Work With Video Display Terminals and the Risk of Reduced Birthweight and Preterm Birth

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To determine whether the use of video display terminals (VDTs) is associated with an increased risk of reduced birthweight (RBW) and preterm birth, a cohort of telephone operators who used VDTs at work was compared to a cohort of non-VDT-users. Among 2,430 women interviewed, 713 eligible singleton live births were reported. Exposure was estimated from company records and a representative sample of electromagnetic fields was measured at the VDT workstations. For RBW (≤2,800 g), we found no excess risk associated with any VDT use during pregnancy (odds ratio [OR] = 0.9; 95% confidence interval [CI] = 0.5–1.7). For preterm birth (≤37 weeks), we similarly found no excess risk (OR = 0.7; 95%CI = 0.4–1.1). The risks estimated did not change substantially when hours working with VDTs were used as exposure variables. By contrast, increased risks were found for several known risk factors for LBW and preterm birth. We conclude that occupational VDT use does not increase the risk of RBW and preterm birth. Am. J. Ind. Med. 32:681–688, 1997.

KEY WORDS: computer terminals; electromagnetic fields; pregnancy; pregnancy outcome; birthweight; infant, premature

INTRODUCTION

The potential effects of working with video display terminals (VDTs) on perinatal outcomes have been of continuing interest since the first clusters of adverse pregnancy outcomes were reported in 1980. Most studies, however, have reported only equivocal associations of VDTs with low birthweight (LBW), preterm birth, and birth defects [Delpizzo, 1994].

Since 1986, eight studies have been published in which the association between VDTs and LBW was investigated [Ericson et al., 1986a,b; McDonald et al., 1988; Nurminen et al., 1988; Windham et al., 1990; Nielsen et al., 1992; Parazzini et al., 1993; Bracken et al., 1995]. In these studies, exposure to VDTs was estimated by using either job titles or self-reported interview data. Most odds ratios (ORs) for delivering a low-birthweight infant were within the range of 0.5–1.1 and did not suggest an LBW-VDT association. The study by Windham et al. [1990] reported an OR of 1.6 (95%CI = 0.9–2.9) for intrauterine growth retardation (IUGR), suggesting an effect of VDT exposure on fetal growth. A decreased risk of LBW was suggested for the offspring of women who used VDTs at home or at work for 1–20 hr/week [Bracken et al., 1995].

Birthweight has long been considered the perinatal outcome of primary interest because of its effect on infant survival. Recently, however, Wilcox et al. [1995] concluded that although most preterm infants are LBW, prematurity rather than LBW has the predominant effect on infant survival. Relatively little is known about the effect of VDTs on preterm birth. Two studies on VDTs and preterm birth reported crude ORs of 1.2 [Nurminen et al., 1988; Windham et al., 1990]. Two other studies, by McDonald et al. [1988] and Nielsen and Brandt [1992], reported adjusted ORs of 1.1 (90%CI = 1.0–1.2) and 1.1 (95%CI = 0.9–1.5), respectively.

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Ericson and Källén [1986b] reported an OR of 2.3 (95%CI = 1.4–3.9) for the combined category of birth defects, very low birthweight (VLBW) and perinatal mortality among women who worked with VDTs of more than 20 hr/week. Other studies did not suggest an association between VDT use and birth defects [McDonald et al., 1988; Goldhaber et al., 1988; Brandt et al., 1990].

This paper describes the second part of a study in which we examined the association between working with VDTs and adverse perinatal outcomes in two groups of female telephone operators with similar work situations. We obtained data on VDT use from the employers' records and measured electric and magnetic fields (EMFs) at a sample of the operators' workstations. In the first part of this study, the use of VDTs and exposure to VDT characteristic EMFs were found not to be associated with an increased risk of spontaneous abortion [Schnorr et al., 1991].

MATERIALS AND METHODS

Study Population

The study population consisted of 2,430 married women aged 18–33 years who were employed as either directory-assistance operators or general telephone operators (reached by dialing 0) at two companies in eight southeastern states. The directory assistance (VDT-exposed) operators used VDTs to provide telephone numbers to customers. The comparison group of general (unexposed) operators primarily assisted customers in placing long-distance calls. Two VDT models were used by the VDT-exposed operators during the study period: International Business Machines (IBM) model 4978 and Computer Consoles Inc. (CCI) model 4500. The unexposed operators used units containing a light-emitting diode (LED) or neon glow tube (NGT) to display the numbers, rather than a VDT. Typically, both VDT-exposed and unexposed operators worked 7 hr/day in front of the equipment. Both groups of operators were monitored by a supervisor and by a computer that recorded the number and length of calls. Education and salary levels were similar for both VDT-exposed and -unexposed operator positions. We did not observe any differences in work practices between the two groups other than the presence or absence of VDTs.

Data Collection

A telephone interview was used to collect lifetime reproductive histories, including the outcome of all pregnancies inside and outside the study period, defined as the period from January 1, 1983 through December 31, 1986. Birthweight and gestational age questions were asked as follows: "How much did he/she weigh at birth?" and "Did the doctor say your baby was born early, late or on time? If early or late, how many weeks?" Use of VDTs at home was obtained by self-report during the interview. Data were also collected on potential confounders or effect modifiers including race, age, smoking habits, pregnancy complications, medical history, and interpregnancy interval. Interpregnancy interval was defined as the time between the end date of the previous pregnancy and the estimated start date of the last menstrual period before the index pregnancy. For validation purposes, birth certificates were collected for live births and medical records were requested for infants with a reported birth defect.

VDT-exposed operators used VDTs exclusively whereas unexposed operators only used units containing a LED or NGT. Neither group of operators had any other duties. Thus, company records of dates of employment as a VDT-exposed or unexposed operator and interview data on dates of pregnancy were used to ascertain the women's use of VDTs for each trimester of pregnancy. For VDT-exposed operators, we also used weekly payroll records to calculate the hours of VDT use during each study pregnancy.

In 1990, the EMFs emitted by the two models of VDTs and the LED/NGT equipment in use during the study period were measured [Schnorr et al., 1991; Tell, 1990]. Both VDT operators and LED/NGT operators were exposed to extremely low-frequency electric and magnetic fields (ELF, 45–60 Hz) in the same range as reported average home exposures. The abdominal ELF geometric means were with the range of 0.4–0.8 V/m for the electric field and 32.4–62.4 mA/m for the magnetic field. VDT-exposed operators were exposed to above-background levels of very low-frequency electric and magnetic fields (VLF, approximately 15 kHz). Their measured abdominal VLF geometric means were with the range of 0.1–0.5 V/m for the electric field and 4.0–17.4 mA/m for the magnetic field.

Outcome Definitions

Pregnancies that met the following criteria were included in the analyses: the pregnancy resulted in a singleton live birth during the study period, and the mother was employed for at least 1 day as a VDT-exposed operator or -unexposed operator during the first 28 weeks of pregnancy. The estimated date of the last menstrual period was considered the start date of each pregnancy. Gestational age was calculated as the number of weeks between the estimated last menstrual period and the date of birth. Reduced birthweight (RBW) was defined as $\leq$2,800 g. We chose this cutpoint for RBW due to small numbers of live births that met the traditional LBW definition of <2,500 g. Preterm birth was defined as a live birth of 21–37 weeks gestation. The criteria identified by Erickson et al. [1984] were used to define and identify infants with major birth defects. These

birth defects are included in codes 740.0–759.9 of the International Classification of Disease (ICD), Ninth Revision, and are considered to affect survival, require substantial medical care, result in marked physical or psychological handicaps, or interfere with a baby's prospect for life.

Definition of VDT Use

VDT use was initially defined as a dichotomous variable for the entire pregnancy and for each trimester separately. Pregnancies or trimesters in which the mother worked as a VDT-exposed operator at any time were classified as exposed. If the mother worked as a unexposed operator only, the pregnancy or trimester was classified as unexposed. From payroll records, we calculated the actual hours of VDT work for each study pregnancy of a VDT-exposed operator by trimester and for the total pregnancy. Analysis of actual hours worked was crucial because work hours might have varied depending on the stage of pregnancy when hired, the timing of vacations, the amount of leave used, and the number of hours worked on a given day. We generated a trimester-specific index of weekly hours of VDT use by dividing the days of VDT use in each trimester by the days pregnant in each trimester. Similarly, we calculated hours of VDT use per week for the entire pregnancy. Pregnancies in which the mother worked as a unexposed operator only were assigned 0 hr of VDT use.

Statistical Analysis

Frequency distributions and stratified analyses were used to assess evidence of confounding and interaction by demographic, medical, and lifestyle variables. Of these variables, age, race, parity, gravidity, alcohol consumption, smoking, infant gender, gestational age (RBW analysis only), previous RBW or preterm live birth prior to the study period, other adverse pregnancy outcomes prior to the study period, diabetes, maternal weight gain during pregnancy, thyroid condition, hypertension medication during pregnancy, pre-eclampsia or toxemia, and interpregnancy interval were included as potential confounders in initial multivariable analyses. All these variables were also examined for interaction with VDT exposure. We used multiple logistic regression analysis to determine the relative odds of RBW and the relative odds of preterm birth. Multiple linear regression analysis was used to assess the effect of VDT use on continuous birthweight. To address the issue of correlated outcomes (multiple pregnancies per woman), we analyzed our linear and logistic regression models with the quasi-likelihood generalized estimating equations of Zeger and Liang [1986]. The effect of VDT exposure on risk of preterm birth was also analyzed in a proportional hazards model, and the marginal analysis approach of Wei et al. [1989] was used to account for multiple pregnancies per woman. For these

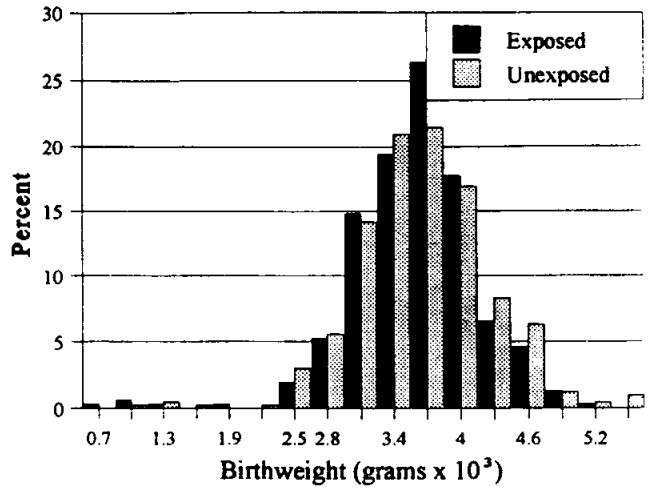

FIGURE 1. Crude distribution of birthweight in percentages by VDT use. Low birthweight and reduced birthweight cutoffs are at 2.5 (2,500 g) and 2.8 (2,800 g), respectively.

survival analyses, all pregnancies that ended after 20 weeks gestation during the study period were included, regardless of outcome. Analyses of residuals, multicollinearity, and goodness-of-fit were conducted to confirm that the final models did not violate analytic assumptions. Multivariable analyses of major birth defects and perinatal death were not conducted due to small sample sizes. PC-SAS® software was used for all statistical procedures [SAS Institute, 1989, 1994].

RESULTS

Details about response rates and demographic characteristics of the study population were reported previously [Schnorr et al., 1991]. Of the initial 5,544 employees found in company records, 94.9% of the 4,475 women we contacted agreed to participate. Among the 2,430 married women interviewed, 713 pregnancies from 647 women met our criteria of ending in a singleton live birth during the study period and employment of at least 1 day as a telephone operator. Of the 707 eligible pregnancies, there were 304 pregnancies in which the woman was exposed to VDTs at work at any time during pregnancy and 403 unexposed pregnancies. The 284 VDT-exposed operators and 363 unexposed operators were similar in age, lifetime number of pregnancies, and percentage employed at the study company at the time of the interview. VDT-exposed operators had worked slightly longer than unexposed operators at the study company (8.2 vs 7.6 years). The proportion with more than a high school education was higher among unexposed operators (36.2% vs 27.1%), as was the proportion of Hispanic women (9.1% vs 2.5%).

Figure 1 shows the crude distribution of birthweight in the study population. The percentage of RBW infants was

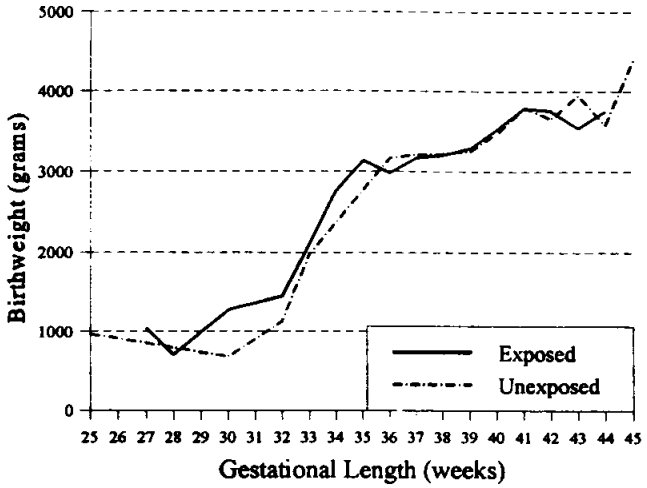

FIGURE 2. Birthweight and gestational length by VDT use.

8.9% (n = 27) in the exposed and 9.7% (n = 39) in the unexposed pregnancies. The distribution of mean birthweight by gestational age for exposed and unexposed pregnancies is depicted in Figure 2. No substantial differences appear to be present between the exposure groups. The logistic regression model for RBW included the dichotomous VDT exposure variable and independent risk factors, i.e., prematurity, race, smoking, use of diuretics, RBW infant prior to the study period, and interpregnancy interval (Table I). None of these risk factors appeared to be a confounder of exposure: crude and adjusted odds ratios for VDT use are equal. No significant interactions with exposure were found. No association was found between VDT use and reduced birthweight (OR = 0.9; 95%CI = 0.5–1.7). When the average number of hours per week (categorized as 0, 1–25, and >25 hr/week) of VDT use in the total pregnancy was substituted in the model, the coefficients for the other risk factors did not vary substantially. In this analysis, reduced birthweight did not appear to have a consistent relationship with hours of VDT use during pregnancy. The point estimates suggest the possibility of a decreased risk of RBW for women working with VDTs no more than an average of 25 hr/week, and a slightly increased risk (OR = 1.4, 95%CI = 0.7–3.1) for women working more than 25 hr/week. A similar pattern was found when trimester-specific hours worked per week (i.e., hr/week in first, second, or third trimester) were substituted into the model.

Two restricted analyses were performed to investigate the slightly increased risk of RBW for women working with VDTs for more than 25 hr/week. First, to determine whether degree of employment contributed to the increased estimate, we performed an analysis restricted to the pregnancies of study participants who had worked an average of 4 or more days/week (4 or more working days/week is roughly comparable to the 25+ hr/week category for continuous VDT exposure, in which exact hours of VDT-exposed operator work were available). Restricting the analysis to those women working 4 or more days/week showed no increased risk of RBW among women using VDTs (OR = 0.7, 95%CI = 0.4–1.4). A second analysis was restricted to

TABLE I. Crude and Adjusted Odds Ratios (OR) With 95% Confidence Intervals (CIs) for Reduced Birthweight (≤2800 g) Associated with Occupational VDT Use and Other Variables in the Logistic Model

Variable	No. of pregnancies	Crude OR	Adjusted 95%CI	Adjusted OR[a]	Adjusted 95%CI
VDT use during pregnancy					
None	392	1.0		1.0	
Any	303	0.9	(0.5–1.5)	0.9	(0.5–1.7)
VDT use (hr/wk), total pregnancy[b]					
0	394	1.0		1.0	
1–25	116	0.5	(0.2–1.1)	0.4	(0.1–1.0)
>25	120	1.4	(0.7–2.6)	1.4	(0.7–3.1)
Born premature (≤37 weeks)					
No	627	1.0		1.0	
Yes	68	9.9	(5.5–17.8)	12.9	(6.6–25.3)
Race					
White	499	1.0		1.0	
Other	196	3.5	(2.1–5.9)	4.4	(2.3–8.4)
Cigarettes smoked per day					
0	540	1.0		1.0	
1–9	77	1.3	(0.6–2.7)	1.5	(0.6–3.6)
10+	78	2.1	(1.1–4.1)	5.0	(2.3–11.3)
Use of diuretics during pregnancy					
No	675	1.0		1.0	
Yes	20	2.5	(0.8–7.6)	4.3	(1.1–16.4)
Reduced birthweight infant prior to study period					
No	623	1.0		1.0	
Yes	72	3.6	(2.0–6.7)	3.3	(1.5–7.3)
Interpregnancy interval					
First pregnancy	210	1.0	(0.6–1.7)	4.3	(1.8–10.3)
0–12 mo	128	1.9	(1.1–3.4)	3.4	(1.5–8.1)
12–48 mo	217	1.0		1.0	
49+ mo	140	1.2	(0.6–2.2)	1.6	(0.6–4.0)

[a]Adjusted for all covariates.
[b]When these VDT exposure variables were substituted in the model, covariate coefficients did not vary substantially. Because of missing data, the total number of pregnancies varied between the two analyses.

third-trimester unexposed operators. The point estimates for unexposed RBW risk were similar to those generated in the presence of VDT exposure (OR = 0.8, 95%CI = 0.3–2.3 for 4 or more days/week; OR = 0.2, 95%CI = 0.01–2.5 for 1–4 days/week).

The covariates in the linear regression model for birthweight were similar, but not identical, to those found in the logistic regression model. The model contained all logistic model covariates except for use of diuretics. Additionally, the linear model contained the covariates infant gender, hypertension medication during pregnancy, diabetes, and thyroid disorder. Again, none of these additional risk factors changed the relationship between VDT use and birthweight substantially. Adjusted least-squares mean birthweights and standard errors were 3,440 ± 27 and 3,475 ± 24 g for exposed and unexposed pregnancies, respectively.

The distribution of gestational age is shown in Figure 3. The percentages of preterm infants were 7.9% (n = 24) and 11.2% (n = 45) for exposed and unexposed pregnancies, respectively. The logistic regression analysis for preterm birth resulted in an exposure odds ratio identical to the crude estimate (OR = 0.7) for women who worked with VDTs (95%CI = 0.4–1.1). The following risk factors, however, were associated with preterm birth: pre-eclampsia or toxemia, diabetes, and a previous preterm infant prior to the study period (Table II). No significant interactions with exposure were found. The substitution of continuous exposure variables in the preterm model did not have a substantial effect on the relationship between exposure and outcome, nor did it change the coefficients of the other risk factors. Proportional hazards analysis of preterm birth resulted in the same model as for logistic regression. The risk ratio (RR) for VDT use during pregnancy was 0.7 (95%CI = 0.4–1.1), which is identical to the logistic regression odds ratio (Table II).

Of the 652 women in the study population, 60 (9.2%) had more than one live birth during the study period, 59 had two births, and one woman had three. Since these multiple births are not independent events, we adjusted for correlation between births by using the quasi-likelihood generalized estimating equations derived by Zeger and Liang [1986]. The coefficients and standard errors from these analyses did not differ from those of the logistic regression models for RBW and preterm birth. Also, the birthweight linear regression coefficients and standard errors did not differ substantially after adjustment for correlated outcomes. When we examined the effect of correlated outcomes on the proportional hazards analysis of preterm birth with the marginal analysis approach of Wei et al. [1989] the data were only sufficient to analyze the unadjusted RR for VDT use. The exposure coefficient from this analysis ($\beta = -0.33$, standard error [SE] = 0.25) was very similar to the analogous coefficient from the proportional hazards model ($\beta = -0.36$, SE = 0.25), which ignores correlation effects.

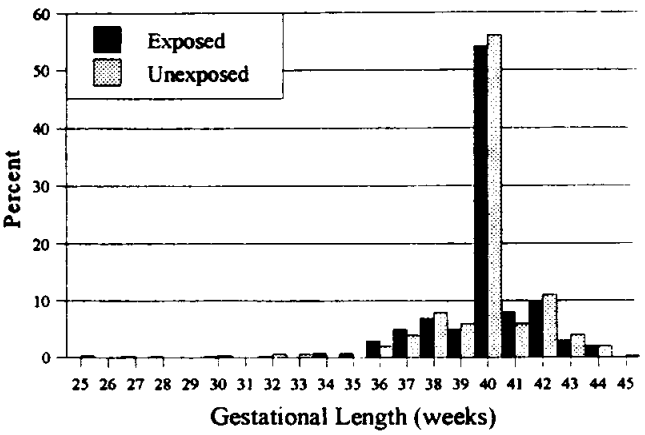

FIGURE 3. Crude distribution of gestational length in percentages by VDT use.

Because the mean values for VLF and ELF emissions at the CCI terminals were higher than the values at the IBM terminals, we conducted analyses for RBW and preterm birth with separate exposure variables for IBM and CCI users. These analyses indicated no differences in risk of RBW or preterm birth between women using an IBM or a CCI unit.

Major birth defect rates, defined as the total number of major birth defects divided by the total number of live births, are generally estimated at 2–3% in the US [Bloom, 1981]. In this study, the rate of self-reported major birth defects was 2.3% (n = 7) in the exposed group and 1.0% (n = 4) in the unexposed group. For the 11 birth defects reported, medical records were obtained for, and confirmed, only three of the self-reported major birth defects. One additional major birth defect was discovered in the review of these records (Table III). Birth certificates were available for 93% (n = 663) of the eligible study pregnancies. However, only one of the eleven major birth defects reported was confirmed by birth certificate. No additional major birth defects were discovered in reviewing the birth certificates.

The perinatal death rate, defined as

$$\frac{\text{(Total number of fetal deaths after 28 or more weeks gestation + infant deaths within 7 days after birth)}}{\text{(Total number of live births plus still births during the study period)}}$$

was 1.0% in the exposed group (two stillbirths and one infant death) and 0.5% in the unexposed group (one stillbirth and one infant death).

DISCUSSION

We did not find an increased risk of RBW and preterm birth among women who worked with VDTs. The risk of delivering an RBW infant was not increased for women who used VDTs during pregnancy, nor was the mean birthweight

TABLE II. Crude and Adjusted ORs[a] and Adjusted RRs[b] With 95% Confidence Intervals (CI) for Preterm Birth (≤37 weeks) Associated With Occupational VDT Use and Other Variables

				Logistic[a]		Proportional hazards[b]	
Variable	No. of pregnancies	Crude OR	95%CI	Adjusted OR	95%CI	Adjusted RR	95%CI
VDT use during pregnancy							
None	400	1.0		1.0		1.0	
Any	304	0.7	(0.4–1.1)	0.7	(0.4–1.1)	0.7	(0.4–1.1)
VDT use (hr/wk), total pregnancy[c]							
0	403	1.0		1.0		1.0	
1–25	116	0.9	(0.5–1.8)	0.8	(0.4–1.7)	0.8	(0.4–1.5)
>25	120	0.7	(0.3–1.4)	0.6	(0.3–1.3)	0.7	(0.3–1.3)
Pre-eclampsia or toxemia							
No	654	1.0		1.0		1.0	
Yes	50	2.2	(1.0–4.7)	2.4	(1.1–5.3)	2.2	(1.1–4.5)
Diabetes (diagnosed before or during the study period)							
No	687	1.0		1.0		1.0	
Yes	17	9.1	(3.4–24.5)	9.0	(3.3–24.9)	6.1	(2.8–13.1)
Preterm infant prior to study period							
No	657	1.0		1.0		1.0	
Yes	47	3.2	(1.5–6.5)	2.9	(1.3–6.1)	2.3	(1.2–4.4)

[a]OR, odds ratio from logistic regression analysis.
[b]RR, risk ratio from proportional hazards analysis.
[c]When these VDT exposure variables were substituted in the model, covariate coefficients did not vary substantially. Because of missing data, the total number of pregnancies varied between the two analyses.

TABLE III. Distribution of Self-Reported Major Birth Defects

Birth defect (ICD 9 code)	VDT user (n = 304)	Non-VDT user (n = 403)
Cleft palate (749.0)	2	0
Club foot (745.7)	1	0
Congenital cataract (743.3)	0	2
Congenital multiple exostosis (756.4)	1	0
Hypospadias (752.6)	1	2
Anomaly of epiglottis or trachea (748.3)[a]	2	0
Total number of major birth defects[b]	7	4

[a]Determination of major vs. minor status not conclusive due to incomplete records.
[b]Multiple heart defects (ventricular septal defect and interruption of aortic arch, ICD 9 745.4 and 747.11) were identified after studying the medical record of one child for a self-reported minor birth defect. These defects are not included in self-reported major birth defect totals and rates in Results.

meaningfully decreased. These results did not change when analyses were performed with continuous or trimester-specific measures of VDT exposure, when monitor type was considered, or when adjustments were made for multiple pregnancies per woman. Although we did not find an association between VDT use and RBW, we confirmed associations with RBW in our logistic or linear models for a number of previously reported risk factors: prematurity, infant gender, nonwhite (primarily African-American) race, smoking more than 9 cigarettes per day, hypertension medication during pregnancy, diabetes, thyroid disorders, RBW infant before the study period, first pregnancy, and short interval between pregnancies (≤12 months).

For prematurity, we did not find an increased risk for women working with VDTs for any measure of exposure we evaluated. Again, previously reported risk factors affected prematurity in our study: pre-eclampsia or toxemia, diabetes diagnosed before or during pregnancy, and a preterm infant prior to the study period. Diabetes and pre-eclampsia/toxemia are risk factors for preterm birth, as labor is often induced early in these women. The number of children with birth defects and the number of perinatal deaths were too small to analyze in multivariable analyses, but the data do not suggest an unusual or specific excess in either the exposed or unexposed groups.

Selection bias seems to be an unlikely explanation for these results. The participation rate was high and minimizes the impact of nonparticipant demographic differences on our results. The demographic characteristics of study participants did not differ greatly by exposure status. All the

women worked for the same company for comparable salaries in similar work situations.

Information on birthweight and gestational age was collected from questionnaires and birth certificates. We were able to obtain birth certificates for 663 (93%) of the births included in the study. Birthweight data were available from all these birth certificates, and gestational age from 633 (89%) of the study births. Because birth certificates were not available for all reported births, and maternal reports of birthweight and gestational age are considered of good quality [Selevan, 1980], we decided to use self-reported data in our analyses. Agreement between self-reports and birth certificates was good for birthweight: 81% of the exposed and 83% of the unexposed mothers' reports differed by <100 g from birth certificate data. For gestational age, reports from 83% of the exposed and 81% of the unexposed participants differed by ≤2 weeks from the birth certificate records.

Differential misclassification of exposure status is also unlikely, since VDT use was ascertained and calculated from company records. Home VDT use was infrequent during the study period: only 0.9% of the exposed women and 2.2% of the unexposed women reported VDT use at home.

With the exception of possible confounding based on employment level, in the multivariable analyses, neither interaction nor confounding of the association between VDT use and RBW or preterm birth occurred. Factors that increased risk for RBW or preterm birth in these models were unrelated to VDT exposure. Weinberg [1993, 1995] and Nurminen [1995] have suggested that previous pregnancy outcomes should not be treated as confounders because of their potential association with previous exposure. It is possible that risk factors such as hypertension medication during pregnancy, preterm birth before the study period, or an RBW infant before the study period may be associated with exposure, although inclusion or exclusion of these factors from our models did not meaningfully affect the exposure risk estimates, and multicollinearity between these factors and VDT exposure was not detected.

Our study design did not allow us to address the possible confounding effects of physical and psychological stress, prepregnancy weight and height, and passive smoking. However, we consider the work-related physical and psychological stress of VDT-exposed and -unexposed telephone operators to be similar, based on work practices and responsibilities.

Although we chose a 2,800-g cutpoint for RBW due to small numbers of live births that met the traditional LBW definition of <2,500 g, we reanalyzed our data with the 2,500-g cutpoint and compared these results to national LBW rates. The 2,500-g LBW analysis resulted in an exposure OR of 1.0 and a broader 95%CI (0.4–2.4). Birthweights of <2,500 g were reported by 3.6% of the exposed women and by 4.3% of the unexposed women in our study, while the U.S. population rate is 7.1% [Centers for Disease Control, 1994]. The relatively low LBW rates in this study may have resulted from the demographic characteristics of the study population (primarily middle class, married, age 18–33 years).

We found a decreased point estimate for the risk of delivering a RBW infant among women working with a VDT of 1–25 hr/week, consistent with the findings of Bracken et al. [1995], who found a decreased risk for women working with a VDT of 1–20 hr/week. On the other hand, we found a slightly elevated point estimate for women who used a VDT more than 25 hr/week. In an analysis restricted to those women who worked 3 or more days/week, however, there was actually a decreased risk among VDT users compared to nonusers. In a second analysis, restricted to third-trimester unexposed operators, point estimates for RBW were similar to those generated for RBW in the presence of VDT exposure. This finding suggests that the apparent increased risk among women who used VDTs more than 25 hr/week compared to all non-VDT users may actually reflect other differences between women who work full-time during pregnancy as compared with those who do not and that these differences are not necessarily related to VDT exposure.

In our study, use of diuretics during pregnancy was associated with RBW, which has not been previously reported. Of the 20 women in our study who used diuretics, nine reported the use of hypertension medication during pregnancy. Hypertension has been associated with LBW in previous studies [Velentgas et al., 1994] and hypertension medication use was determined to be a risk factor for RBW in our linear analysis. Thus, in our data, use of diuretics and hypertension medication may represent surrogate measures for hypertensive disorders.

The strengths of this study include the use of payroll records to assess the number of hours worked with VDTs during pregnancy, as opposed to using job titles or self-reported exposure; the measurement of EMFs at the workplace; and the similarity of the two study groups for factors other than VDT use.

Our findings are similar to those reported in previous studies [Ericson et al., 1986a,b; McDonald et al., 1988; Nurminen et al., 1988; Windham et al., 1990; Nielsen et al., 1992; Parazzini et al., 1993; Bracken et al., 1995]. Exposure to ELF (45–60-Hz) and VLF (15-kHz) electromagnetic fields produced by VDTs was not associated with low birthweight, preterm birth, birth defects, and perinatal death. The lack of an association suggests that exposure to EMFs produced by VDTs was too low to cause the outcomes studied but does not imply a lack of association between all EMF exposures and adverse reproductive outcomes. We conclude that in this study, the occupational use of VDTs was not associated with reduced birthweight or preterm birth.

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VIDEO DISPLAY TERMINALS AND THE RISK OF SPONTANEOUS ABORTION

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Abstract *Background.* The relation between spontaneous abortion and the use of video display terminals (VDTs) is of great public health concern. Previous investigators of this issue have reported inconsistent findings.

Methods. To determine whether electromagnetic fields emitted by VDTs are associated with an increased risk of spontaneous abortion, a cohort of female telephone operators who used VDTs at work was compared with a cohort of operators who did not use VDTs. To obtain reliable estimates of exposure, we determined the number of hours of VDT use per week from company records and measured electromagnetic fields at VDT workstations and, for purposes of comparison, at workstations without VDTs. Operators who used VDTs had higher abdominal exposure to very-low-frequency (15 kHz) electromagnetic fields (workstations without VDTs did not emit very-low-frequency energy). Abdominal exposure to extremely-low-frequency fields (45 to 60 Hz) was similar for both operators who used VDTs and those who did not. Among 2430 women interviewed, there were 882 pregnancies that met our criteria for inclusion in the study.

Results. We found no excess risk of spontaneous abortion among women who used VDTs during the first trimester of pregnancy (odds ratio = 0.93; 95 percent confidence interval, 0.63 to 1.38), and no dose–response relation was apparent when we examined the women's hours of VDT use per week (odds ratio for 1 to 25 hours per week = 1.04; 95 percent confidence interval, 0.61 to 1.79; odds ratio for >25 hours per week = 1.00; 95 percent confidence interval, 0.61 to 1.64). There continued to be no risk associated with the use of VDTs when we accounted for multiple pregnancies, conducted separate analyses of early abortion, late abortion, and all fetal losses, or limited our analyses to spontaneous abortions for which a physician was consulted.

Conclusions. The use of VDTs and exposure to the accompanying electromagnetic fields were not associated with an increased risk of spontaneous abortion in this study. (N Engl J Med 1991; 324:727-33.)

CONCERN about the potential reproductive effects of using video display terminals (VDTs) was first raised in 1980, when adverse pregnancy outcomes among several clusters of women who used VDTs were reported.[1-5] Most subsequent epidemiologic analyses of the use of VDTs and pregnancy outcome had equivocal results or found no effect.[6-14] Two studies found a significantly increased risk of spontaneous abortion among women who used VDTs more than 15 hours[15] or more than 20 hours[16] per week. Only a few studies were initially designed to investigate the effects of VDTs on reproduction.[11-13] All the studies estimated the extent of VDT use on the basis of responses to interview questions[11-16] or data on job titles.[6-10,14,15] None measured the electromagnetic fields produced by the VDTs.

A VDT containing a cathode-ray tube to generate a visual display emits both extremely-low-frequency (approximately 45 to 60 Hz) and very-low-frequency (approximately 15 kHz) electromagnetic fields. Extremely-low-frequency fields have been found to be associated with spontaneous abortion in two studies that showed a seasonal pattern of abortions in families with electrically heated beds[17] or ceiling-cable electric heat.[18] Studies of the relation of very-low-frequency electromagnetic fields and spontaneous abortion in humans have been limited primarily to studies of the effects of VDTs.[6-16]

In this study we examined the hypothesis that electromagnetic energy produced by VDTs might cause spontaneous abortions. By selecting two groups of full-time female telephone operators with similar work situations, we intended to minimize any potential ef-

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fect of physical and psychological stress. We obtained data on VDT use from the employers' personnel records and measured electromagnetic fields at a sample of the operators' workstations.

METHODS

Study Population

The study population consisted of women employed as directory-assistance operators and general telephone operators (reached by dialing zero) at two companies in eight southeastern states. The directory-assistance operators used VDTs to provide telephone numbers to customers, whereas the comparison group of general operators primarily assisted customers in placing long-distance calls. The general operators used units containing a light-emitting diode or neon glow tube to display the numbers, rather than a VDT. Typically, both directory-assistance and general operators worked an 8½-hour day, which included 1 hour for lunch and two 15-minute breaks. Both groups of operators sat in front of their equipment for the entire workday. A computer automatically routed incoming calls to the next available operator, so the time between calls was usually less than a second. Both groups of operators were monitored by a supervisor and by a computer that recorded the number and length of calls. During the study period, 50 directory-assistance offices and approximately 36 general-operator offices were in operation at the two companies. Education and salary levels were similar for both directory-assistance–operator and general-operator positions. Although there may have been some differences in work practices between the two groups, we did not observe any. The primary difference was the presence or absence of the VDT.

Recruitment and Interviews of Study Subjects

To maximize the number of pregnancies in the study population, we set the following criteria: a woman was eligible for participation in the study if she was 18 to 33 years of age (born after June 30, 1953) and married at any time during the study period. In addition, a woman had to be employed full time at any time between January 1, 1983, and August 1, 1986, as a directory-assistance or general operator. We used employers' personnel records to identify women who met the eligibility criteria for age and employment. These women were then telephoned at home and asked to participate in the study. Because the personnel records did not include marital status, we screened out unmarried women during the interviews. A valid phone number was obtained by visiting the home if it could not be obtained from the telephone company or directory-assistance services.[19] The study was described to both the interviewers and the potential participants as a study of the outcomes of pregnancy among office workers. The 25-minute telephone interviews, conducted between July 1987 and August 1988, were used to obtain lifetime reproductive histories. For each pregnancy during the study period, information on the consumption of alcohol and cigarettes, use of medications and other treatments, and medical conditions was recorded.

Definition of a Study Pregnancy

Only pregnancies that met the following criteria were included in the study: the pregnancy resulted in a live birth, stillbirth (fetal loss after 28 weeks' gestation), or spontaneous abortion (fetal loss at 28 weeks' gestation or earlier); the operator was employed for at least one day as a directory-assistance operator or general operator during the first 28 weeks of pregnancy; the pregnancy ended between January 1, 1983, and December 31, 1986, for spontaneous abortions, or between May 1, 1983, and December 31, 1986, for live births and stillbirths. The latest date for live births and stillbirths eligible for inclusion in the study had originally been set at April 30, 1987. After December 1986, however, VDTs began to be introduced into the general operators' workstations. Since after this date general operators would have been exposed to VDTs, only pregnancies that ended on or before December 31, 1986, were included in our analyses.

The date of the last menstrual period, obtained during the interview, was considered the beginning date of each pregnancy. The pregnancies of two women who reported using an intrauterine device at the time of conception were excluded from analyses because of the high rate of spontaneous abortion among women who become pregnant while using this method of contraception.

Validation of Data on Spontaneous Abortions

To identify possible recall differences in subject-reported data on outcome, we collected state vital records on each live birth reported during the study period. We then compared the number of previous terminations reported on the birth certificate with the number reported in the interview. In addition, we asked each woman if she had consulted a physician regarding the spontaneous abortion and conducted a separate analysis including only data on spontaneous abortions reported to a physician.

Definition of VDT Use

Directory-assistance operators used VDTs exclusively and had no other duties, whereas general operators used units containing a light-emitting diode or neon glow tube exclusively and had no other duties. Thus, company records on dates of employment as a directory-assistance or general operator could be used to ascertain the women's use of VDTs. We used personnel records and interview data on dates of pregnancy to determine whether the women had used a VDT during each pregnancy (exposure status).

We defined VDT use in two ways. First, we defined VDT use as a dichotomous variable (yes or no). If the woman had worked as a directory-assistance operator at any time during the first trimester (defined as the first 13 weeks of pregnancy), a pregnancy was classified as exposed. If the woman had worked only as a general operator during the first trimester, a pregnancy was classified as unexposed. Second, to examine the possibility of a dose–response relation, we used weekly payroll records to calculate the hours of VDT use during each study pregnancy. From payroll records, we calculated each woman's actual hours of work with a VDT during her pregnancy. Information on actual hours worked was crucial, because the total number of hours a woman worked with a VDT depended on the stage of her pregnancy when she was hired, the timing of vacations, the amount of sick leave used, and the number of hours worked in a given day. For pregnancies during which the woman worked as a directory-assistance operator, we constructed two indexes of continuous exposure. For the first index, we calculated the woman's hours of VDT use per week in the first trimester, the period of greatest risk for spontaneous abortion, as follows:

$$\text{hours of VDT use per week} = \frac{\text{hours of VDT use during first trimester}}{\text{hours of pregnancy during first trimester}} \times 168 \text{ hours per week.}$$

For the second index, we calculated each woman's hours of VDT use per week during the first 28 weeks of gestation (the entire period of risk for a spontaneous abortion in our study). For both indexes, a pregnancy that terminated early had fewer hours of VDT use (numerator), as well as a smaller denominator. Pregnancies during which the mother worked only as a general operator during the first trimester or the first 28 weeks were assigned zero hours per week of VDT use.

Statistical Analysis

We defined the rate of spontaneous abortion as the number of reported spontaneous abortions divided by the total number of reported spontaneous abortions plus reported live births. Multiple logistic-regression analysis[20] was used to assess the effect of VDT use on the incidence of spontaneous abortion while controlling for the effects of other variables.[19] All potential confounders were examined for interaction with exposure to a VDT. We performed separate analyses for early spontaneous abortion (≤8 weeks' gestation) and late spontaneous abortion (9 to 28 weeks). In addition, analyses were performed that included stillbirths and excluded spontaneous abortions not reported to a physician.

A problem with the analysis of studies of pregnancy outcome is that the outcomes of several pregnancies in the same woman are not independent events. To address the problem of correlated out-

comes, we performed additional analyses for each measure of VDT exposure, as proposed by Zeger and Liang.[21] In these analyses, a class of generalized estimating equations is used that takes into account the correlation of pregnancy outcomes for the same woman and adjusts odds ratios and their corresponding standard errors.

Measurements of Electromagnetic Fields

Only two models of VDT were used by the directory-assistance operators during the study period: International Business Machines (IBM) model 4978 and Computer Controls, Inc. (CCI), model 4500. In 1990, we visited 8 of the 50 directory-assistance offices and measured electromagnetic fields at 6 randomly selected VDTs at each site, for a total of 48 VDTs (24 IBM and 24 CCI).

Only a single model of light-emitting diode and a single model of neon glow tube, both made by Western Electric, were used by the comparison population of general operators. After December 1986, the end of the study period, VDTs were introduced into the general-operator offices. Therefore, in 1990, when we measured the fields emitted by the light-emitting diodes and neon glow tubes, we disabled all VDTs in the offices, so that only emissions from the light-emitting diodes and neon glow tubes were measured. Twenty-four light-emitting-diode and 24 neon-glow-tube units were randomly selected for measurement at two sites.[19]

A VDT containing a cathode-ray tube can produce several types of electromagnetic energy, including x-rays and electric and magnetic fields at both extremely low and very low frequencies. To detect x-ray emissions, an x-ray monitor (Stoms meter) was slowly passed over every accessible surface of VDT and non-VDT units. Several background measurements were made at each office. The electric fields and magnetic fields in the very-low-frequency and extremely-low-frequency bands were measured with two field-strength meters (Holaday Industries models HI 3600-01 and HI 3600-02). With the operator absent, the very-low-frequency and extremely-low-frequency emissions were measured at a distance of 30 cm from each side of the unit. While the operator was seated at her terminal, exposure measurements were taken at her face, chest, and abdomen. Detailed measurements of very-low-frequency and extremely-low-frequency emissions were made at one of the six units at each site. These measurements included the spatial variation of the strength of the electric and magnetic fields between 10 cm and 100 cm from the screen and the rate of change in the very-low-frequency magnetic-flux density per unit of time (dB/dt).[22] Geometric means and geometric standard deviations were calculated for data on emissions and exposure for all VDTs, light-emitting diodes, and neon-glow-tube units.

Results

Of 5544 subjects identified from company records, we could not contact 19.3 percent (Table 1). Of the 4475 women contacted, 4246 (94.9 percent) agreed to participate (76.6 percent of the women initially identified). Both groups of operators had similar rates of participation. Of the 4246 women who agreed to participate, 2430 were married during the study period and were interviewed in detail.

Of the women we interviewed, 730 had one or more pregnancies that met our criteria for inclusion ("eligible pregnancies"). The two groups of operators were similar in mean age, mean lifetime number of pregnancies, race, education, percentage currently employed at a company included in the study, and mean years employed by a company included in the study (Table 2). The proportion of Hispanic women was higher among general operators. The 730 women in the study had 882 eligible pregnancies, which included 16 pregnancies with twins. The proportions of live births, spontaneous abortions, and stillbirths were similar for directory-assistance and general operators

Table 1. Response Rate of Potential Study Participants, According to Job Category.*

Category	Directory-Assistance Operators	General Operators	All Operators
		number (percent)	
Agreed to participate	2118 (78.3)	2128 (75.0)	4246 (76.6)
Unable to contact	483 (17.9)	586 (20.6)	1069 (19.3)
Ineligible	21 (0.8)	24 (0.8)	45 (0.8)
Declined	83 (3.1)	101 (3.6)	184 (3.3)
Total	2705	2839	5544

*Directory-assistance operators used VDTs in their work, whereas general operators did not. Because of rounding, percentages may not total 100.

(Table 3). The overall crude rates of spontaneous abortion for all reported pregnancies were 14.8 percent for VDT-exposed pregnancies and 15.9 percent for unexposed pregnancies. In both groups, the rate of reported spontaneous abortion was highest during the second and third months of gestation (Fig. 1).

The rate of spontaneous abortion for pregnancies during which the mother had 1 to 25 hours of VDT use per week in the first trimester was slightly but not significantly higher than that for women with no hours of use per week (17.2 vs. 15.6 percent) (Table 4). The rate of spontaneous abortion for women with more than 25 hours of VDT use per week was similar to that for women with no hours of use per week (15.4 vs. 15.6 percent). A similar pattern was observed when we analyzed hours of VDT use during the first 28 weeks of gestation.

The final multiple logistic-regression model included the dichotomous VDT-exposure variable, spontaneous abortion before the study period, cigarette smoking, thyroid disorder, and alcohol consumption (Table 4). The analysis showed no association between VDT use in the first trimester and spontaneous abortion (odds ratio = 0.93; 95 percent confidence interval, 0.63 to 1.38). When we substituted the other two VDT-exposure variables (hours of VDT use per week in the first trimester and in the first 28 weeks) in the model, we continued to find no increased risk with VDT use (Table 4). These results did not change

Table 2. Characteristics of Study Participants, According to Job Category.*

Characteristic	Directory-Assistance Operators (N = 323)	General Operators (N = 407)
Mean age†	29.6	29.6
Mean lifetime no. of pregnancies	2.6	2.6
Mean duration of work at study company (yr)	8.2	7.7
Currently employed at study company (%)†	50.8	57.0
White (%)	71.5	68.3
Hispanic (%)	2.8	8.6
More than a high-school education (%)	28.9	35.3

*Directory-assistance operators used VDTs in their work, whereas general operators did not. For eligibility criteria, see Methods.

†As of July 1, 1987.

when the hours of VDT use per week were modeled as a continuous variable.

Only 17.1 percent of the women (n = 125) had more than one pregnancy during the study. The maximal number of pregnancies during the study was four (for six women). Adjustment for multiple pregnancies with the correlated-outcome method of Zeger and Liang[21] did not significantly affect the coefficients in our final models (odds ratio for VDT exposure as a dichotomous variable = 0.94; 95 percent confidence interval, 0.61 to 1.44).

Logistic-regression analyses of data for early and late spontaneous abortion showed no effect of VDT use. The odds ratios were 0.84 (95 percent confidence interval, 0.51 to 1.38) for early spontaneous abortion and 1.05 (95 percent confidence interval, 0.58 to 1.88) for late spontaneous abortion. When all fetal losses, including the nine stillbirths that occurred after 28 weeks' gestation, were included in the model, there was a negligible change in the odds ratio for VDT use (odds ratio = 0.99; 95 percent confidence interval, 0.68 to 1.44). When we eliminated the 10 spontaneous abortions that were not reported to a physician, we found only a minimal change in the odds ratio (odds ratio = 0.90; 95 percent confidence interval, 0.61 to 1.35).

Although our analyses demonstrated no significant association between the use of VDTs and spontaneous abortion, we found that several other factors were associated with an altered risk of spontaneous abortion, notably a history of spontaneous abortion, consumption of more than eight alcoholic drinks per month, smoking more than 20 cigarettes a day, and the presence of a thyroid disorder (Table 4). The coefficients for these factors did not vary substantially when we substituted different VDT-use variables in the model. The exclusion of these factors individually or in combination did not change the relation between VDT use and spontaneous abortion.

None of the measurements of x-ray emissions from the VDT and non-VDT units differed from background levels. The VDTs in this study emitted extremely-low-frequency electromagnetic energy at 45 Hz (the CCI units) and 60 Hz (the IBM units) and very-low-frequency energy in the range of 15 kHz. Geometric means for very-low-frequency emissions from the front of the VDTs and for abdominal exposure were statistically higher for the VDTs than for the non-VDT units ($P<0.05$) (Table 5). The neon-glow-tube and light-emitting-diode displays do not produce very-low-frequency fields above background levels. The rate of change in the magnetic-flux density of the very-low-frequency fields for the VDT units ranged between 9.0 and 38.0 mT per second. Although the mean extremely-low-frequency emissions were significantly higher for VDT units than for non-VDT units, there was substantial overlap in individual measurements of operator exposure. The measurements of spatial variation in the extremely-low-frequency range showed that the electrical environment in the room contributed to the operators' exposure.[22] Because mean values for very-low-frequency and extremely-low-frequency emissions at the CCI terminals were, in some cases, higher than the values at the IBM terminals, we conducted an additional analysis that included separate exposure variables for pregnancies during which the women used CCI or IBM terminals. This analysis showed no difference in the risk of spontaneous abortion between women using a CCI unit (odds ratio = 0.92; 95 percent confidence interval, 0.58 to 1.47) and those using an IBM unit (odds ratio = 0.98; 95 percent confidence interval, 0.58 to 1.64).

Table 3. Outcome of Eligible Pregnancies, According to Job Category.*

Outcome	Directory-Assistance Operators	General Operators	All Operators
	number (percent)		
Live birth	307 (83.9)	430 (83.3)	737 (83.6)
Stillbirth	5 (1.4)	4 (0.8)	9 (1.0)
Spontaneous abortion	54 (14.8)	82 (15.9)	136 (15.4)
Total	366	516	882

*Directory-assistance operators used VDTs in their work, whereas general operators did not. For a definition of pregnancies included in the study, see Methods. Because of rounding, percentages may not total 100.

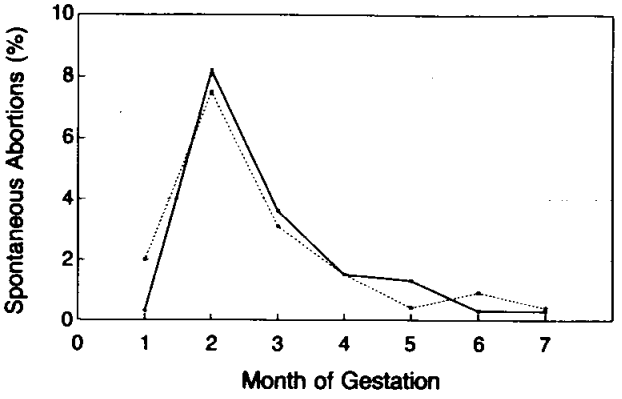

Figure 1. Rate of Spontaneous Abortion According to Month of Gestation and VDT Use.

The denominator for each month of gestation was obtained by subtracting the number of spontaneous abortions in the previous period from the previous denominator. The solid line represents pregnancies during which the woman used a VDT (exposed pregnancies), and the dotted line pregnancies during which the woman did not use a VDT (unexposed pregnancies).

Discussion

In this study we found no increase in the risk of spontaneous abortion associated with the occupational use of VDTs. We did not observe an increased risk associated with three different measures of VDT use or with the VDT model used, after adjusting for confounders, or after accounting for more than one pregnancy in the same woman. Separate analyses of early spontaneous abortion, late spontaneous abortion, all fetal loss, and spontaneous abortions reported to a physician also failed to identify an increased risk of spontaneous abortion associated with VDT use. Al-

Table 4. Unadjusted Rates of Spontaneous Abortion and Adjusted Odds Ratios for Occupational VDT Use and Other Variables in the Final Logistic Model.*

Variable	No. of Pregnancies	Spontaneous Abortion Rate (95% CI)	Odds Ratio (95% CI)	P Value
		%		
Spontaneous abortion before study period				
No	709	12.8 (10.3–15.3)	1.0	
Yes	167	25.7 (19.1–32.3)	1.64 (0.98–2.77)	0.06
No. of alcoholic drinks/mo				
None	716	16.6 (13.9–19.3)	1.0	
1–8	143	4.9 (1.4–8.4)	0.22 (0.10–0.49)	<0.01
>8	17	47.1 (23.4–70.8)	2.81 (0.99–8.04)	0.05
Cigarettes smoked/day				
None	671	14.2 (11.6–16.8)	1.0	
1–19	144	14.6 (8.8–20.4)	1.09 (0.64–1.84)	0.76
≥20	61	29.5 (18.1–40.9)	2.89 (1.50–5.56)	<0.01
Thyroid disorder (diagnosed during or before first trimester)				
No	853	14.8 (12.4–17.2)	1.0	
Yes	23	34.8 (15.3–54.3)	2.75 (1.09–6.94)	0.03
VDT use in first trimester				
No	510	15.7 (12.5–18.9)	1.0	
Yes	366	14.8 (11.2–18.4)	0.93 (0.63–1.38)	0.73
Other VDT-exposure variables†				
VDT use in first trimester (hr/wk)				
None	499	15.6 (12.4–18.8)	1.0	
1–25	128	17.2 (10.7–23.7)	1.04 (0.61–1.79)	0.88
>25	169	15.4 (10.0–20.8)	1.00 (0.61–1.64)	0.99
VDT use in first 28 wk (hr/wk)				
None	494	15.8 (12.6–19.0)	1.0	
1–25	119	18.5 (11.5–25.5)	1.18 (0.69–2.04)	0.54
>25	179	14.5 (9.3–19.7)	0.90 (0.55–1.47)	0.67

*Odds ratios compare the odds of spontaneous abortion for a pregnancy with the specified risk factor with the odds for a pregnancy without that risk factor. Each odds ratio is adjusted for all the other risk factors in the model. CI denotes confidence interval. P values are for the comparison between pregnancies in each category and the reference group (odds ratio = 1.00).

†When these VDT-exposure variables were substituted in the model, confounder coefficients did not vary substantially and the relation between VDT use and spontaneous abortion remained unchanged. Because of missing data, the total number of pregnancies varied in each analysis.

though the upper confidence limit on the odds ratio (1.39) cannot exclude a moderate positive association, there were no other indications of a causal association, such as a trend toward increased risk with increasing hours of VDT use. The overall rates of spontaneous abortion among the VDT users (14.8 percent) and among those who did not use VDTs (15.9 percent) were within the range in published data (11 to 20 percent).[23] Although we found no association between VDT use and spontaneous abortion, we did find significant associations with spontaneous abortion for three previously reported risk factors: heavy alcohol consumption, cigarette smoking, and the presence of a thyroid disorder.[23-26]

Because information on the outcomes of pregnancy was reported by the women themselves, there was a possibility of differences in recall between the two groups. The 2430 women we interviewed reported a total of 203 spontaneous abortions between 1983 and 1986. The women who reported 77 (38 percent) of these spontaneous abortions had subsequent live births, which provided us with the opportunity to confirm previous spontaneous abortions from information recorded on birth certificates. We found that 89 percent (49 of 55) of the spontaneous abortions reported by general operators and 86 percent (19 of 22) of the spontaneous abortions reported by directory-assistance operators were recorded in subsequent vital records. We discovered only one spontaneous abortion that had not been reported in the interview. Although we were able to review only spontaneous abortions that were followed by live births (38 percent of all spontaneous abortions), the consistent findings in both the exposed group and the comparison group argue against differences in the recall of spontaneous abortions as a logical explanation for our negative findings.

Differences in the rate or timing of induced abortions between the exposed and the comparison group are unlikely explanations for our negative findings. We identified all reported induced abortions among directory-assistance or general operators during the study period. The rates of induced abortion in VDT-exposed pregnancies (4.8 percent) and unexposed pregnancies (5.3 percent) were similar, as was the gestational age at the time of the induced abortion (mean number of weeks at abortion, 9.6 and 7.9, respectively).

Since the ascertainment period for live births and stillbirths (May 1, 1983, through December 31, 1986) differed slightly from that for spontaneous abortions (January 1, 1983, through December 1, 1986), our study contained proportionally fewer full-term pregnancies during the later months of 1986. If the

Table 5. Geometric Mean (GM) and Standard Deviation (GSD) of Measurements of Electromagnetic Fields.*

Type of Unit	Very Low Frequency		Extremely Low Frequency	
	E field (V/m)	H field (mA/m)	E field (V/m)	H field (mA/m)
	GM (GSD)			
Frontal emissions (operator absent)				
VDT				
CCI	4.2 (1.54)†	98.9 (2.61)†	1.9 (1.63)†	313.6 (1.22)†
IBM	3.3 (2.07)†	22.1 (4.68)†	1.8 (1.93)†	236.1 (2.14)†
Non-VDT				
LED	0.1 (1.16)	1.6 (1.01)	0.4 (1.10)	72.3 (1.68)
NGT	0.1 (2.05)	1.4 (1.04)	0.5 (1.40)	30.3 (1.72)
Abdominal exposure (operator present)				
VDT				
CCI	0.5 (1.68)†	17.4 (1.74)†	0.8 (3.61)†	62.3 (1.59)
IBM	0.1 (1.71)†	4.0 (1.85)†	0.4 (1.70)†	57.7 (2.12)
Non-VDT				
LED	0.1 (1.35)	2.0 (1.15)	0.4 (1.18)	62.4 (2.79)
NGT	0.2 (1.64)	1.6 (1.00)	0.4 (1.92)	32.4 (2.01)

*E denotes electric, H magnetic, CCI Computer Controls, Inc., and IBM International Business Machines. For details, see Methods. Non-VDT units were units with light-emitting diodes (LED) or neon glow tubes (NGT).

†P<0.05 for the comparison of VDT units (IBM and CCI units combined) with non-VDT units (LED and NGT units combined).

two groups of operators had a different number of pregnancies during the later months of 1986, the number of spontaneous abortions in one group could have been artificially increased. To examine this possibility, we reanalyzed the data after eliminating the 11 spontaneous abortions that occurred after April 30, 1986, and found no increased risk (odds ratio = 0.86; 95 percent confidence interval, 0.57 to 1.30).

Differences in VDT use outside the workplace are not a likely explanation for our findings. We examined data from the interviews on home VDT use and found that only 1.9 percent of the VDT-exposed pregnancies and 2.2 percent of the unexposed pregnancies involved VDT exposure at home.

When we compared payroll records with data on VDT use from the interviews, we found that approximately 52 percent of general operators who did not use a VDT while pregnant reported such use in the interview. Only 4 percent of directory-assistance operators who used a VDT while pregnant reported no use. A likely reason for this overreporting by the general operators is that they may have mistakenly referred to the light-emitting-diode or neon-glow-tube equipment as a VDT in the interview. If this is the reason for the overreporting, studies of different populations might have fewer errors in reported VDT use than documented here. However, the discrepancy between reported and record-based VDT use indicates that the accuracy of self-reported data may vary. When we analyzed the data according to women's reports of VDT use, we still observed no effect on the rate of spontaneous abortion (odds ratio = 0.85; 95 percent confidence interval, 0.56 to 1.29).

Elements of the study design did not allow us to address certain other questions directly. First, we could not assess whether early (subclinical) fetal loss might be affected by VDT use. The data shown in Figure 1, however, suggest that the incidence of the earliest recognized losses was similar for the exposed and unexposed pregnancies. Second, we could not assess effects of VDT use on older or unmarried women, since our study was limited to married women from 18 to 33 years of age. Such women make up the majority of pregnant women in the United States. Third, we studied a population that used only two models of VDT; the electromagnetic fields produced by the VDTs in our study were similar to those reported for other VDTs, however.[27-29] Finally, we selected the directory-assistance and general operators because of the similar levels of physical and psychological stress in their jobs. Therefore, this study could not address the association between spontaneous abortion and physical or psychological stress — two factors that may accompany the use of VDTs.

Although concern has been expressed that VDTs may produce harmful levels of electromagnetic energy, our research found that VDT operators had abdominal exposure to extremely-low-frequency fields (45 to 60 Hz) in the same range as exposures in the home. Studies of exposure to extremely-low-frequency electromagnetic fields have found average exposures to magnetic fields in the home between 40 and 200 mA per meter,[30-32] and average electric-field exposures of 2.5 V per meter.[32] Although VDT operators were exposed to very-low-frequency fields (in the range of 15 kHz), light-emitting-diode or neon-glow-tube units used by the general operators produced no measurable emissions in this range.

The strengths of this study include the similarity of the VDT-user group and the comparison group, the use of record-based data on the extent of VDT use during each pregnancy, and the direct measurement of electromagnetic fields. When we examined our data for potential biases, we found none that were likely to have substantively influenced the results. We conclude that in this study, the use of VDTs and exposure to the electromagnetic fields they produce were not associated with an increased risk of spontaneous abortion.

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