Seasonal Factors and Birth Weight:

New Evidence From the Southern Hemisphere

By

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University of Manitoba

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

Master of Arts

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Abstract

Birth weight has implications for multiple psychological and physical conditions throughout life. Birth weight is known to be affected by many factors, such as gestational age, maternal nutrition, cigarette smoking, hormones, and maternal height, weight, age, and parity. An additional intriguing correlate of birth weight is season-of-birth. Existing research suggests that seasonality in birth weight from equatorial countries depends on food availability and maternal physical labor. North of the Tropic of Cancer (23.5°N), higher birth weights occur in the late winter and spring, and the most prevalent explanatory hypotheses concern the influences of temperature or day length. The seasonal pattern would be expected to be offset by six months in the Southern Hemisphere, but only one study was found from south of the Tropic of Capricorn (23.5°S). Thus, in this study, time series analyses of a 20-year, million-birth New Zealand sample tested the hypothesis that heavier birth weights will occur in the spring. The results support hypotheses that seasonally varying factors, such as temperature and day length, affect fetal growth during the gestational period, resulting in seasonal birth weight differences.

Acknowledgments

First, I would like to thank my adviser, Dr. Warren Eaton, for giving me the opportunity to develop this thesis and for providing excellent guidance; Dr. A. Thavaneswaran, for teaching me time series analysis and answering many questions; and Dr. Lorna Jakobson, for offering necessary information and interesting suggestions for studying low birth weight and pre-term infants. I would also like to thank Darren Campbell and Dr. Nancy McKeen for offering many good suggestions, for asking me to teach them time series analysis, and for pointing out the very interesting Murray et al. (2000) article; Dr. Liam Murray, from The Queen's University of Belfast, for the additional information he provided me regarding his study; John Grivell for first telling me about the time series course taught by Dr. Thavaneswaran; and Statistics New Zealand for providing the data. Finally, I wish to thank Brian Bodnarchuk, who suggested toward the end of my writing process that I begin each additional sentence with “In conclusion...”

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Introduction

The study of birth weight may not seem relevant to the field of psychology at first glance. However, it is one of many early measurements that can indicate long-term consequences of prenatal development on psychological variables, such as cognitive abilities, temperament, and behavior. Cognitive abilities and birth weight often show a positive correlation in studies of low birth weight infants (infants weighing less than 2500 g), but a very recent study (Richards, Hardy, Kuh, & Wadsworth, 2001) reports that cognitive function is related to birth weight for the general population as well. Richards et al. (2001) report that a British cohort born in 1946 was tested on various cognitive abilities at 8, 11, 15, 26, and 43 years of age. At age 8 these individuals were tested on reading comprehension, word pronunciation, vocabulary, and non-verbal reasoning. At age 11 they were tested on verbal and non-verbal intelligence, arithmetic, word pronunciation, and vocabulary, and at age 15, on verbal and non-verbal intelligence, reading comprehension, and mathematics. The tests for adults at age 26 consisted of reading comprehension, and at age 43, of verbal memory and timed letter searches. At ages 8, 11, and 15 years a significant positive relationship existed between birth weight and cognitive abilities for all birth weight categories up to 4000 g. For individuals with birth weights above 4000 g (defined as high birth weight), cognitive scores declined with increasing birth weight. Similar results were found for 18-year-old Danish men who were tested on letter matrices, verbal analogies, number series, and geometric figures (Sørensen et al., 1997). Again, increased cognitive function was related to increased birth weight, this time up to 4200 g, after which point the correlation became slightly negative.

Later in adulthood, the relationship between birth weight and cognitive ability loses strength. Richards et al. (2001) reported that at age 26 the relationship was due mostly to the difference between low birth weight and normal birth weight infants, and at age 43 the relationship was not significant. However, individuals with lower test scores tended to suffer from attrition, and thus it is possible that when tested at 43 years of age, the sample consisted mostly of people with higher cognitive scores. It is also possible that in later life, environmental influences outweigh intrauterine growth in determining cognitive function. This is supported by a non-significant relationship between cognitive function and birth weight in a study of 50- to 70-year-old men and women born in the early twentieth century (Martyn, Gale, Sayer, & Fall, 1996).

In addition to cognitive abilities, birth weight differences have been linked to temperamental and behavioral differences in twin studies. Matheny and Brown (1971) compared two groups of twins: those with birth weight differences less than 113 g (0.25 lb), and those with differences greater than 680 g (1.5 lb). Behavioral differences were measured through interviews with the twins' mothers. The mothers were encouraged to compare their twins to each other and not to other children so that the differences between the twins were reflected in the interviews. The researchers found that the twins with more discordant birth weights showed more discordant behaviors. For example, in the group with larger birth weight differences, the lighter twin had more problems feeding, sleeping, and toilet training, but smiled more easily. The heavier twin had a longer attention span, vocalized better, was more sensitive, cried more, and adapted better to new situations. Whereas when the twins had more similar weights, the only significant differences were that the heavier infant was more sensitive and vocalized better. Another twin study compared only full-term (born after 37 weeks gestation) twins who differed in birth weight by at least 15%, and the difference in mean birth weights for the two groups was 722 g (Riese, 1994). This study compared the same types of behaviors as the Matheny and Brown (1971) study, and reported that the larger twin was more irritable, more active while awake, less responsive to visual and auditory stimuli, and less reinforcing to the examiner (e.g., less cuddly). Thus, these results show that the larger twin showed more "problem" behaviors, in contrast to Matheny and Brown's (1971) study where the smaller twin seemed to show more problem behaviors. Nonetheless, these studies do show that differences in birth weight have been associated with differences in temperament and behavior.

In addition to these psychological variables, birth weight may predict physical conditions, such as obesity, high blood pressure, and glucose intolerance, that develop in childhood, adolescence, or later in adulthood. It seems that higher birth weight shows a clear relationship to increased potential for adult obesity; however, it is not known how this relationship is influenced by parental weight, gestational age, or social class (Parsons, Power, Logan, & Summerbell, 1999; Phillips & Young, 2000). Lower birth weight has been linked to higher blood pressure in both children and adults (Law & Shiell, 1996). This finding was consistent across 34 studies and suggests that blood pressure may be affected by events *in utero*. Lower birth weight has also been linked to a higher prevalence of glucose intolerance (Phillips, 1998), which is associated with an increased susceptibility to acquiring diabetes mellitus. There is evidence that insulin resistance plays an important role for both low birth weight and diabetes (Phillips, 1998).

In contrast to the relatively few studies presented above, a majority of the studies analyzing birth weight's relationship to postnatal outcomes are studies of infants with extreme birth weights. Because the focus of the current study is on the whole range of birth weights, I will only very briefly mention information on the extreme birth weights. Low birth weight infants "are at a higher risk for developmental delay and physical complications, such as birth defects and death" (Cohen & MacWilliam, 1995, p. DS27), and low birth weight is one of the classic indicators of health status. At the other end of the scale, high birth weights are associated with maternal diabetes (e.g., Kieffer et al., 1998), developmental disturbances, and poor psychomotor development (e.g., Rizzo, Silverman, Metzger, & Cho, 1997; Silverman, Rizzo, Cho, & Metzger, 1998).

From the information presented above, it becomes evident that understanding what affects differences in birth weight may shed light on what affects differences in other areas of interest, both in psychological and medical research. The current study adds information to this important area, and next I present an overview of some literature on factors known to affect birth weight variability.

Factors Known to Affect Birth Weight

Birth weight is influenced by many factors, probably the most important of which is gestational age (Kramer, 1987; Matsuda, 1990; Roberts, 1976). Birth weight and gestational age are undeniably related, but assuming that a given gestational age predicts a certain birth weight is not always correct, especially when low birth weight or pre-term infants are considered. For example, a full-term gestation could produce a low birth weight, or small-for-gestational age, infant who suffered from intrauterine growth restriction. That infant would weigh less than an appropriate-for-gestational age infant also born at full-term (Herman, Yu, Hoffman, Krulewitch, & Bakketeig, 1993; Roberts, 1976; Thomson & Billewicz, 1976).

A second important influence on birth weight is maternal nutrition during pregnancy. A mother's diet must meet the constant demand that the fetus has for nutrients, and if she cannot maintain sufficient nutrition, the fetus may acquire permanent changes in body structure and metabolism, including a smaller size at birth (Godfrey & Barker, 2000; Fall et al., 1995). The demand for nutrients is greatest during the third trimester of pregnancy, when the fetal increase in weight is the fastest (Carlson, B. M., 1999; Vorherr, 1982). Incidentally, Mathews, Yudkin, and Neil (1999) and Vorherr (1982) argue that maternal nutrition does not have a large impact on birth weight in developed countries because malnutrition is uncommon.

Mathews et al. (1999) reported that maternal cigarette smoking and height both had more impact on birth weight than maternal nutrition. Mothers who quit smoking while pregnant increased the birth weight of their neonate by an average of 241 g in a study by Li, Windsor, Perkins, Goldenberg, & Lowe (1993). Maternal height, as well as maternal weight, shows a positive relationship with birth weight (Lawoyin, 1993; Roberts, 1976). Birth weight also shows a positive relationship with the number of children a woman has given birth to and with mothers' age, which are positively correlated (Lawoyin, 1993; Lawoyin & Oyediran, 1992). However, as Selvin and Janerich (1971) point out, when these effects are considered jointly, new information emerges. For the youngest mothers, higher parity usually does not mean higher birth weights; if a woman has her fourth child by the time she is 20 years old, that child will weigh less on average than her first child. At older maternal ages the positive correlation holds, and higher parity does mean higher birth weights. However, the first child born to a 40-year-old mother will weigh less on average than the first child born to a 20-year-old mother.

Hormones, both maternal and fetal, are another set of factors that have been investigated in relation to birth weight. Although hormonal pathways are complex and only partially understood, researchers believe that maternal growth hormone does not affect the fetus because it cannot cross the placenta (Challis, Robinson, Rurak, & Thorburn, 1976; Grumbach, 1966; Vorherr, 1982). Some also believe that maternal growth hormone-binding protein (GHBP) may be involved in processes that influence fetal growth. Elevated levels of GHBP have been found in pregnancies that resulted in low birth weight infants (Barnard, Chan, & McIntyre, 1997), and GHBP may interact with maternal glucose, insulin, and insulin-like growth factor-1 (IGF-1; Wang & Chard, 1992). Insulin and IGF-1 do seem to be the major growth-promoting factors for the fetus (Fall et al., 1995; Kovar & Harvey, 1981; Page, Villee, & Villee, 1972), and fetal growth hormone appears to play a much smaller role (Challis et al., 1976; Grumbach, 1966; Rosenfeld, Thorsson, & Hintz, 1979).

Although these factors are known to influence birth weight, a full understanding of the immensely complex process of fetal growth and development is incomplete. Fetal development is influenced by maternal genetic and environmental factors, but it also seems to be affected by less obvious factors. One such factor is the season in which an infant is born, which is the focus of this study.

Seasonal Patterns in Birth Weight

Seasonal patterns in birth weight have been reported since the mid-twentieth century. Perlstein and Levinson (1937) reported that summer-born infants tended to be slightly heavier than winter-born infants, but a lack of graphs or tables in the article meant additional information was not available. McDonald (1966) found seasonality in the birth weights of males, but not of females. Male infants born in September, October, and November had heavier birth weights than those born in March, April, and May. Birth weight data was presented in a table, but was not easily interpretable due to missing unit labels and unusual values (e.g., a mean birth weight of 113.84). McDonald (1966) suggested that one reason for the pattern in birth weight may be the "protein deficiencies and heat stress resulting from high summer temperatures and humidity" (p. 86).

More recent studies of birth weight also have hypotheses that center around environmental influences, such as temperature, rainfall, and sunlight. These environmental factors follow somewhat predictable seasonal patterns. Because seasons occur to different degrees in different parts of the world, my review of birth weight seasonality studies will be divided along seasonal lines, which where chosen based on the path of the sun. The sun is directly over the Tropic of Cancer (23.5°N) at the Northern Hemisphere's summer solstice in June, and directly over the Tropic of Capricorn (23.5°S) at the Southern Hemisphere's summer solstice in December. The sun moves between the Tropics of Cancer and Capricorn during the rest of the year (Rosenberg, 1999). Thus, the seasonality studies are grouped into those between the Tropics of Cancer and Capricorn, those north of the Tropic of Cancer, and those south of the Tropic of Capricorn.

Between the Tropics of Cancer and Capricorn. The studies of seasonality in birth weight from this region are summarized by Table 1 and Figure 1.

Table 1.

Summary Characteristics of Published Seasonality Studies from Countries Between the Tropics of Cancer and Capricorn

Country	Latitude[a]	*N*	Years	MBW[b]	Dry Season	Source
Hong Kong	21° N	43,141	1959-1962	3086	–	Roberts (1976)
Gambia	13° N	2,047	1989-1994	2860[c]	Nov–May	Ceesay et al. (1997)
Burkina Faso	12° N	1,841	1987-1989	2900	Jan–Jun	Wendl-Richter (1997)
Sierra Leone	8° N	3,725	1980-1981	3030	Nov–Apr	Aitken (1990)
Zaire	4° S	8,815	1972-1981	2720	May–Aug	Fallis & Hilditch (1989)
Tanzania	6° S	19,783	1985-1989	3020	Jun–Oct	Kinabo (1993)
Australia	19° S	4,508	1981-1993	3125[c]	Jul–Dec	Rousham & Gracey (1998)

[a] Latitude estimated from city nearest the specified regions of countries, or as latitude midpoints for whole countries (Kindred, 2001). [b] Mean birth weight. [c] Estimated from published figure.

From Figure 1 it is apparent that birth weights vary widely in these countries throughout the year, and that the patterns for the countries north of the equator are

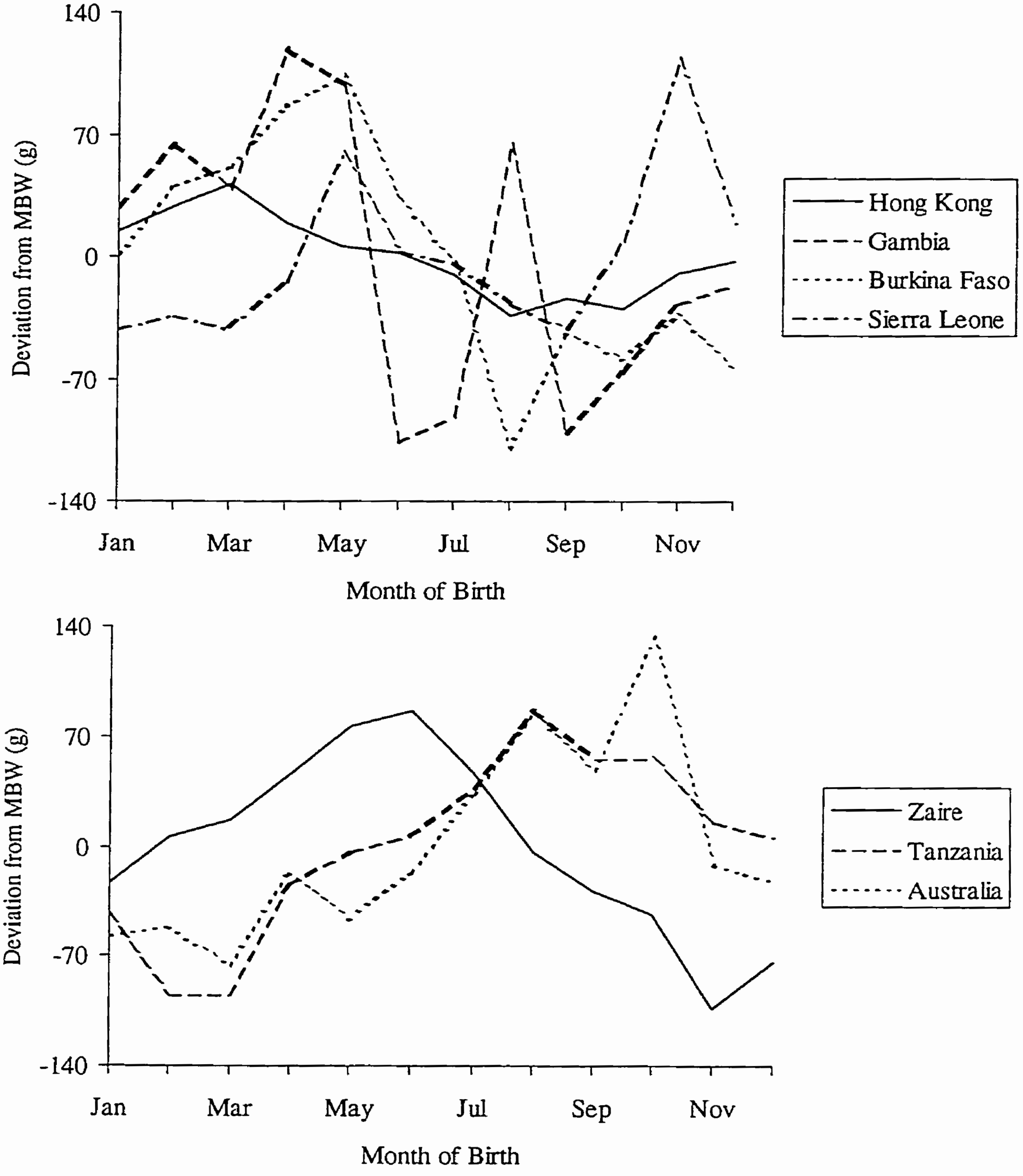


Figure 1. Deviation from yearly mean birth weight (MBW) for countries between the Tropics of Cancer and Capricorn. Hong Kong, Gambia, Burkina Faso, and Sierra Leone are north of the equator. Zaire, Tanzania, and Australia are south of the equator.

opposite of those south of the equator. During the wet seasons in these countries, events such as food shortages, physical work by the mothers, malarial infections, and poor drainage seem to cause lower birthweights. In contrast, during the dry seasons, adequate food is available, there is less work for the mothers, and birth weights are higher (Aitken, 1990; Ceesay et al., 1997; Fallis & Hilditch, 1989; Kinabo, 1993; Rousham & Gracey, 1998; Wendl-Richter, 1997). Roberts (1976) did not report the dry season for Hong Kong, but did mention reduced food intake and infections as possible causes of low birth weight. In addition, Roberts extensively analyzed meteorological variables, such as mean temperature and mean hours of sunshine, in relation to birth weight. Roberts may have been interested in these additional variables because Hong Kong is near the Tropic of Cancer, which as I mentioned before, is the line that indicates the beginning of four seasons. Studies done north of the Tropic of Cancer have investigated these variables as well.

North of the Tropic of Cancer. The studies of seasonality in birth weight from this region are summarized by Table 2 and Figure 2. It may be observed from Figure 2 that higher birth weights tend to occur in the late winter and early spring, and lower birth weights tend to occur in the late summer and early fall, but this pattern is not entirely consistent. It is worth noting that the country closest to the Tropic of Cancer has a pattern most like the equatorial countries reported in the previous section. Taiwanese mothers faced increased work during the harvesting seasons, had more food available during December to February, and gave birth to infants with widely varying birth weights from

Table 2.

Summary Characteristics of Published Seasonality Studies From Countries North of the Tropic of Cancer

Country	Latitude[a]	*N*	Years	MBW[b]	Source
Taiwan	25° N	450	1974-1980	3044	Adair & Pollitt (1983)
India	29° N	2979	1981-1982	2620	Lakshmi & Bandyopadhyay (1987)
Japan	34° N	16,796,415	1974-1983	3200	Matsuda et al. (1993)
USA	40° N	1,508,797	1959-1967	3361	Selvin & Janerich (1971)
Canada	43° N	15,954	1979-1983	3285	Fallis & Hilditch (1989)
Ireland	54° N	418,817	1971-1986	3415	Murray et al. (2000)
Denmark[d]	55° N	1,166,206	1973-1994	3375[c]	Wohlfahrt et al. (1998)

[a] Latitude estimated from city nearest the specified regions of countries, or as latitude midpoints for whole countries (Kindred, 2001). [b] Mean birth weight. [c] Estimated from published figure. [d] Denmark was omitted from Figure 2 because birth weight data was not presented by month.

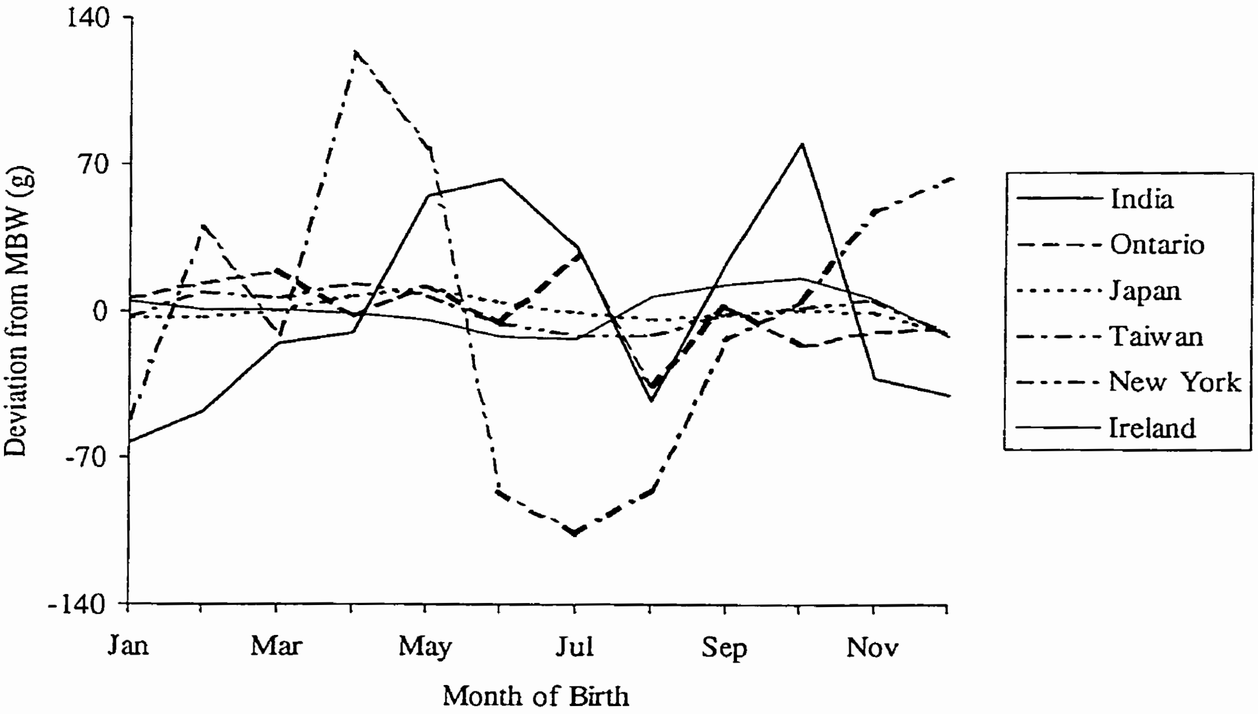


Figure 2. Deviation from yearly mean birth weight for countries north of the Tropic of Cancer.

season to season (Adair & Pollitt, 1983). The Indian study (Lakshmi & Bandyopadhyay, 1987) refers to differences in climate, without reference to differences in food and work, as the main reason for seasonal differences in birth weight. The Japanese authors (Matsuda, Sone, Doi, & Kahyo, 1993) give many potential reasons for the seasonality they found. They claim that the seasonality in birth weight could be due to seasonality in the gestational period, which may be affected by meteorological factors. The meteorological factor of day length may affect the circadian system and consequently, the timing of parturition, according to Matsuda et al. (1993). Or, they claim, seasonal variation in gestational period may be created by seasonal variation in the number of pre-term births. Selvin and Janerich (1971) concur that the differences are probably due to environmental factors operating during gestation, but do not speculate on causes. Fallis and Hilditch (1989) note that the seasonal pattern in Ontario is non-significant. The most recent study (Murray et al., 2000) again looked at the relation between birth weight and meteorological factors. Murray et al. (2000) report that colder winter temperatures during mid-gestation may be the reason for their finding that lower weight births occur in the spring. In addition, they suggest that a potential cause may be seasonality in vitamin C intake, which is a vitamin that has been shown to be significantly related to birth weight (Mathews et al., 1999). Murray et al. (2000) also mention infections, decreased physical activity, and increased second-hand smoke as potential reasons for decreased birth weights following winter pregnancies in the north. Finally, the authors from Denmark (Wohlfahrt, Melbye, Christens, Andersen, & Hjalgrim, 1998) agree with the Japanese authors that the seasonal variation could be due to seasonality in gestational period.

South of the Tropic of Capricorn. Here, the only study I found was a Spanish article from Chile, South America (Cruz-Coke & Navarro, 1970). The results from this study are shown in Figure 3. The Chilean study came from a hospital at 35°S latitude, had a total *N* of 14,458 from the years 1968 to 1969, and yielded a mean birth weight of 3175 g. It is not clear whether this seasonal pattern is typical or atypical for countries south of the Tropic of Capricorn.

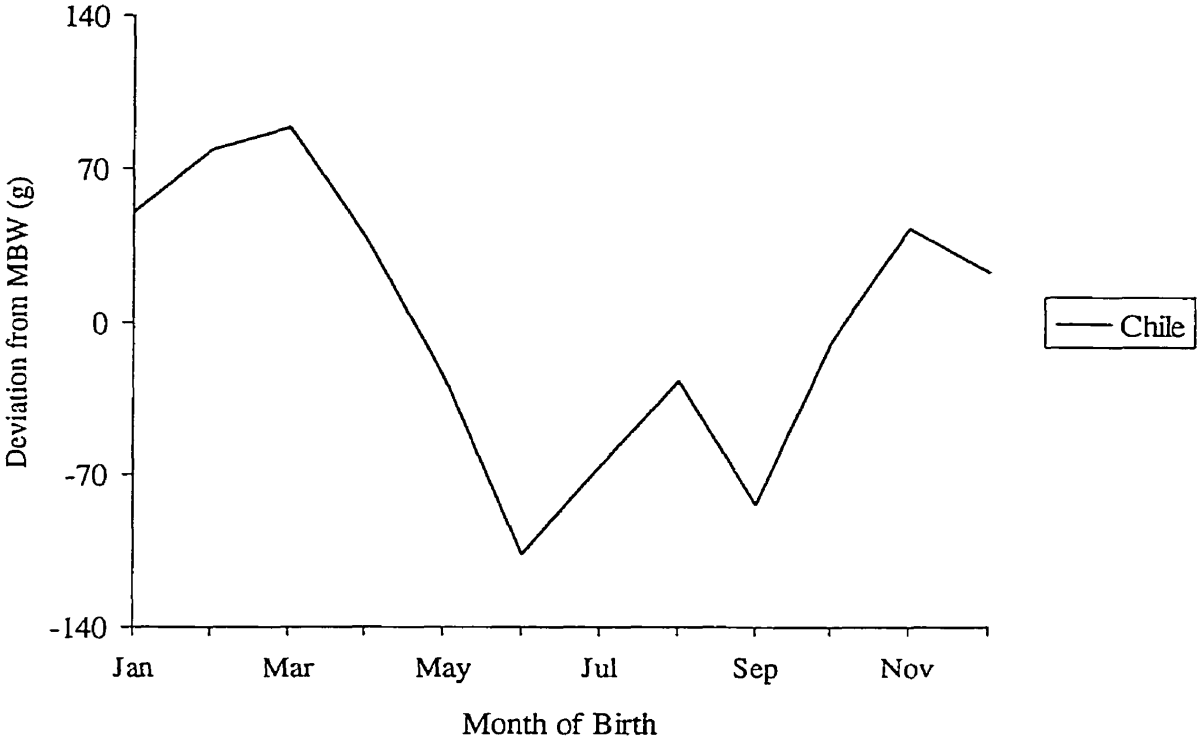


Figure 3. Deviation from yearly mean birth weight for Chile, which is south of the Tropic of Capricorn.

More Evidence From South of the Tropic of Capricorn

From Figures 1, 2, and 3 it is obvious that the southernmost region has far fewer studies than the other two regions of the world. Although the list of studies presented here is not exhaustive, I believe it is well representative of the studies that have been done, aside from a bias toward more recent studies. Therefore, if any hypotheses on seasonality are to be tested at a global level, the first step is to gain more evidence from south of the Tropic of Capricorn.

New Zealand is ideally situated to test the seasonality effect in the south. It is a long narrow country that spans from approximately 32°S to 46°S latitude. New Zealand is a developed country that, along with Australia, ranks second in the economic measure of per capita gross regional product to northern North America (United Nations, 1993). New Zealand has 3.8 million people living on a total land area of 268,021 square kilometers. For comparison, the population density is approximately five times that of Canada and half that of the United States. The ethnicity of the New Zealand population, according to the 1996 Census, is mostly European (79.6%), followed by New Zealand Mäori (14.5%), Pacific Islanders (5.6%), Chinese (2.2%), and Indian (1.2%). Life expectancy for males is 74 years, and for females is 80 years, which is similar to life expectancy in Canada where male life expectancy is 75 years and female life expectancy is 81 years (Statistics Canada, 2001; Statistics New Zealand, 2000).

Birth data from New Zealand may provide a strong test for the hypothesized seasonality. Based on the extremely large sample size and a very southernly location, the New Zealand data should show a seasonal pattern that is offset by six months from the pattern from studies in the north, particularly those with similar latitude, similar mean birth weight, and similar sample size (see Figure 4). Thus, if seasonal factors like temperature

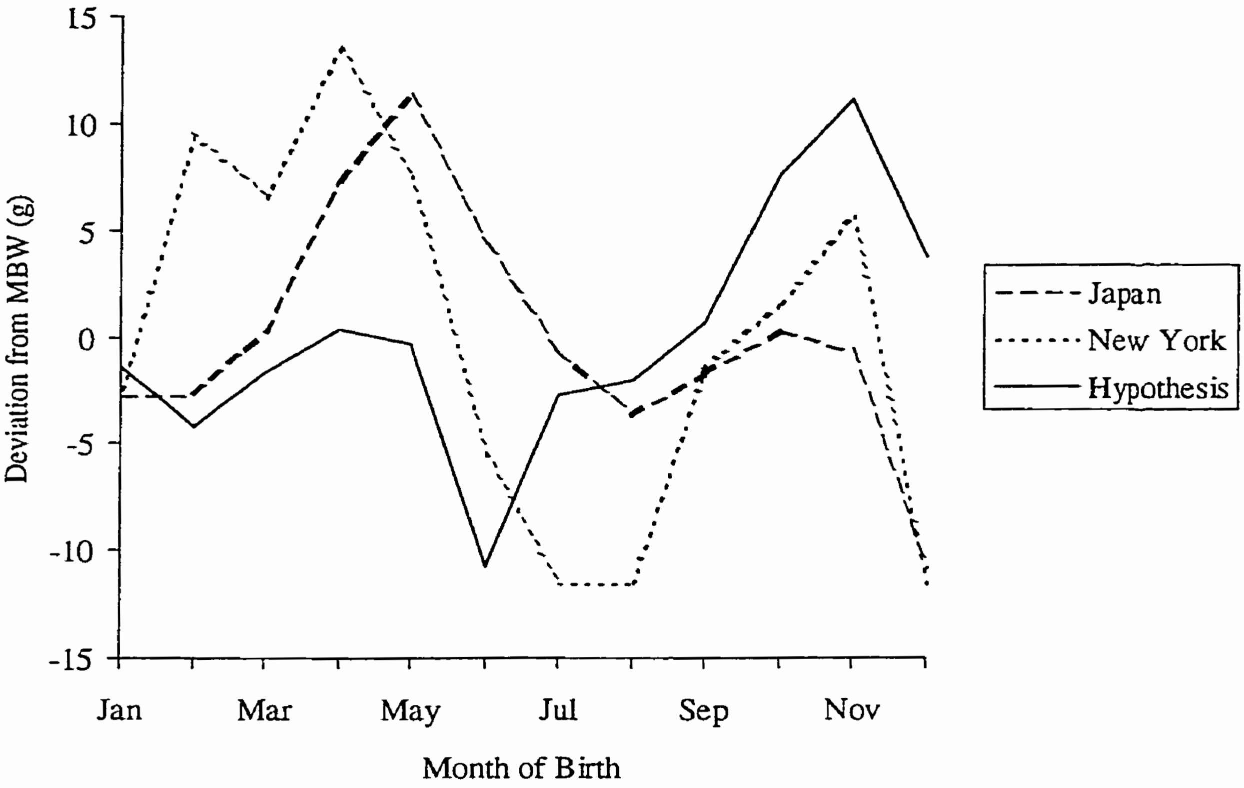


Figure 4. Deviation from yearly mean birth weight for Japan, New York, and the hypothesized seasonal pattern for New Zealand.

and day length affect birth weight, I hypothesize that heavier babies should be born around November and lighter babies born around June.

In addition, because other authors (Matsuda et al., 1993; Rousham & Gracey, 1998; Wohlfahrt, et al., 1998) have suggested that seasonality in birth weight may be due to seasonality in gestational age, the seasonal pattern in gestational age will also be assessed. I hypothesize that seasonality in gestational age, if present in New Zealand, should mimic the seasonal pattern in birth weight; that is, shorter gestations should accompany lower birth weights.

Method

Statistics New Zealand provided 1,078,754 birth records (51% male), comprising 99.9% of all live, singleton infants born in New Zealand between January 1980 and December 1999. The infants whose records are included in these data are defined by Statistics New Zealand's (2001) definition of "Live Birth":

> The birth of a child, who breaths or shows any other evidence of life, such as beating of the heart, pulsation of the umbilical cord or definite movement of voluntary muscles, whether or not the umbilical cord has been cut or the placenta is attached: each product of such a birth is considered live-born. All live-born infants should be registered and counted as such irrespective of gestation age or whether alive or dead at the time of registration, if they die at any time following birth they should also be registered and counted as deaths. (Glossary of Terms: Live Birth)

The birth records I obtained were grouped by birth weight, gestational age, gender, and birth month. Birth weight was separated into eleven 500 g intervals from the smallest, 1-499 g, to the largest, 5000+ g. Gestational age was categorized by the number of weeks between conception and birth (Statistics New Zealand, 2001). Gender and birth month were labeled with the expected "male" and "female," and the calendar months of January through December.

Statistics New Zealand maintains birth records by obtaining forms from two sources. First, when an infant is born, the hospital or midwife must send a form to the Registrar-General within five days. Second, the parents of the infant must send a different form to the government department responsible for births, deaths and marriages within two years. These two forms together include date of registration, date of birth, place of birth, birth weight, length of gestation, whether the birth was a multiple birth, and information about the parents. The completed infant files are supplied to Statistics New Zealand once a month. Statistics New Zealand then uses the information to maintain and publish birth statistics (Statistics New Zealand, 2001).

Statistics New Zealand provided a note with the birth record data stating that a change in the processing of the birth registration forms occured in January 1998. During the transition period that followed, the usual reminders were not sent out to parents. This resulted in lower than expected numbers of registered births from January 1998 to the end of the data collection period, December 1999. Therefore, the analyses presented in this study used only the data from January 1980 to December 1997. Deleting the data from 1998 and 1999 resulted in a loss of 102,779 birth records (49% female), leaving 975,975 birth records (51% male) for the analyses presented in the current study.

Results

Birth weight and gestational age were analyzed separately to determine if season-of-birth effects were present as hypothesized. For each of the variables, three time series models were developed: one for males, one for females, and one for both sexes combined. To begin this section I describe the steps I used in each case to obtain the specific results described later. I used recommendations from Wei (1990) and Tabachnick and Fidell (2001) to guide my analytic decisions, and additional detail is included here because many readers may not be familiar with time series analysis.

Step One: Create the Time Series

The first step in these analyses was to create a time series for each variable, which consisted of a mean for every month from January 1980 to December 1997. The three time series for mean monthly birth weights were estimated by multiplying the number of birth records in each birth weight interval by the midpoint of the interval, summing across all intervals for that month, and then dividing the sum by the total number of birth records for that month. The same procedure to calculate means was used by Matsuda et al. (1993) and Selvin and Janerich (1971). As they point out, estimation of means by this method included some error because birth weights did not always center on the interval midpoint for all intervals; however, this error was minimal because of the very large number of birth records in most intervals for all three of these studies. The three time series for mean monthly gestational ages were estimated by multiplying the number of birth records at each gestational age by the gestational age in weeks, summing across all gestational ages for that month, and then dividing the sum by the total number of birth records for that month.

After the three time series were created for each variable, the last five means (August to December 1997) were set aside to be used in step four, leaving the 211 monthly means from January 1980 to July 1997 to be used in the bulk of the analyses as described in steps two and three. Time series analysis is a data-driven procedure and, as you will see, it is the exploration of the data that helps to determine what the end model will be.

Step Two: Determine the Degree of Differencing

The second step in the analyses was to determine the degree of "differencing" necessary to move on to the next step. Differencing is a procedure used to remove the linear trend from the data by subtracting a previous value in the series from the current value in the series at each time point. The differencing parameter (d) has a value of 1 if differencing is done once, a value of 2 if differencing is done twice, and so on. The d is one parameter in an Autoregressive Integrated Moving Average (ARIMA) model (to be discussed further in step three).

The best way to find out if there is a linear trend is to look at a plot of the data. In addition to a visual examination of the plot, it is useful to look at the autocorrelation functions (ACFs) and the partial autocorrelation functions (PACFs). The term autocorrelation refers to the fact that the values in the time series are correlated with themselves at different points in time. The ACFs and PACFs show a characteristic pattern if the data need differencing. The ACF and PACF plots are part of the output produced by the ARIMA procedure in SAS (1999).

The ARIMA procedure also produces an "autocorrelation check for white noise." White noise is the term used in time series analysis to describe a series of data that is simply random error; that is, there are no systematic patterns in the data. The autocorrelation check for white noise is a chi-square test that determines whether the data are significantly different from "white noise." If this test is significant, it means that one has reason to proceed with the time series analysis, because there is something more than random error to model in the data.

Step Three: Find Adequate ARIMA Models

After differencing, a new ACF and a new PACF are generated from the differenced data. These are then used to decide which ARIMA models to try. ARIMA models are like regression models, except that they are intended for data that violate the assumption of independence by having values that are correlated with each other in time.

In ARIMA models there are three basic parameters to estimate. These are the "autoregressive" parameter (p), the "moving average" parameter (q), and the parameter for differencing (d), which was described in step two. These parameters are indicated by the notation ARIMA (p, d, q), where p, d, and q usually have values of 0, 1, or 2. Some models, like the ones I used, are called "seasonal" models and have two estimates of each parameter, ARIMA (p, d, q) (P, D, Q)$_s$, where the uppercase P, D, and Q are the seasonal parameters and also usually have values of 0, 1, or 2. The subscript s indicates the "seasonal index," which in my analyses was 12, representing the 12 months.

The autoregressive parameter, p, can be determined from the significant "lags" on the PACF. Similarly, the moving average parameter, q, can be determined from the significant lags on the ACF. "Lag" refers to how many time points lie between the current value (e.g., mean birth weight) and a previous value in the series. Significant lags are lines on the ACF and PACF plots that extend past the 95% confidence bounds that are automatically included on the plots. For example, in terms of the analyses presented in this paper, if the line corresponding to lag 12 goes beyond the confidence bound on the ACF plot, it is significant, and that means that each January is significantly correlated with the adjacent January, each February is significantly correlated with the adjacent February, and so on.

The significant lags from the ACFs and PACFs help to determine what values to test as parameters in the models. Thus, by looking at the post-differencing ACF and PACF, one can begin to try to find adequate ARIMA models to describe the data. To continue with the example from the previous paragraph, I would try a model with a value of 1 for the seasonal moving average parameter (Q) and the seasonal index (subscript s) would be 12. At this point in each analysis, it is largely trial and error to find at least one adequate model. This is because the ACFs and PACFs are usually not very clear as to which lags are significant. For example, a line may end right on the confidence bound, in which case a decision could be made either way. Another thing that makes the decision vague is that there is always the problem of "capitalizing on chance" because one knows with 95% confidence that for every 20 lags, one lag will be significant simply "by chance."

Once many ARIMA models are tried, one may find a few models that can be deemed "adequate." If an ARIMA model is adequate, that means that all of the parameters in the model are significant and the "autocorrelation check of residuals" is non-significant. Significant parameters are desired just as they are in regression analyses. The autocorrelation check of residuals is another chi-square test, this time testing whether or not the fit is good between the model tried and the actual data. A non-significant chi-square is desired because that means that the model used is not significantly different from the observed data. In other words, the model describes the data well and no remaining systematic variance is detectable.

Step Four: Determine the Best ARIMA Model

The fourth and final step is to determine which one of the adequate models from step three best describes the observed time series. This is where the last five observations from August to December 1997 were used. These five observed values were compared to the five values forecast for the data using the adequate models that were developed. Only five values were used because time series analysis cannot create reliable forecasts for many values past the observed data. After subtracting the observed values from the forecasted values, the differences were used to create a sum-of-squared residuals (SSR). The adequate model that produced the smallest SSR was chosen as the best model, because that indicated that that model predicted the actual values most closely. In addition, any nested models were compared with a chi-square difference test using Akaike's Information Criterion (AIC). When models are nested, it means that a smaller model is a subset of a larger model, and the smaller model has one less parameter than the larger model (examples of nested models can be found in the next sections). The larger model will always fit the observed data better, but the chi-square difference test will determine if the improved fit makes up for the loss of parsimony. In other words, if the two models are not significantly different, then the model with one less parameter is better because it is more parsimonious. However, if the models are significantly different, then the larger, or more complex, model is better (Tabachnick & Fidell, 2001).

Before describing the results from the time series analyses, I will provide a brief summary of the four steps just described. First, the time series has to be created. Second, the plot of the data is viewed, along with the ACF and PACF. Any linear trends observed determine the degree of differencing to try. Third, from significant lags on the differenced ACF and PACF, I determined which ARIMA models to try. When I found many adequate models for a time series, the fourth step was to determine which adequate model was the best model. This decision was based on which model produced the smallest SSR, and a chi-square difference test was done when the models were nested. Presented next are the results from the three sets of time series analyses I performed.

Birth Weight Time Series Analyses

In the first step of the time series analysis for birth weight, I deleted the 1335 birth records (49% female) with unknown birth weights. I used the remaining 974,640 birth records (51% male) to perform the following time series analyses.

The time series plots of birth weight showed no obvious outliers among the monthly means, and the variance appeared stable over time (see Figure 5). The mean birth weight increased roughly 25 g over 18 years, from 3465 to 3490 g for males, from 3360 to 3385 g for females, and from 3415 to 3440 g for the combination. To eliminate this increasing trend from the data, differencing was required. From the differenced ACF and PACF I found multiple adequate models, which are presented in Table 3 with the SSR for each model and the AIC for nested models.

Table 3.

Adequate Models for the Birth Weight Time Series

	Adequate Models	SSR	AIC	χ^2	*p*
Male	ARIMA (0 1 2)	2940.64			
	*ARIMA (0 1 1)(0 0 1)$_{12}$	2520.22	1727.87		
	*ARIMA (0 1 1)(0 1 1)$_{12}$	1834.39	1674.44	53.43	<.001
Female	ARIMA (0 1 1)	3806.03			
	ARIMA (0 1 1)(0 1 1)$_{12}$	2240.78			
Both	ARIMA (0 1 1)(0 1 1)$_{12}$	1392.97			

* For this pair of nested models, the significance test results are presented. The model with the additional parameter was significantly better.

From this information, I determined that a seasonal ARIMA (0 1 1)(0 1 1)$_{12}$ model produced the best results for each of the three birth weight time series. Thus, there were

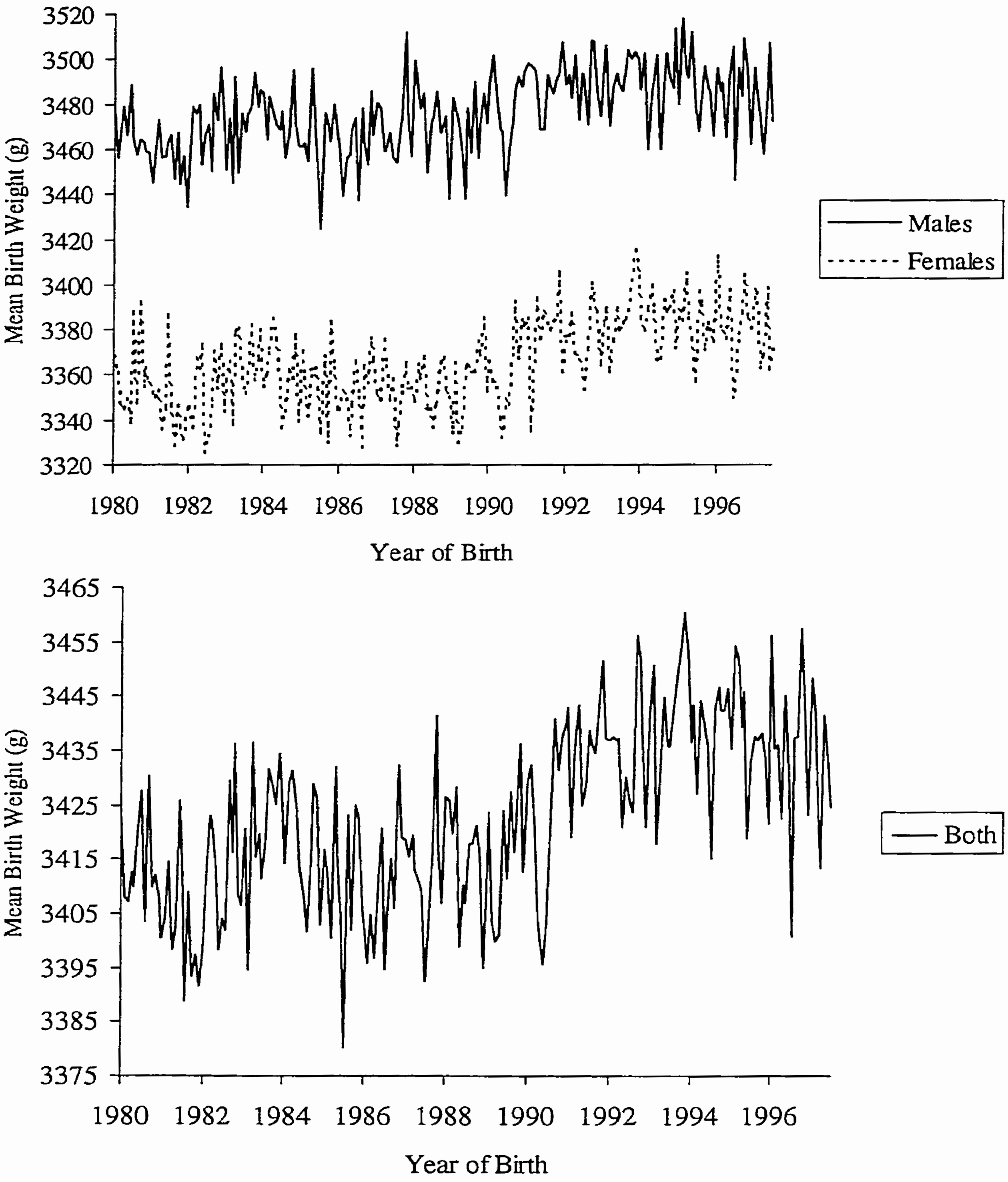


Figure 5. Trend in mean birth weight from January 1980 to July 1997 for males, females, and both males and females combined.

four significant parameters: *d*, *q*, *D*, and *Q*. The significant *d* and *D* parameters with a seasonal index of 12 mean differencing was required at lags 1 and 12. The significant *q* parameter means that each month was significantly correlated with the adjacent month. For example, January was correlated with February, February with March, and so on. The significant *Q* parameter means that each month was significantly correlated with itself, one year later. For example, March 1980 was correlated with March 1981. See Table 4 for the parameter estimates.

Table 4.

Parameters for the Birth Weight Time Series

	Local Moving Average Parameter			Seasonal Moving Average Parameter		
	q	*t*	*p*	*Q*	*t*	*p*
Male	0.77	16.50	<0.0001	0.69	12.46	<0.0001
Female	0.83	20.27	<0.0001	0.68	12.34	<0.0001
Both	0.73	14.73	<0.0001	0.70	12.88	<0.0001

Each parameter estimate is essentially a correlation, thus the values range from -1 to 1. These estimates become part of a time series equation, which is similar to a regression equation. As an example, the time series equation for both males and females combined is:

$$Z_t - Z_{t-1} - Z_{t-12} + Z_{t-13} = a_t - (0.73)a_{t-1} - (0.70)a_{t-12} + (0.73)(0.70)a_{t-13}$$

where Z_t is the mean birth weight for month *t* and a_t is random error for month *t*.

Because the time series analyses indicated a 12-month pattern in the data, I created a mean birth weight for each month, collapsing over all 18 years of data. From Figure 6 it is apparent that the highest birth weights occur in the months of September, October, and November, which is spring in the Southern Hemisphere.

Gestational Age Time Series Analyses

The birth weight time series included some birth records that did not have information on gestational age; thus, the same set of birth records could not be used in these analyses. Rather, a subset of the data was used here. From the data used in the birth weight analysis, I deleted the 736 birth records (51% female) with unknown gestational ages, which resulted in a 0.08% loss of data. I used the remaining 973,904 birth records (51% male) to perform the following time series analyses.

The time series plots of gestational age showed no obvious outliers among the monthly means, and the variance appeared stable over time (see Figure 7). The mean gestational age decreased roughly one-third of a week over the 18 years, from 39.64 to 39.31 weeks for males, 39.70 to 39.36 weeks for females, and 39.67 to 39.33 weeks for the combination. To eliminate this decreasing trend from the data, differencing was required, as in the birth weight analyses. From the differenced ACF and PACF I found multiple adequate models, which are presented in Table 5. From this information, I determined again that a seasonal ARIMA $(0\ 1\ 1)(0\ 1\ 1)_{12}$ model produced the best results for each of the three gestational age time series. See Table 6 for the parameter estimates (cf. parameter descriptions in Table 4).

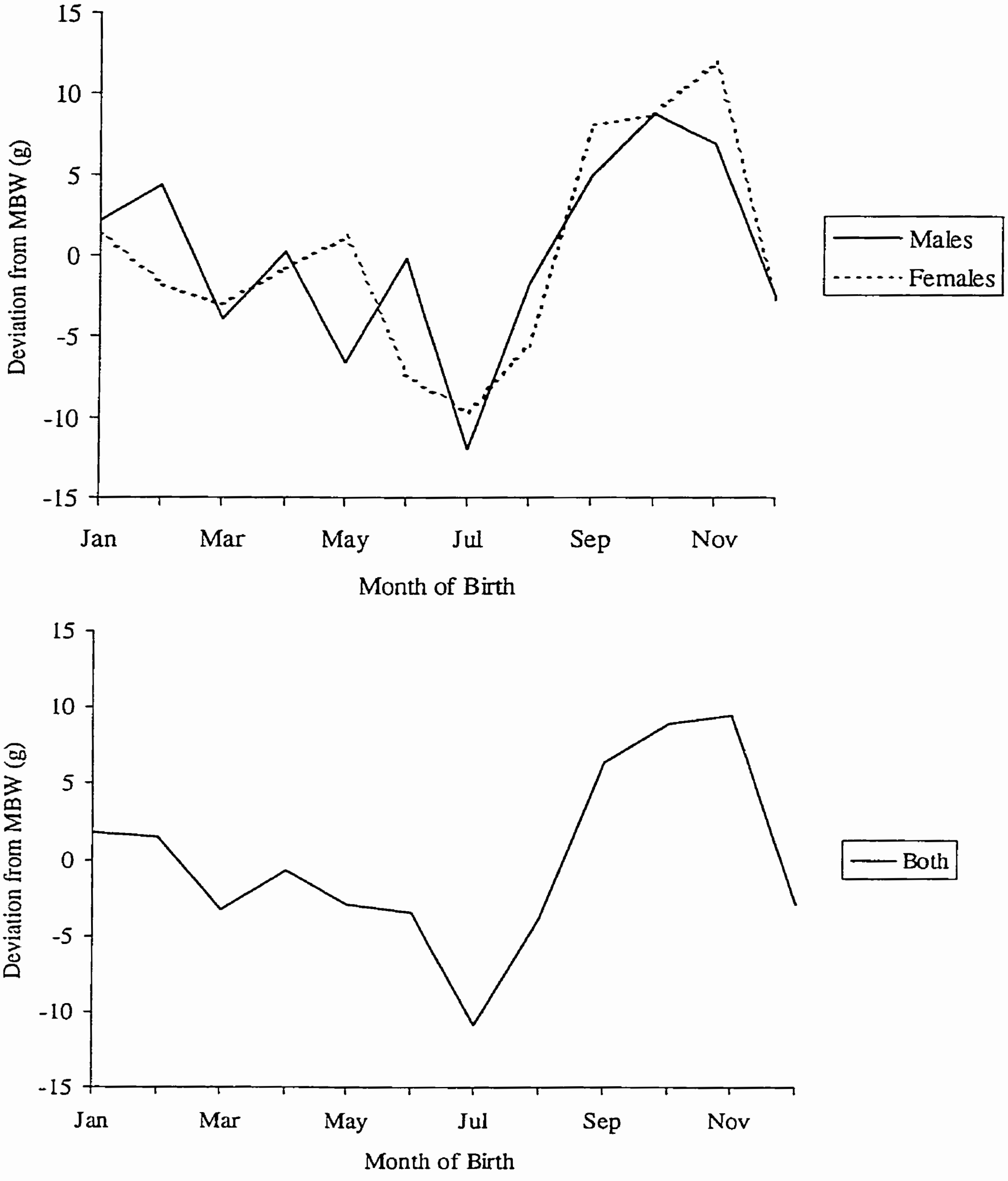


Figure 6. Deviation from yearly mean birth weight for New Zealand for males, females, and both males and females combined.

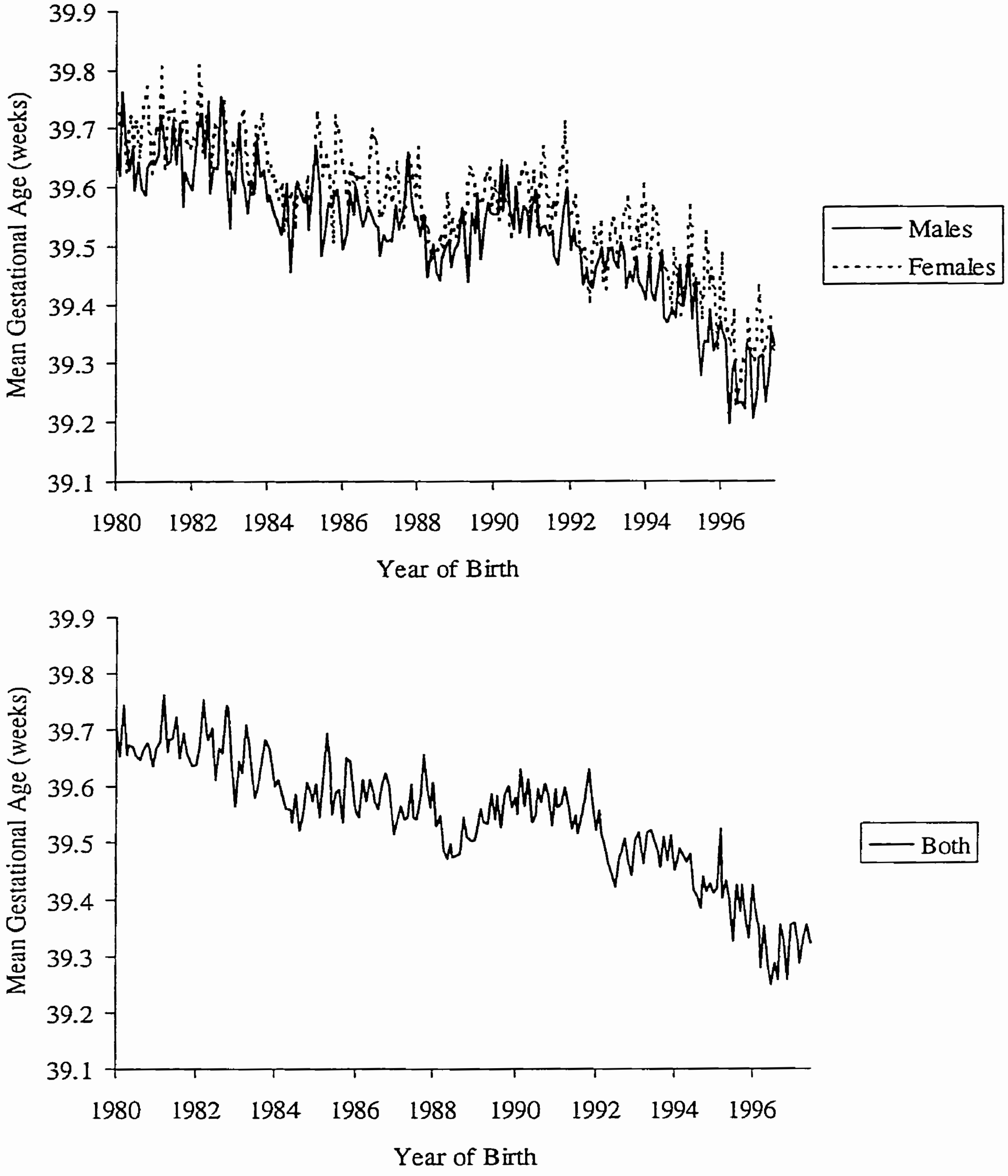


Figure 7. Trend in mean gestational age from January 1980 to July 1997 for males, females, and both males and females combined.

Table 5.

Adequate Models for the Gestational Age Time Series

	Adequate Models	SSR	AIC	χ^2	p
Male	ARIMA (0 1 1)	.00708			
	ARIMA (0 1 2)	.00639			
	*ARIMA (0 1 1)(0 0 1)$_{12}$	.00510	674.69		
	*ARIMA (0 1 1)(0 1 1)$_{12}$	.00378	613.97	60.72	<.001
Female	*ARIMA (0 1 1)(0 0 1)$_{12}$	.02163	626.90		
	*ARIMA (0 1 1)(0 1 1)$_{12}$	.01346	589.14	37.76	<.001
Both	*ARIMA (0 1 1)(0 0 1)$_{12}$	.01047	753.42		
	*ARIMA (0 1 1)(0 1 1)$_{12}$	.00701	715.67	37.75	<.001

* For these pairs of nested models, the significance test results are presented. The models with the additional parameters were significantly better.

Table 6.

Parameters for the Gestational Age Time Series

	Local Moving Average Parameter			Seasonal Moving Average Parameter		
	q	t	p	Q	t	p
Male	0.74	14.66	<0.0001	0.77	15.77	<0.0001
Female	0.68	12.90	<0.0001	0.83	18.58	<0.0001
Both	0.62	10.77	<0.0001	0.85	20.09	<0.0001

Because the time series analyses indicated a 12-month pattern in the data, I created a mean gestational age for each month, collapsing over all 18 years of data. The pattern here was more variable than that of the birth weight. The longest gestations do occur in October, but long gestations also occur in March (see Figure 8).

Further Time Series Analyses

In order to rule out the possibility that the seasonal patterns observed in these data are due to atypical values found at the extreme ends of the distributions, particularly the low birth weight and pre-term infants, a third set of time series analyses were performed on mean birth weights that excluded those infants. The infants excluded were those who had a birth weight of less than 2500 g (18,431; 57% female), who had a gestational age of less than 37 weeks (19,926; 57% male), or who fit into both categories (27,362; 48% female). The remaining group consisted of 908,185 birth records (49% female), which was 93% of the data used for the birth weight and gestational age analyses.

The time series plots of the full-term birth weight means showed no obvious outliers among the monthly means, and the variance appeared stable over time (see Figure 9). The birth weight mean increased roughly 40 g over the 18 years, from 3540 to 3585 g for males, 3430 to 3475 g for females, and 3490 to 3530 g for the combination. To eliminate this increasing trend from the data, differencing was required. From the differenced ACF and PACF I found multiple adequate models, which are presented in Table 7. From this information, I determined again that a seasonal ARIMA (0 1 1)(0 1 1)$_{12}$ model produced the best results for the females and both combined, but an ARIMA (0 1 2) model was estimated for the males. The male model had two local moving average parameters instead of one local and one seasonal moving average parameter (see Table 8

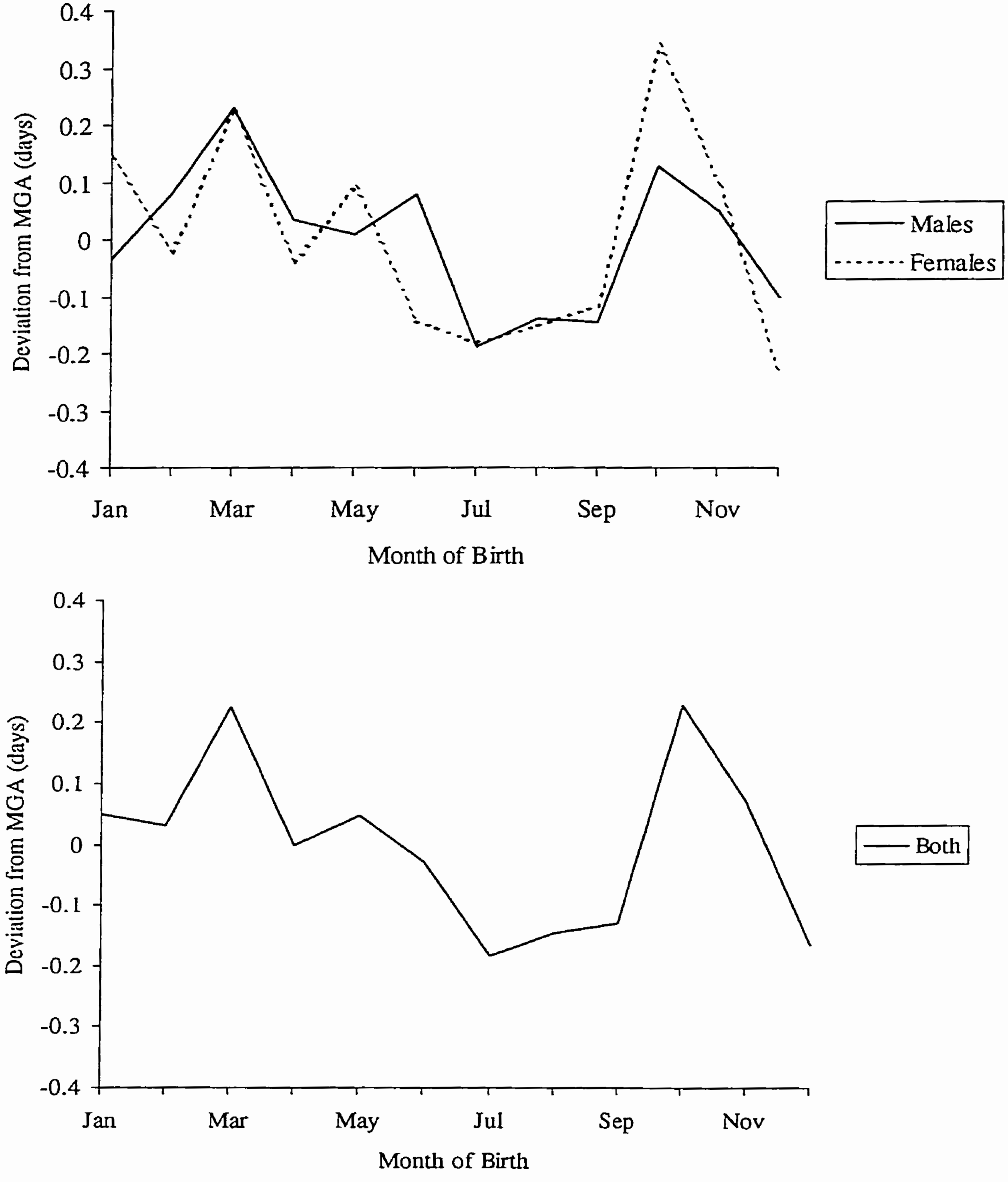


Figure 8. Deviation from yearly mean gestational age (MGA) for New Zealand for males, females, and both males and females combined.

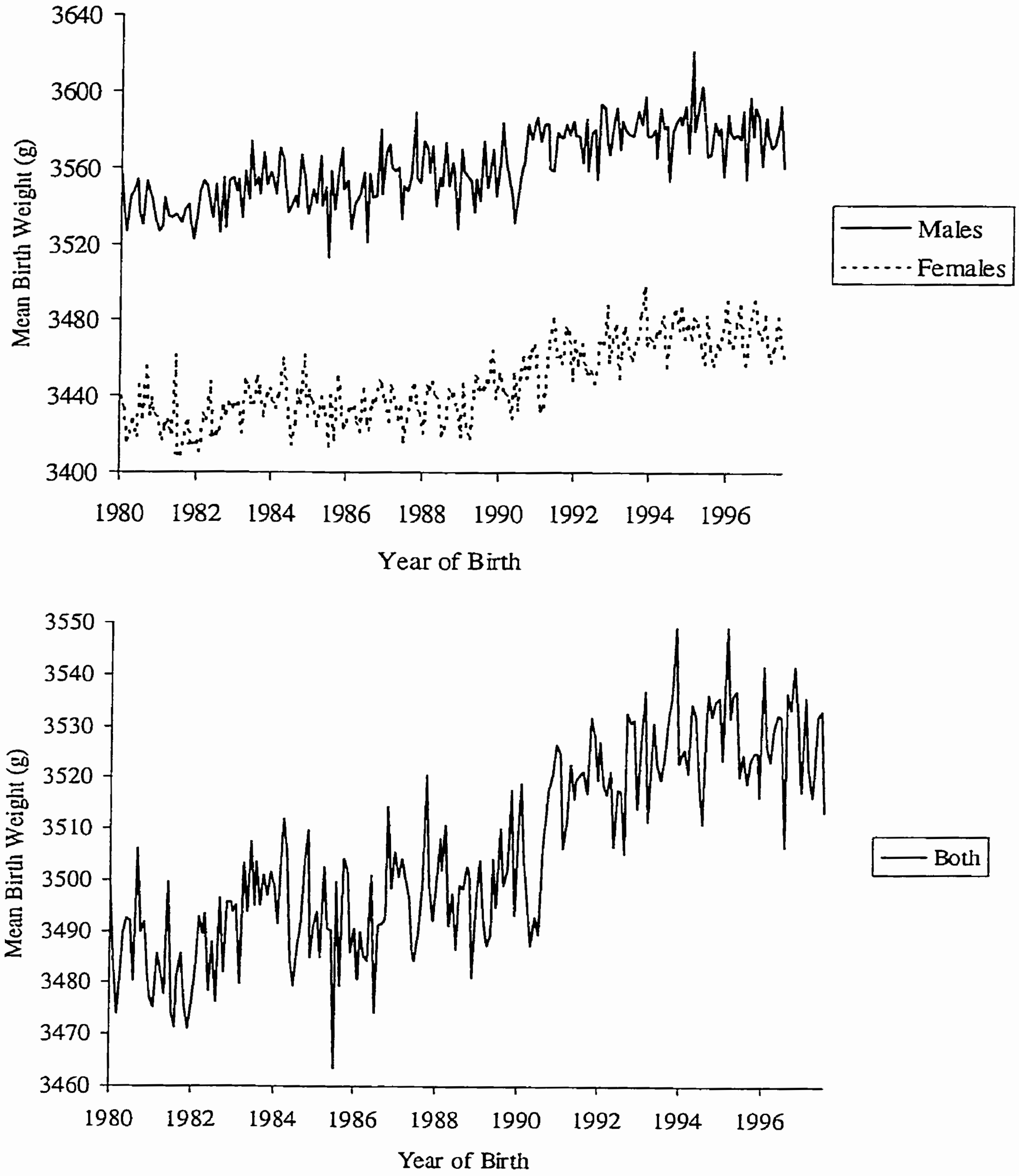


Figure 9. Trend in mean birth weight for full-term infants from January 1980 to July 1997 for males, females, and both males and females combined.

Table 7.

Adequate Models for the Full-Term Birth Weight Time Series

	Adequate Models	SSR	AIC	χ^2	p
Male	ARIMA (0 1 2)	1537.65			
	*ARIMA $(0\ 1\ 1)(0\ 0\ 1)_{12}$	1575.97	1674.14		
	*ARIMA $(0\ 1\ 1)(0\ 1\ 1)_{12}$	1572.07	1621.00	53.14	<.001
Female	ARIMA (0 1 1)	1961.11			
	ARIMA $(0\ 1\ 1)(0\ 1\ 1)_{12}$	981.22			
Both	ARIMA $(0\ 1\ 1)(0\ 0\ 1)_{12}$	984.16			

* For this pair of nested models, the significance test results are presented. The model with the additional parameter was significantly better; however, neither nested model had the smallest SSR.

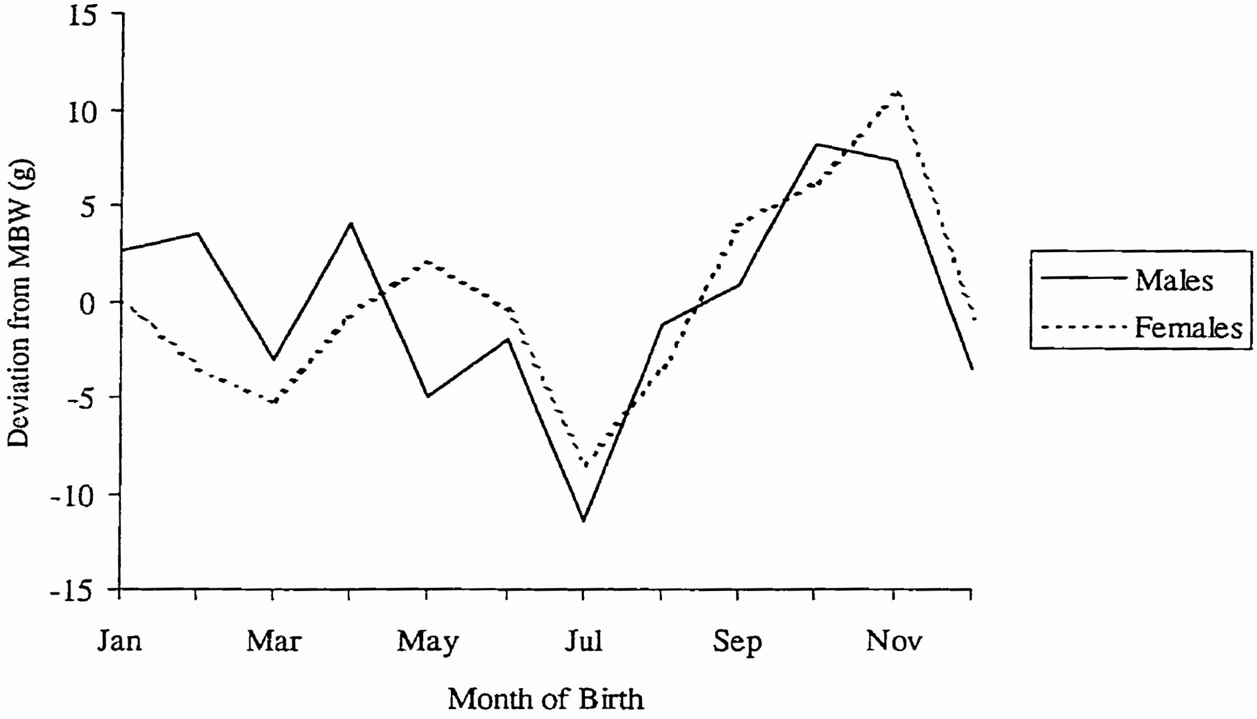
Table 8.

Parameters for the Full-Term Birth Weight Time Series

	Local Moving Average Parameter			Seasonal Moving Average Parameter		
	q	t	p	Q	t	p
Male	0.82	24.86	<0.0001			
	-0.19	5.60	<0.0001			
Female	0.79	17.51	<0.0001	0.71	13.41	<0.0001
Both	0.68	12.77	<0.0001	0.66	11.67	<0.0001

for the parameter estimates). The two moving average parameters for the male model were at lags 1 and 12. These have a similar interpretation to the local and seasonal moving average parameters discussed in the original birth weight analysis.

Once again, the time series analyses indicated a 12-month pattern in the data, so I created a mean birth weight for each month, collapsing over all 18 years of data. Because the data for these analyses were composed of 93% of the original birth weight data, Figure 10 is very similar to Figure 6. However, the absence of low birth weight and pre-term neonates from these analyses suggests that the seasonal pattern is not a function of seasonal fluctuations in the numbers of low birth weight and pre-term infants.



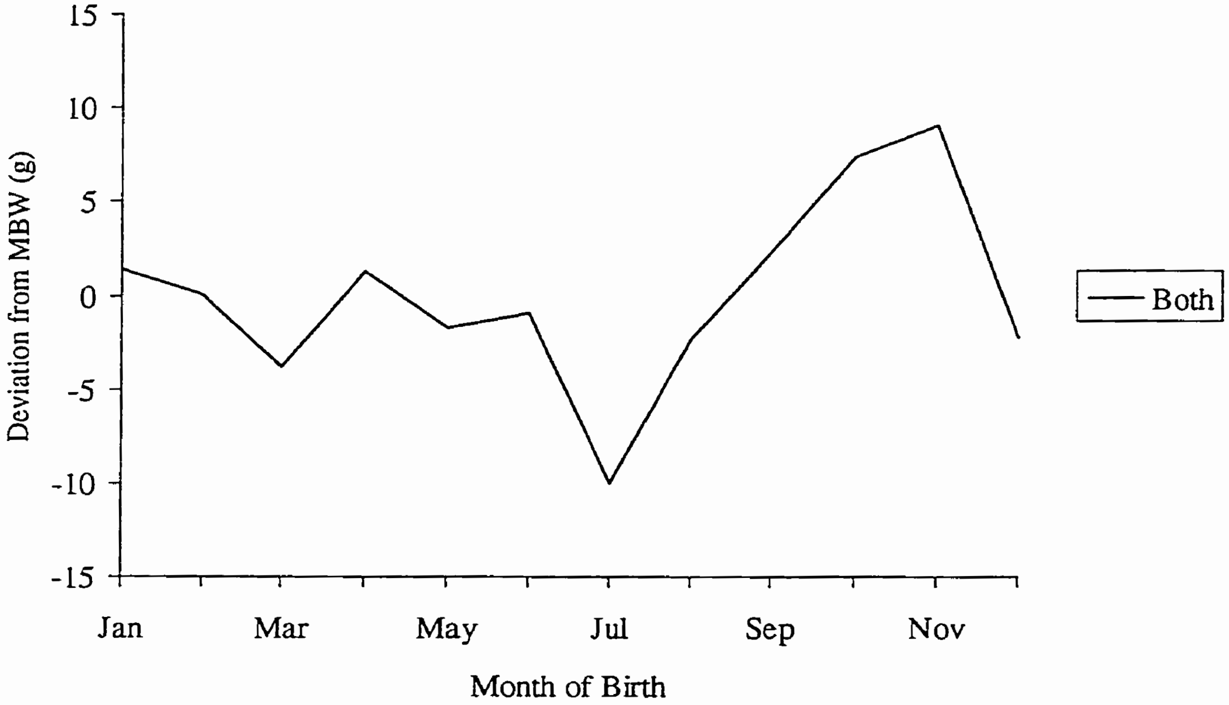


Figure 10. Deviation from yearly mean birth weight for full-term infants from New Zealand for males, females, and both males and females combined.

Discussion

The results presented here from New Zealand, a country south of the Tropic of Capricorn, add an interesting piece to the collection of seasonal birth weight studies from around the world. The match between the hypothesized seasonal pattern in birth weights and the observed pattern was striking (see Figure 11).

Figure 11. Comparison between hypothesized seasonal pattern and actual seasonal pattern of birth weights in New Zealand.

Because the pattern in New Zealand was offset by six months from the pattern in northern countries with similar latitudes, similar mean birth weights, and similar sample sizes, these results support the hypotheses that environmental factors influence development during the gestational period to create seasonal differences in birth weight. Notice in Figures 4 and 11 that the heaviest birth weights occur in the spring: March, April, and May in the Northern Hemisphere, and September, October, and November in the Southern Hemisphere. In addition, there is a winter nadir in all three countries. But how can this be explained?

All three of these studies are from regions that do not experience the wet and dry seasons associated with the problems of seasonal food availability, heavy physical work for mothers, and malarial infections. Therefore the differences must be attributable to other factors. The differences in birth weight may be due to differences in temperature, day length, or gestational age, all of which have been suggested in previous studies (Matsuda et al., 1993; Murray et al., 2000; Roberts, 1976; Rousham & Gracey, 1998; Wohlfahrt et al., 1998). If the focus is placed on events that occur during the third trimester of pregnancy, when the fastest fetal growth occurs (Carlson, B. M. 1999), and if the focus further is placed on the heavier birth weights that occur in the spring, then the search for information can be narrowed to winter. This is because the third trimester for spring-born infants occurs mostly during the winter. Thus, heavier spring births may be due to colder temperatures or fewer hours of daylight in the winter, or these factors could act on gestational age, which in turn could affect birth weight variability. Although the hypotheses for temperature or day length differences affecting birth weight are plausible, neither of these factors have direct links to fetal development. Thus many possible mechanisms have been suggested.

Possible Mechanisms for the Birth Weight Hypotheses

The hypothesis that seasonal differences in temperature are a major cause of seasonal differences in birth weight may act through various indirect means. First, cold weather in the winter may encourage weight gain in mothers over the winter. This in turn may increase the weight of their infants born in the spring. The weight gain may result from seasonal changes in diet. de Castro (1991) found increased food consumption during the fall months for adults in the southeast United States over six years. However, his study did not include pregnant women, so the results may not generalize to support the present hypothesis.

Second, cold temperatures may induce an accelerated fat storage system in the neonate (Phillips & Young, 2000). Phillips and Young found that heavier males born following a colder than average winter showed an increased body mass index (BMI) and were more likely to be obese as adults. The same results were not seen after warmer winters, and were not significant for females; however, the sample size for women in this study was half that of men, and perhaps was not large enough to detect the difference.

The day length hypothesis may be more plausible than the temperature hypothesis to explain these results for several reasons. Day length affects the endocrine system via the pineal gland and its hormone, melatonin (Matsuda et al., 1995; Weber et al., 1998). The pineal gland obtains its information about day length from the supra chiasmatic nucleus

(SCN) of the hypothalamus, which is connected directly to the retinas. Melatonin is then secreted by the pineal gland during the night, and controls hormones, physiological processes, and behaviors that show seasonal variations (Carlson, N. R., 1998).

Melatonin is a good candidate for the seasonality effect in birth weight and gestational age for many reasons. First, women may respond to the natural photo period better than do men (Wehr, Giesen, Moul, Turner, & Schwartz, 1995). Even more interesting is the fact that in pregnant women, the rhythm of melatonin appears to have greater amplitude and higher levels of secretion, especially in the third trimester (Kivelä, 1991). Second, melatonin can affect infants perinatally. Fetuses have many more high-affinity binding sites for melatonin than do adults (Morgan, Barrett, Howell, & Helliwell, 1994; Thomas, Drew, Abramovich, & Williams, 1998). Melatonin crosses the placenta (Reppert, Shea, Anderson, & Klein, 1979) and is present in the umbilical cord blood (Vicente, Garcia, Alvarez, Clements, & Blasquez, 1989) and in maternal milk (Illnerová, Burešová, & Presl, 1993). Third, melatonin may regulate growth, but the exact mechanism for this remains unclear in humans (Davis, 1997; Thomas et al., 1998; Valcavi, Zini, Maestroni, Conti, & Portioli, 1993). Melatonin does affect insulin (Bailey, Atkins, & Matty, 1974), which could affect growth of the fetus, and maternal melatonin is known to influence growth and development of offspring in other species (Thomas et al., 1998). Finally, melatonin may also affect the gestational period, because the SCN appears to control the timing of parturition in rats (Reppert, Henshaw, Schwartz, & Weaver, 1987).

Indeed, it may be that these environmental influences affect gestational age rather than birth weight, and it is then differences in gestational age that cause the differences in birth weight. This possibility was supported by the results from New Zealand. The seasonal pattern in gestational age approximately matched that of birth weight, and the seasonal difference of roughly half a day in gestational age, between the low in July and the high in October, more or less corresponds to the seasonal difference of 20 g in birth weight, between the low in July and the high in November (Carlson, B. M. 1999; see Figure 12).

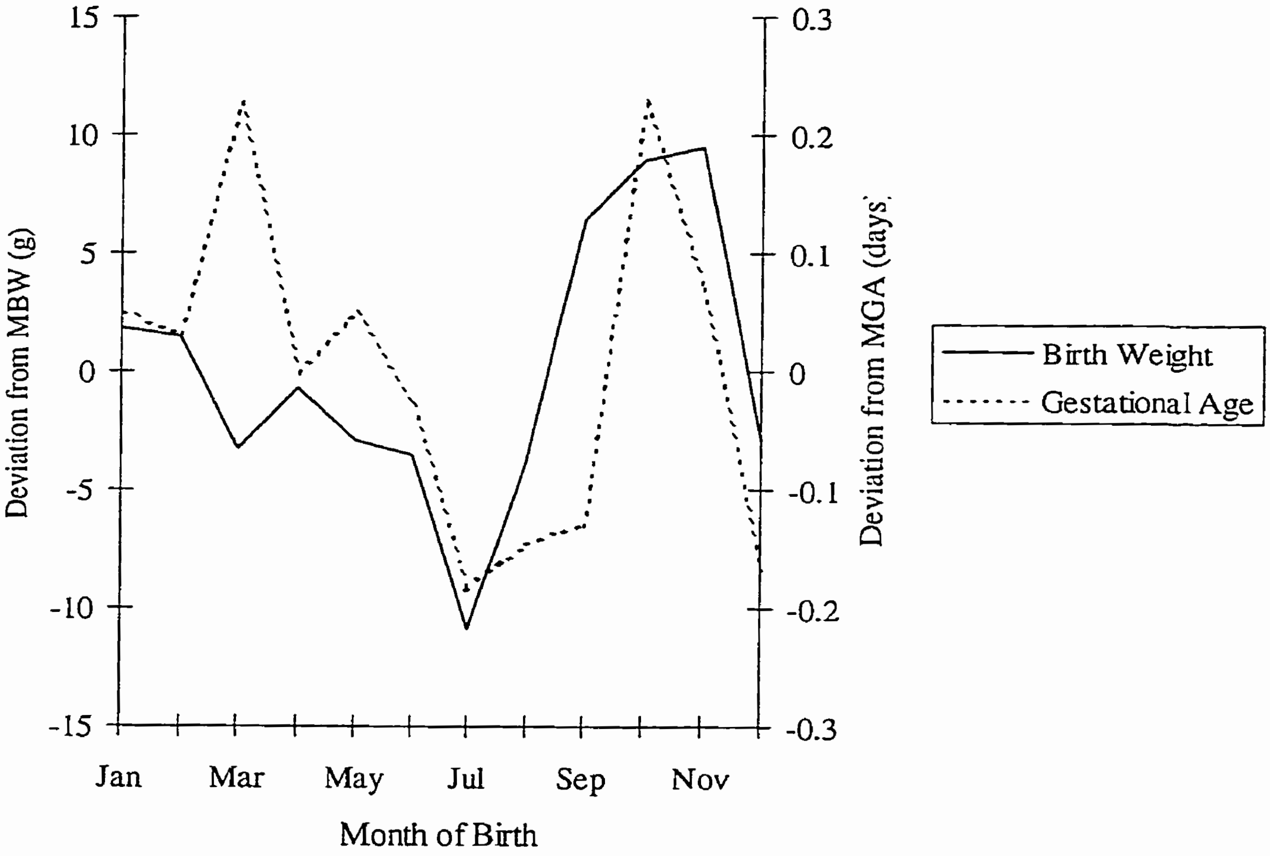


Figure 12. Seasonal pattern in birth weight and gestational age from New Zealand for both males and females combined.

In addition, other researchers have also come to the conclusion that seasonal differences in gestational age affect birth weight (Matsuda et al., 1993; Matsuda et al., 1995; Rousham & Gracey, 1998; Wohlfahrt, et al., 1998). However, the relationship between gestational age and birth weight cannot be deemed causal in either direction simply from the results of seasonality studies. The correlation could just as likely indicate that, for example, fetal size triggers parturition, and therefore, birth weight affects gestational age.

A potential cause of the seasonality in gestational age was mentioned by Matsuda et al. (1995) and Rousham and Gracey (1998). They suggest that seasonality in gestational age is caused by seasonality in the number of pre-term births. However, when the pre-term and low birth weight infants were excluded from the present analyses, the seasonal pattern in birth weight remained unchanged. The prevalence of low birth weight infants in the Rousham and Gracey study was 12.2%, Matsuda et al. (1995) did not report this figure, and in the present study was 4.7%. This suggests that the influence of the low birth weight infants was not as strong in the current study, and that the seasonal influences affect the general population as well as the smallest neonates.

In contrast to the above suggestions, Murray et al. (2000) stated that the seasonality in birth weight was not explained by the seasonality in gestational age. In addition, it is interesting to note that the general pattern in birth weight from Murray et al.'s very recent study does not entirely agree with the present results. However, like all studies, the current study had certain limitations.

Limitations

First, the data presented here were grouped in 500 g intervals, which inherently caused some loss of information, and Statistics New Zealand admits that their data may have contained errors (Statistics New Zealand, 2001). Thus, the means created in the analyses may have been slightly incorrect. Second, this study did not have information on interesting variables such as maternal hormone levels, maternal nutrition, or temperature, and their relationships with the seasonal patterns in birth weight could not be explored. Third, the current study did not have extensive information on the variables that were included in the analyses. For example, it was not known exactly how gestational age was measured. Gestational age can be measured in various ways and there was no information on how it was measured in New Zealand over the 18 years of the study. However, the current study did include nearly one million birth records from the population of New Zealand over 18 years, which most likely compensated for any small errors acquired from the above limitations.

Future Directions

The current study supports the idea that seasonality in birth weight may be caused by seasonal differences in temperature or day length, because the seasonality pattern in the Southern Hemisphere is offset by six months from that of the Northern Hemisphere. Thus the goal for future studies should be to find evidence for any mechanisms that might be at work to cause these differences. However, one simple study that could precede mechanism studies on the temperature hypothesis would be a time series analysis using both mean birth weight and mean temperature as variables. The two variables would be "cross-correlated," and it could be determined how closely seasonal changes in birth weight match seasonal changes in temperature. It would be most interesting to look at mean birth weights following colder or warmer than average winters over many years. If differences in temperatures really do make a difference for birth weights, one would expect greater differences in the means to correspond to more extreme temperatures. In addition, results from such cross-correlational analyses could be compared between a location with large seasonal temperature differences, such as central Canada, and a location at a similar latitude where the temperatures do not vary as much, such as New Zealand. Again, one would expect greater birth weight differences in the location with greater temperature differences. Even if this were the result, it would still not answer the question of mechanism, but it could provide one more small piece of evidence for the hypothesis and reason to proceed to search for mechanisms.

To search for evidence of a mechanism for either the temperature or day length hypothesis, the ideal method would be to follow a large number of mothers longitudinally through their pregnancies over multiple years, collecting data on many variables thought to be involved. But a more plausible method may be a cross-sectional study of pregnant women over part of a year. The temperature hypothesis could be tested by collecting data on outdoor and indoor temperatures to which the mothers are exposed on a daily basis, maternal weight gain and changes in diet. A researcher could then determine if the cold weather really affects birth weight or if mothers are exposed to relatively constant temperatures throughout the year because of indoor temperature control. The effects of the other variables could be controlled for or analyzed in their own right. For example, average maternal weight gain could be compared between summer and winter pregnancies.

The day length hypothesis could be tested by obtaining melatonin samples. Maternal melatonin can be collected through saliva (Salimetrics LLC, 2001), so this could be a non-invasive, relatively straightforward collection of data. If these data were collected, a strong correlation may be found between melatonin levels during pregnancy and weight at birth. If this result occured then further research could investigate complex hormonal interactions between maternal melatonin and fetal growth.

Of course, the seasonal differences in birth weights are small for developed countries. The New Zealand results show an average seasonal difference in birth weight of 20 g. To estimate a rough effect size, this seasonal variation was divided by the variation for the whole sample. However, because the New Zealand study was based on grouped data, a standard deviation could not be calculated. Therefore, the standard deviation from the Ireland study (L. Murray, personal communication, February 14, 2001) was substituted, resulting in an effect size of .04. This effect, though quite small, appears to be very consistent, and implicates processes that may influence other early developmental phenomena. For example, the hormone largely responsible for fetal growth, insulin, may also be responsible for early development of learning and memory (Berger, 2001; Wickelgren, 1998). Thus, by studying the possible reasons for the seasonal differences in birth weight, researchers may be led to discoveries of important ways in which the seasons affect other aspects of early development as well.

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