while any DBN model should contain at least one first order influence, a model of order k does not need to include influences of all orders between 1 and $k-1$.

Our previous paper (Łupińska-Dubicka and Drużdżel, 2011) presented the results of an experiment with a series of DBN models monitoring woman's monthly cycle. We have shown that higher order models are significantly more accurate than a static BN and first order models. However, we have also observed over-fitting and a resulting decrease of accuracy when the chosen time order or the number of temporal arcs were too high.

We found empirically that the models showed the best performance when their order was between 6 and the half of total length of the menstruation and follicular phases (this was different for each woman). Lower order would be weaker in predicting ovulation six days in advance and a higher order led to over-fitting. We have also found that it was not necessary to include influences of all orders. Skipping some of them reduced over-fitting.

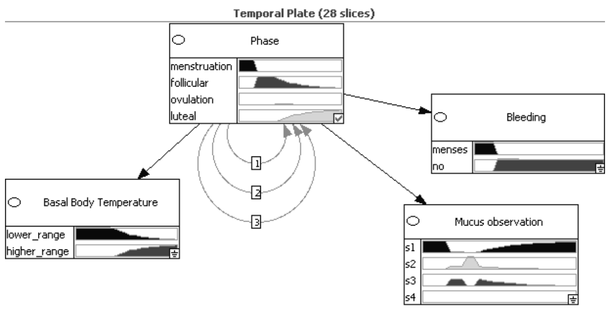

Figure 2: An example of third-order DBN model of woman's monthly cycle

In order to provide more meaningful results and to compensate for the absence of much data, we determined the initial structure of a model and its parameters based on the domain knowledge and adjusted them to a particular woman using data for her first six cycles. While a woman's body can also change over time and with it the characteristics of the cycle, we updated the structure and parameters using not more than the last 12 woman's cycles. After each cycle, we changed the structure of a model by updating its parameters and adding or removing temporal arcs bearing in mind that first order is necessary and cannot be removed. For the last 12 cycles we calculated the minimal and most frequent day of the ovulation. Dividing these values by two we received the order of temporal arcs that should appear in model. Typically these orders were between six and nine.

4.3 Experiments

In our experiments, we simulated the usage of each method by women who want to become pregnant or want to avoid pregnancy, focusing on the effectiveness of each method, including our DNB model. We implemented the 11 fertility awareness method described in Section 3. To our knowledge there is no comprehensive comparison of all different FAMs.

In case of monitoring woman's monthly cycle the main goal is to predict right time of ovulation and based on it to determine the fertile window. Days inside the fertile window that were classified as infertile are *false negatives.* If the model is used to avoid pregnancy, it is critical to reduce the false negative rate to zero. Days that were marked as fertile and were outside the fertile window are *false positives.* The smaller the false positive rate, the closer the predicted day of ovulation is to the real day of ovulation, what can be helpful for couples seeking pregnancy. The number of fertile days during a menstrual cycle is difficult to specify. In our experiment, we based it on the definition given by Wilcox et al. (1995), who define the fertile window as the period between day of ovulation minus five days and day of ovulation plus one day. Many authors agree that the start of the fertile interval is strictly connected with estrogenic-type cervical mucus secretions. However, they differ in their estimates of the length of the fertile window.

We chose as our comparison criterion the percentage length of pre–ovulatory and post–ovulatory phase, and the percentage length of the fertile window. We determined the number of fertile and infertile days in all cycles, as indicated by each of the method, and divided this number by the total length of the cycle for each woman and for each cycle. Effectively, we obtained the percentage of all days that were classified as infertile and percentage of all days that were classified as fertile. In our opinion, these two numbers (they add to 100%) are a good indication of the precision of each method. If each of these methods avoided false negatives perfectly, the larger the percentage of infertile days and the smaller the percentage of fertile days, the more precise the method and the better approximation of the ovulation day.

At every time step (i.e., every day of the cycle) our DBN model computed the most probable day of the ovulation. If a time interval between the current day and the day with the highest probability of the ovulation equaled at least six days (DBN_5 model, five days for life span of sperm and one more day to provide a safety margin against false negatives) or at least seven days (DBN_6 mode) we marked the current day as infertile. In other case the current day is the beginning of fertile period. To find the beginning of the post–ovulatory phase, our model uses the BBT shift. The third day after the BBT shift is considered as infertile.

For every implemented fertility awareness method, according to its rules, we identified the percentage length of fertile and infertile periods in all cycles. We also calculated false negative and false positive rates.

5 Results

Table 1 and Figure 3 show the average percentage of fertile and infertile days during a woman's monthly cycle sorted in the descending order (i.e., the longest to the shortest infertile period). The number of days in which a woman should abstain from intercourse to prevent unplanned pregnancy is larger for methods using two or more fertility indicators (i.e., sympto–thermal) than in symptom–based methods. As we can see, the percentage of fertile and infertile days indicated by he DBN model was close to the mucus only based FAMs and more precise than any of the sympto–thermal methods studied. At the same time, the number of false negatives for the DBN model was close to zero for the DBN_5 model and zero for the DBN_6 model, while methods with the mucus–based methods yielding a fairly high false negative rate.

Table 1: Average percentage of fertile and infertile days and false negatives during monthly cycle for each of the compared methods (sorted by accuracy).

Method	**% infertile days**	**% fertile days**	**% false negatives**
BO	64.62%	35.38%	5.68%
CM	64.62%	35.38%	5.68%
2D	59.32%	40.68%	3.18%
DBN_5	58.66%	41.34%	0.03%
DS	55.95%	44.05%	0.49%
DBN_6	52.41%	47.59%	0.00%
Rhythm	47.57%	52.43%	1.03%
GM	46.63%	53.37%	0.02%
RM	45.76%	54.24%	0.17%
CCL	44.90%	55.10%	0.18%
EM	44.55%	55.45%	0.02%
PM	40.27%	59.73%	0.17%
BBT	27.47%	72.53%	0.00%

In addition to percentage of fertile and infertile days, we plotted the percentage of days of each cycle that were misclassified as infertile, i.e., percentage of false negatives. False negatives are an important measure of accuracy of a FAM, because on one hand they may lead to unplanned pregnancy and on the other hand to less likely conception in case of couples seeking pregnancy. We would like to point out that the way we determined a day to be fertile can be considered as conservative and unfair towards the modern FAMs based on mucus. Absence of mucus is an important sign of infertility and it is possible that the days that we classified as fertile were in fact infertile. However, there are women who have problems with observing and interpreting mucus secretions and methods based only on mucus are not suitable for them. And for that reason we decided to use the definition given by Wilcox et al. (1995).

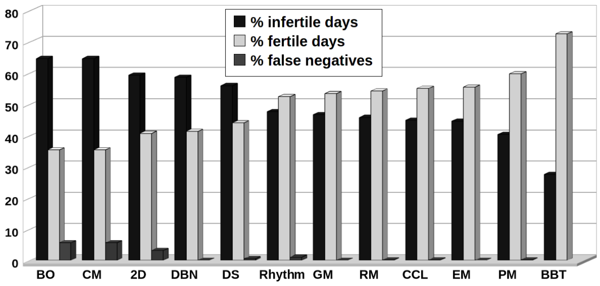

Figure 3: Graphical representation of Table 1 .

6 Discussion

We have presented the results of a comparison of a DBN model of a woman's monthly cycle to 11 fertility awareness methods. In our analysis, methods based on observation of the cervical mucus (i.e., the BO method and CM) performed best in the sense of indicating the shortest fertile period. Our DBN model performed close to the best FAMs and showed at the same time much lower false negative rate (zero or near zero). The only other method with zero false negatives is the BBT method, but we have to take into consideration that this method determines only post–ovulatory infertility and all days before the BBT shift are considered fertile. The FAMs using two or more fertility indicators provide longer fertile window and, therefore, a lower false negatives rate, comparing to the methods based only on the cervical mucus. However, absence of cervical mucus is a strong indication of an infertile day, because without fertile type of secretions sperm cannot survive. Consequently, the false negative rate, as computed, is conservative and possibly unfair towards the mucus–based methods.

The strength of a DBN model is in that it can combine all information that a woman can collect about her cycles. It can fit an individual woman and take into consideration all fertility indicators. As our experiment showed, its performance closely matches that of the best available FAMs. Additionally, DBN model is able to predict the day of the ovulation, which can be helpful for couples seeking pregnancy.

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