8 Does the Month-of-Birth Effect Exist in Cohorts Born Today?

8.1 Introduction

The fetal-origins hypothesis (Barker 1995) suggests that low birth weight and fast catch-up growth in the first months of life are associated with higher susceptibility to cardiovascular disease later in life. Central to this hypothesis is the reported inverse relationship between birth weight and systolic blood pressure later in life (for a review see Joseph & Kramer 1996). However, a recent study has cast doubt on whether there exists an association at all (Huxley et al. 2002).

The fetal-origins hypothesis uses birth weight as a surrogate measure of fetal nutrition, and malnutrition *in-utero* and/or exposure to infectious disease have been proposed as the causal mechanisms that link birth weight to later blood pressure (Barker 1989, Eriksson et al. 2000, Forsen et al. 2000, Eriksson et al. 2001). Other studies show that genetic factors may contribute to the relationship between blood pressure and birth weight (Christensen et al. 2001).

The previous chapters provide evidence that life span after age 50 depends on the month of birth and that seasonal differences in nutrition and the incidence of infectious diseases during the pregnancy of the mother or in the first months of life are the most likely causal factors. Nutrition and the incidence of infectious diseases vary seasonally. Thus, in the context of the fetal-origins hypothesis one would expect that seasonal fluctuations in nutrition and infectious-disease incidence should be reflected in seasonal fluctuations in birth weight. Taking this idea one step further, one would also expect to find a month-of-birth pattern in factors related to later-life health such as current weight, current height and current systolic blood pressure.

The fetal-origins hypothesis claims that nutrition and infectious diseases during the pregnancy of the mother are responsible for an increased susceptibility of the child to heart disease once it reaches adult ages. This claim, however, has been repeatedly challenged (Kuh & Davey-Smith 1993). Deprivation *in-utero* and during childhood may simply be the starting point of deprivation throughout life. The increased susceptibility later in life may simply be the result of the life-long accumulation of detrimental effects.

The season of birth does not have any life-course interpretation. Differences in mortality and health-related measures later in life by season of birth indicate that the fetal environment and the first months of life influence the susceptibility to chronic disease later in life independently of other life-course factors.

To test whether the seasonal changes in the early-life environment affect later-life health, there are two hypotheses. The first hypothesis is that seasonal fluctuations in nutrition and in the incidence of infectious diseases are reflected in a seasonal birth weight pattern and that this pattern is correlated with the season-of-birth pattern in systolic blood pressure, current weight, and current height in their young adult years. It is tested on the basis of the Minnesota twin family study. The second hypothesis is that the month-of-birth pattern in twins' birth weight is positively correlated with the differences in mean age at death by month of birth for decedents aged 50+ who were born in Minnesota. If this is the case, then it could suggest that the differences in life span by month of birth also exist in contemporary cohorts.

Twins are exposed to harsher conditions *in-utero* than singletons because they have to share resources. It has been argued (Phillips 1993) that even small differences in the birth weight of twins could reflect important differences in intrauterine conditions because twins already have considerably lower birth weights than singletons. Since the interest is primarily in the effect of month of birth in contemporary populations, these seasonal effects may be more readily detected among twins than among singletons because they should be larger among twins.

Evidence concerning the relationship between month of birth and birth weight, length at birth, current adult and adolescent height and weight exist for different regions of the world and for different time periods (Table 8.5 at the end of this chapter). This evidence is reviewed briefly below. Only few of these studies have information on all these measures, however, and many are based on historical populations or populations from developing countries. Only one study concerning the effect of month of birth on blood pressure exists. The study is based on Spanish men aged 45-64 and finds a significant difference of 11.1 mmHG between the minimum in systolic blood pressure among the spring-born and the maximum among the fall-born (Banegas et al. 2000).

8.1.1 Birth Weight

Plenty of evidence exists concerning seasonality in birth weight. The studies range from contemporary populations in tropical and sub-tropical regions among whom malnutrition is endemic to contemporary populations in Australia, Japan, Ontario, and Denmark and to historic births between the end of the 19th century and the middle of the 20th century in Germany and Austria. Equally important are studies on weight gain in developing countries which demonstrate that the seasons of the year significantly influence both birth weight and the rate of weight gain during infancy and childhood.

In tropical and sub-tropical regions, hot and rainy summers are usually associated with low birth weight (Pollit & Arthur 1989, Roberts et al. 1982, Bantje & Niemeyer 1984, Kinabo 1993, Wendl-Richter 1997), and slow weight gain in infants and children (Brown et al. 1982, Chen et al. 1979) and weight loss in women (Chen et al. 1979, Cole 1993).

In Bangladesh (Brown et al. 1982) the percentage of expected monthly gain in infant weight or length varied by a factor of three or four during different months of the year. The most acute growth faltering was observed during the hot and rainy period in August and September. On the other hand, both the velocity of infant growth and women's weight increase in cold dry winters, from about February to June.

A longitudinal study of infants born in rural Taiwan showed that birth weights were lowest during the hot and wet months of June, July, and August (Adair & Pollit 1985, 1983). The authors did not find a statistically significant effect in weight gain during the first trimester by month of birth. However, the summer cohorts, despite their lower birth weights, tended to surpass the weight of infants born in other months for a greater part of the remainder of the first year. This is mainly due to the higher weight gains in autumn and winter. By the age of 12 months, there were no significant differences in weight between any of the four cohorts.

Similar results are obtained in a study of infants born in Shanghai (Xu et al. 2001). In particular, weight velocity was higher in autumn and winter than in summer in all age groups. The study fails, however, to report whether differences in birth weight exist.

Seasonality in birth weights has also been observed in contemporary populations of developed countries. A study of indigenous Australians demonstrates that significantly more babies with a very low birth weight (<1500g) were born during the wet season (Rousham & Gracey 1998) than during the dry season, while there was no significant seasonal difference in births of 1500-2499g. The authors conclude: "since very low birth weight babies have a strong likelihood of being pre-term the findings suggest that seasonality of birth weight may be due to the increase in pre-term births rather than an increase in rates of intra-uterine growth retardation."

A Japanese study of all births occurring between 1974 and 1983 found similar significant differences in mean birth weight and mean birth weight at 40 weeks of gestation (Matsuda et al. 1995). The pattern is bimodal, with peaks in spring and autumn and troughs in winter and summer. These results indicate that both pre-term births and the intrauterine growth rate contribute to the seasonality in birth weight.

A Danish study of gestational age, length, and weight at birth of all infants born between 1973 and 1994 found seasonal variation in mean length and weight at birth. It fails, however, to report the exact pattern of the differences in birth weight (Wohlfahrt et al. 1998).

A comparison of seasonal variations in birth weights between rural Zaire and Ontario, Canada, (Fallis & Hilditch 1989) did not find a statistically significant seasonal variation in birth weight in Ontario. This is also true for 1,750 men and women born in Hertforshire between 1920 and 1930, where the authors failed to find any significant seasonality in birth weight. However, the number of subjects included in the study might be too small to find significant results.

Seasonality in birth weight has been widely studied in Germany on the basis of historical data. In a study of 101,444 births in Berlin and Leipzig (Otto & Noack 1957) for the years 1936-1953 (Berlin) and 1937-1953 (Leipzig) the authors find that infants born in autumn and early winter had higher birth weights that those born in the first half of the year. The difference is about 35g. In the same study they report differences in birth weight on the basis of data from Marburg, Vienna and Odessa over the years 1920-1922. In this dataset the difference between the peak in mean birth weight in the autumn and the trough in February is more than 60g.

Based on 26,515 births in Hamburg in the time period 1912 to 1922, Hellmuth & Wnorowski (1923) concluded that the autumn-born have higher birth weights, although the differences are not significant. A study of weight at birth in Vienna between 1865 and 1930 (Ward 1987) shows a difference of 58g between infants born in winter and spring (trough) and those born in summer and autumn (peak).

8.1.2 Current Weight

Fewer studies have been conducted on the relationship between current weight and month of birth. An early study was carried out by Hillman and Conway (1972) involving 9,103 patients who attended a public-health nutrition clinic in the United States during the 5-year period 1966 to 1970.

They found a significant deficit of the birth months October and November ($p<=0.01$) among the 5,627 overweight patients and a single peak in March. This pattern was most pronounced in patients aged 20 to 30. Although the overall patterns for underweight and normal-weight patients did not vary significantly, they found a relative deficit of birth dates during June and July ($p<0.05$). The authors suggest that the relationship between month of birth and being overweight changes with age, "an impression consonant with the concept that the pathogenesis of later acquired (adult) obesity commonly differs from the type that is manifested in childhood".

Hillman and Conway observed that, under the age of 20, people born in spring and early summer seem less apt to be overweight. Above the age of 20, this is true for those born in the second part of the year. They mention, however, that their results are only partly consistent with other studies about season of birth and body form (Chenoworth & Canning 1941, Mills 1941, Fitt 1955). The study by Fitt (1955) is based on data from New Zealand. He reports the mean height and weight of adult men in the New Zealand army by month of birth. Taking their weight for height ratio, one finds a bi-modal pattern. Those born between February and July and in October-November are slimmer than those born in August, September, and January.

In a study of 2,500 young women, those born in September and October show the highest weights (Hillman et al. 1970). A recent study about birth weight, climate at birth, and the risk of obesity later in life (Phillips & Young 2000) studied 1,750 men and women born in Hertfordshire between 1920 and 1930. Average age at the time of the interview was 64.9 years. Among men, the prevalence for obesity varied with month of birth and was greater among those born in January to June than among those born in July to December. Among women there was no specific trend.

Several studies on the relationship between current weight and birth weight have been performed which do not consider the month of birth. A study of 14-year old Polish adolescents (Koziel & Jankowska 2002) shows that boys who were small for their gestational age at birth (SGA) had a lower body mass index at age 14, while SGA girls had accumulated more centralized fat. In a study of 3,447 women born in Helsinki who developed coronary heart disease (Forsen et al. 1999) the mean heights and weights at ages 7 to 15 of those who developed coronary heart disease were below those of all other women. They had, however, experienced catch-up growth in childhood since at birth the difference in height and weight was larger than in adolescence. A similar study for males (Forsen et al. 1997, Erikson et al. 1999) finds the highest death rates from coronary heart disease later in life among boys who were thin at birth and who had caught up in weight by the age of seven.

In conclusion, the studies on current weight and weight gain indicate that a relationship with the month of birth does indeed exist. However, this relationship is complicated by the fact that it seems to differ with age and for the two sexes. The latter fact might be explained by differences in the tempo of growth during adolescence between boys and girls.

8.1.3 Length at Birth and Height Gain During the First Year of Life

Many studies about seasonal differences in height by month of birth look at height gain during the first years of life or at length at birth. For example, Xu et al. (2001) found that, in Shanghai, month of birth has some association with attained size but that this is reduced during the first two years of life. A study of infants born in Gambia arrived at similar results (Cole 1993). All the studies confirm the general knowledge reflected in the German saying that " *Mairegen laesst die Kinder wachsen* ("Rain in May lets children grow)", i.e. that height gain differs by the seasons of the year. This implies that infants and children of the same age grow at different rates depending on their month of birth.

There is one contemporary study about differences in length at birth (Wohlfahrt et al. 1998). It is a population-based study of 1,166,206 children born in Denmark between 1973 and 1994. Children born in April were 2.2 mm longer than those born in December. In their study of births in Leipzig and Berlin Otto and Noack (1957) report both the seasonal distribution in birth weight and length at birth. They find that length at birth peaks in March, April, and October and reaches a trough in May and June. In a second article Otto and Glaas (1959) use the same data from Leipzig and calculate mean gestational age, mean birth weight, and mean length at birth by month of birth. On the basis of these three measures it appears that, corrected for their gestational age, the autumn-born infants are tall and heavy while the spring-born infants are tall and thin.

8.1.4 Current Height

As early as 1941 Fitt analysed the relationship between month of birth and current height among children and adolescents (Fitt 1941) and came to not always consistent results with other contemporary studies (Mills 1941, Chenoweth & Canning 1941). Fitt attributes this to the different ages of the adolescents and to the fact that they were still growing at different rates. In his 1955 article he presents results for the heights of 21,342 adult men from a large sample of men drafted into the New Zealand army in World

War II. Arranging the height measures by month of birth, he finds a cyclical pattern. Those born in June are the shortest, and the tallest are born between September and February. The peak-to-trough difference in height is 0.31 inch=0.8 cm. Turning to the Northern Hemisphere, Weber et al. (1998) report a sinusoidal cycle for the heights of the entire male population aged 18 for ten one-year birth cohorts. The Austrian Federal Army measured these cohorts throughout the whole year in five conscription centres. They find that the tallest are born in March and the shortest in September. The peak-to-trough difference is 0.6 cm. These results are consistent with a study by Breitinger (1966), who found a similar pattern for those born in January to June and July to December. A Spanish study (Banegas et al. 2001) of 2021 men and women found that males born in summer were 1.7 cm taller than those born in winter. This difference was most marked for those with manual occupation. No differences existed for females.

The past studies about month of birth and height lead to three conclusions: First, the spring-born seem to be the longest infants at birth. There is evidence, however, that they are long and thin while the autumn-born are long and heavy. Second, due to the seasonality in the velocity of growth, infants and children of the same age have very different heights according to their month of birth, which complicates the analysis. Third, at adult ages the spring-born are the tallest in the Northern Hemisphere while the pattern is shifted by a quarter of a year in the Southern Hemisphere.

8.2 Data and Method

This study is based on adolescent twin participants of the same sex from the Minnesota Twin Family Study. Two cohorts are assessed: the first consists of twins born between 1977 and 1984 who were approximately 11 years old (age range 11 to 12 years) at the time of the interview, the second consists of twins born between 1972 and 1979 aged approximately 17 (age range 17 to 18 years). A description of the Minnesota Twin Family Study and how the measurements were obtained can be found in Christensen, Støvring and McGue (2001).

The sample used in this study consists of 1,353 twin-pairs (660 male, 693 female). Twin-pairs with missing measurements and outliers are excluded. Outliers of height, current weight, current systolic blood pressure and birth weight are identified on the basis of the inter quartile range (IQR) and the first (q1) and third (q3) quartile. Those measures are classiefied as extreme outliers that either exceeding q1-3*IQR or q3+3*IQR. Table 8.1

Table 8.1. Number of twin pairs used in the cosinor analysis.

	Current weight	Current height	Current systolic BP	Birth weight
Ages 11-12				
Males	347	359	346	363
Females	340	350	348	347
Ages 17-18				
Males	268	273	274	273
Females	299	308	305	305
Both Ages				
Males	615	632	620	636
Females	639	658	653	652

contains the number of twin pairs that are used in the different calculations.

A total of 340,328 US death records for the years 1989 to 1998 were used to calculate mean age at death by month of birth for people born in Minnesota. The data are publicly available from the Multiple Cause of Death Data from the National Center for Health Statistics (NCHS), to which the information about month of birth was added.

In the twin data the mean of each outcome measure is calculated by week of birth. Cosinor analysis is used to test whether the week-of-birth pattern is statistically significant and whether the fluctuations are seasonal. For each of the four measures birth weight, current weight, current height, and current systolic blood pressure the following model is estimated.

$$y = \alpha_0 + \alpha_1 \sin(t) + \alpha_2 \cos(t) + u$$

$$t = \begin{cases} \text{week of birth} / p * 2\pi & \text{if one peak} \\ \text{week of birth} / \frac{p}{2} * 2\pi & \text{if two peaks} \end{cases} \qquad [8.1]$$

In Equ. 8.1 y denotes one of the five outcome measures, α_1 and α_2 are regression parameters, α_0 is the general mean and t is the week of birth defined in the known period of 2π; p is the number of time units in period 2π. The error term u follows a normal distribution with mean zero and variance σ^2.

For each measure three models are estimated: the first model tests whether an unimodal sinusoidal function fits the data and defines the period 2π in terms of 52 weeks (i.e. p=52); the second model tests for a bimodal sinusoidal function and assumes that the period is defined over p=26 weeks. The third model tests whether the sum of a unimodal and a bimodal sinusoidal function fits the data best. Equ. 8.1a allows for modeling of seasonal fluctuations that depart from pure sinusoidal functions.

$$y = \alpha_0 + \alpha_1 \sin(t) + \alpha_2 \cos(t) + \alpha_3 \sin(t_1) + \alpha_4 \cos(t_1) + u$$

$$t = week\ of\ birth / p * 2\pi \qquad [8.1a]$$

$$t_1 = week\ of\ birth / \frac{p}{2} * 2\pi$$

Equation 8.1 is the linearized version of an equivalent formulation with slightly different parameterization:

$$y = \beta_0 + \beta_1 \cos(t - \beta_2) + u \qquad [8.2]$$

It has been shown (Bingham et al. 1982) that

$$\beta_1 = \sqrt{\alpha_1^2 + \alpha_2^2}$$

$$\beta_2 = \arctan\left(\frac{\alpha_q}{\alpha_2}\right) + k \qquad [8.2a]$$

$$\beta_o = \alpha_0$$

In cosinor analysis β_0 is named mesor and estimates the general mean, β_1 is the amplitude and β_2 is called acrophase, the point were the sinusoidal function reaches its maximum/minimum.

US death data contain information about the date of birth on the level of month of birth but not by week of birth. Therefore, all calculations are also performed on a monthly basis with p=12.

The final model is selected on the basis of the Akaike information criteria max (2LL-2p), where LL denotes the log likelihood and p the number of parameters in the model. Since twin data are correlated *Generalized Estimating Equations* (GEEs) based on Liang and Zeger are used to estimate the models. The GEE method is implemented through the "REPEATED" statement of the "GENMOD" procedure in SAS.

Table 8.2. Parameter estimates and p-values of the cosinor analysis of birth weight, current weight, current height and current systolic blood pressure.

		Birth weight	Current weight	Current height	Current systolic blood pressure
Boys					
11-12	Periodicity	26	52	52	26
	α_1 *(sin)*	-.06	**4.27**	**2.33**	1.03
	p-value	(.13)	(.01)	(.00)	(.18)
	α_2 *(cos)*	-.07	-1.66	**-1.05**	-1.18
	p-value	*(.07)*	(.20)	(.03)	(.07)
17-18	Periodicity	26	52	26	52
	α_1*(sin)*	-.05	-.91	**1.23**	-1.34
	p-value	(.25)	(.61)	(.05)	(.17)
	α_2 *(cos)*	**-.09**	-2.71	-.17	.86
	p-value	(.04)	(.15)	(.76)	(.35)
Girls					
11-12	Periodicity	52	52+26	52	52+26
	α_1 *(sin)*	-.03	**3.70**	**2.64**	1.43
	p-value	(.47)	(.03)	(.00)	(.17)
	α_2 *(cos)*	-.04	**-3.40**	**-1.29**	**3.22**
	p-value	(.26)	(.03)	(.01)	(.00)
	α_3 *(sin)*		**3.59**		-1.65
	p-value		(.03)		(.11)
	α_4 *(cos)*		-0.79		**-2.71**
	p-value		(.60)		(.01)
17-18	Periodicity	26	26	52	52
	α_1 *(sin)*	-.05	0.72	-.17	**1.0**
	p-value	(.22)	(.64)	(.73)	(.05)
	*α_1 *(sin)*	-0.05*			
	**p-value*	(.16)*			
	α_2 *(cos)*	-.04	**-3.49**	-.70	1.63
	p-value	(.40)	(.03)	(.09)	(.11)
	*α_2 *(cos)*	**-0.08 ***			
	**p-value*	(.05)*			

1. Significant values are set in bold
2. Periodicity: 26 weeks indicate one bimodal fluctuation; 52 weeks one unimodal fluctuation; 52 + 26 weeks the sum of one bimodal and one unimodal fluctuation
3. The best fitting model is chosen based on the Akaike information criteria
4. * refers to the parameter estimates based on the definition of outliers: q1-1.5*IQR or q3+1.5*IQR

Table 8.3. Predicted peaks and troughs in birth weight, current weight, current height and current systolic blood pressure based on Equ. 8.1 and 8.1a of twins aged 11-12 and 17-18.

		Weeks Males/Females			
		Birth Weight kg	Current Weight kg	Current height cm	Current systolic blood pressure Hg
Ages 11-12	Periodicity	26/..	52/52	52/52	26/52+26
	Maximum1	16/..	16/10	16/17	10/13
	Maximum2	42/..	../30	../..	36/44
	Minimum1	3/..	42/21	42/43	49/2
	Minimum2	29/..	../46	../..	23/29
	Max diff.	0.19/..	4.16/6.31	5.10/5.87	3.14/10.19
Ages 17-18	Periodicity	26/26	../26	26/..	../52
	Maximum1	15/17	../12	7/..	../7
	Maximum2	41/43	../38	33/..	../..
	Minimum1	2/4	../25	20/..	../33
	Minimum2	28/30	../51	46/..	../..
	Max diff.	0.20/0.12	../3.56	2.48/..	../5.06

8.3 Results

Twins Ages 11-12

Significant month-of-birth patterns exist for all four measures (Table 8.2) and they are generally similar for males and females. Current weight and current height each follow a unimodal pattern with a peak in spring and a trough in fall (Figures 8.1 and 8.2). They are highly correlated and it is obvious that the seasonal fluctuations in current weight are caused by the seasonal fluctuations in height. The differences between the peaks and troughs are considerable. Among boys the spring-born are 5.10 cm taller and 4.16 kg heavier than the fall-born, the difference among girls is 5.87 cm and 6.13 kg (Table 8.3). For males current systolic blood pressure follows a bimodal function with peaks in spring and fall and troughs in summer and winter and a difference of 3.14 Hg (Figure 8.3). For females there

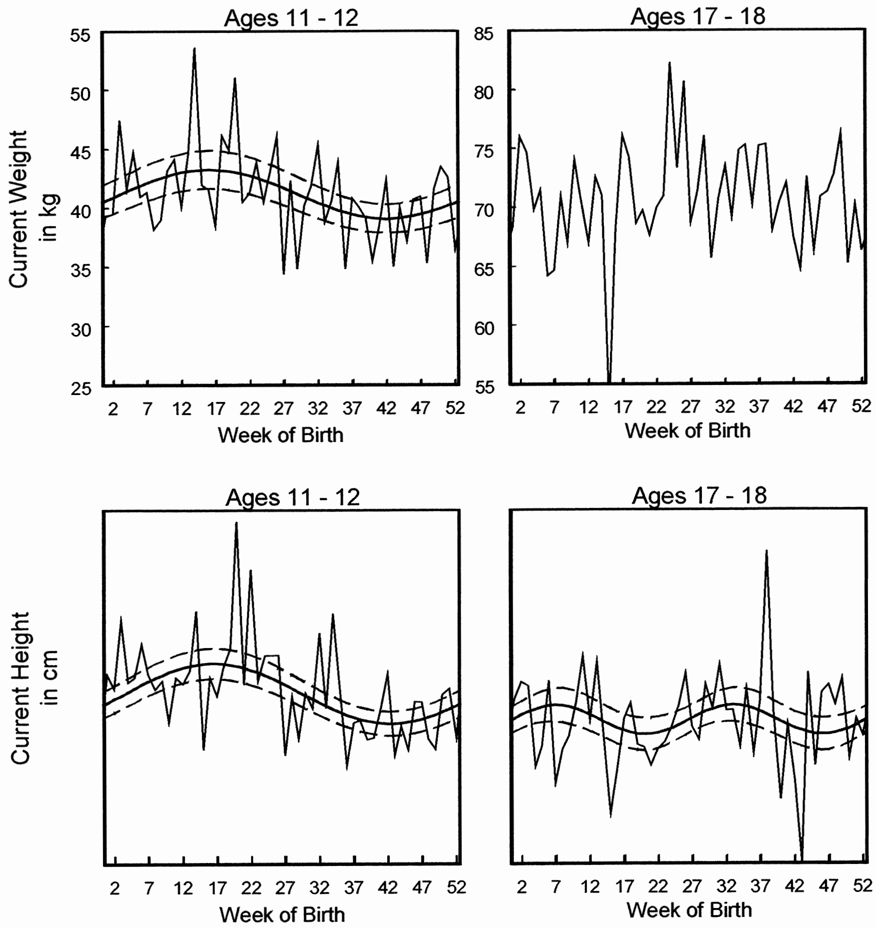

Figure 8.1. Mean current weight and current height by week of birth and sinusoidal functions incl. 95% confidence bands estimated by Equ. 8.1 and 8.1a, males, ages 11–12 and 17–18.

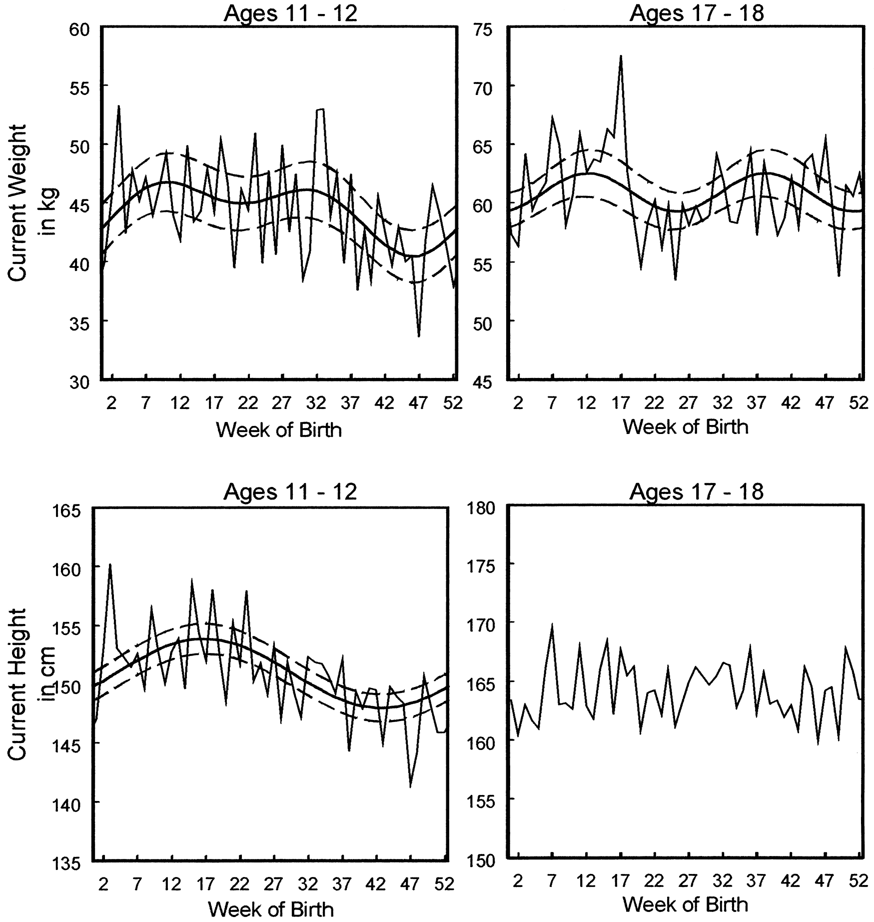

Figure 8.2. Mean current weight and current height by week of birth and sinusoidal functions incl. 95% confidence bands estimated by Equ. 8.1 and 8.1a, females, ages 11–12 and 17–18.

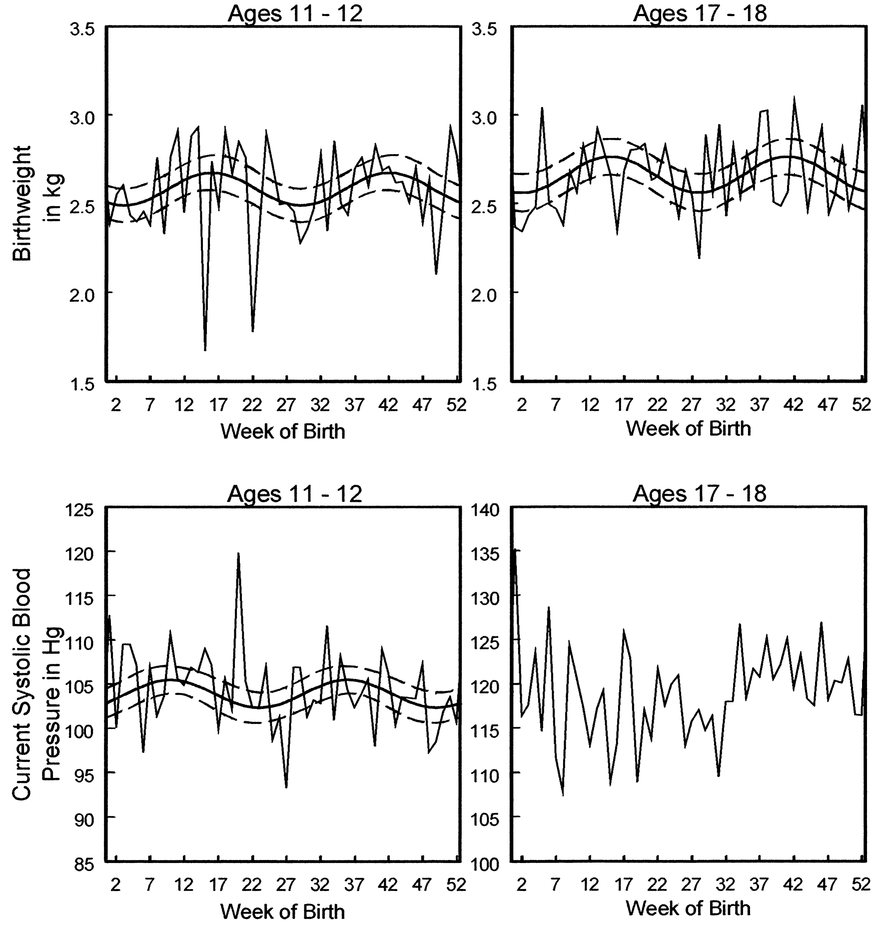

Figure 8.3. Mean birth weight and current systolic blood pressure by week of birth and sinusoidal functions incl. 95% confidence bands estimated by Equ. 8.1 and 8.1a, males, ages 11–12 and 17–18.

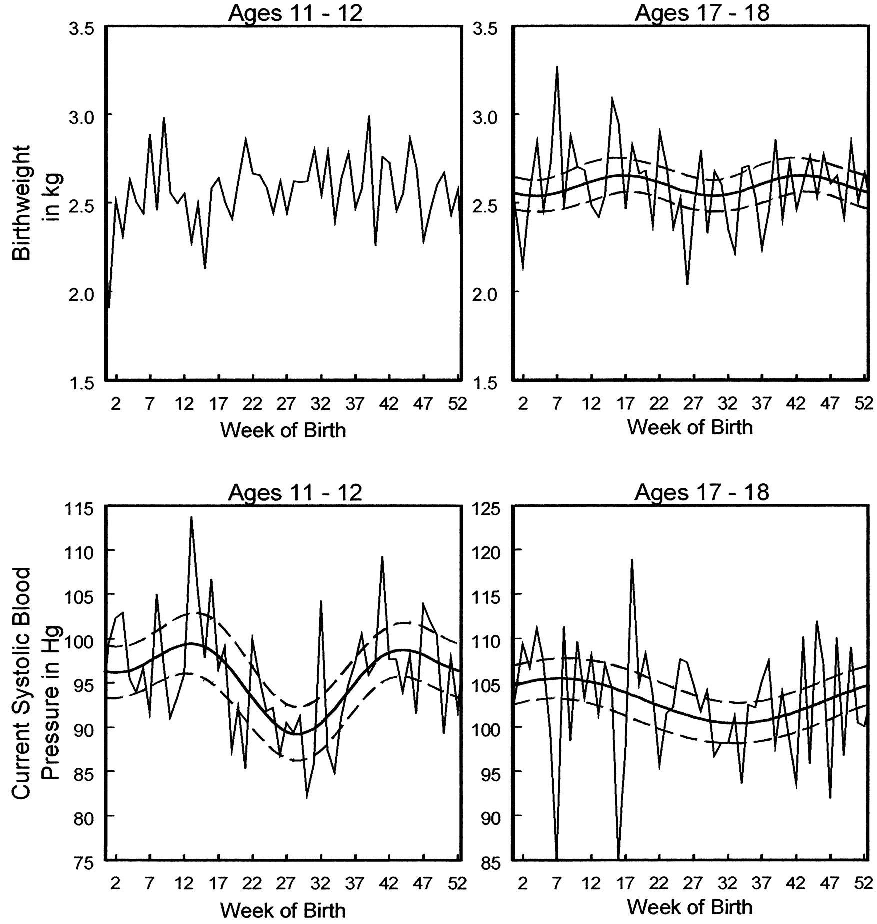

Figure 8.4. Mean birth weight and current systolic blood pressure by week of birth and sinusoidal functions incl. 95% confidence bands estimated by Equ. 8.1 and 8.1a, females, ages 11–12 and 17–18.

is a difference of 10.19 Hg between the trough among the summer-born and the peak among the winter-born (Figure 8.4). A striking seasonal pattern exists for male birth weight (Figure 8.3). It is bi-modal with peaks in spring and fall and troughs in summer and winter and a difference of 0.19 kg. No seasonal pattern exists in the birth weight of female twins. For males there is a high and significant positive correlation between the pattern in birth weight and in systolic blood pressure (PCC: 0.63, p<0.03).

Twins Ages 17-18

Among the older twins the seasonal pattern in birth weight is significant for both sexes and similar to the pattern of the younger male twins (PCC between ages 11-13 and 17-19: 0.99, p=0.01). The difference between the peak and the trough is 0.12 kg for females, and 0.20 kg for males. Among female twins the seasonal pattern in systolic blood pressure remains significant, although compared to the younger twins the peak-to-trough difference decreases from 10.19 Hg to 5.06 Hg. There is no correlation between the seasonal pattern in birth weight and in systolic blood pressure for the older female twins. Significant seasonal fluctuations still exist in the height of the older male twins, however they are neither correlated with the fluctuations in birth weight nor with the fluctuations in current height of the younger twins.

Correlation Between the Seasonal Fluctuations in Mean Age at Death, Birth Weight and Systolic Blood Pressure

Significant seasonal fluctuations by month of birth exist in mean age at death of the decedents born in Minnesota. This is also true for cause-specific mortality with the exception of the group of non-natural causes of death among males (Table 8.4.).

If one calculates the correlation between the 12 monthly values predicted by the sinusoidal patterns then a positive correlation exists between the sinusoidal fluctuations by month of birth in birth weight and mean age at death. The Pearson correlation coefficient is generally about 0.42 for both sexes, however, statistically it is only of borderline significance. Between systolic blood pressure and mean age at death the correlation is strong and significant among younger female twins (PCC=0.72, p=0.009).

Among males the sinusoidal fluctuations in total mortality, cancer, heart disease and other natural causes of death consist of a unimodal part defined over 12 months and a bimodal part defined over 6 months. The acrophases of the bimodal parts are highly consistent for total mortality, birth weight and systolic blood pressure: the values range from 0.95 for total

Table 8.4. Parameter estimates and p-values of the cosinor models of the effect of month of birth on total mortality, cause-specific mortality, birth weight and current systolic blood pressure.

Males	Minnesota death records					Minnesota twin study			
	Total	Cancer	Heart disease	Other natural	Non-natural	Birth weight ages 11-12	Birth weight ages 17-18	Systolic BP ages 11-12	Systolic BP ages 17-18
Periodicity	*12+6*	12+6	12+6	12+6	6	6	6	6	
α_1 (sin)	-.04	.01	.01	***.12***	n.s.	n.s.	n.s.	n.s.	n.s.
95% LCI	(-.11–	(-.14–	(-.09–	*(-.26–*					
95% UCI	.04)	.12)	.11)	*.02)*					
α_2 (cos)	**.19**	**.13**	**.18**	**.22**	n.s.	n.s.	n.s.	n.s.	n.s.
95% LCI	(.12–	(.05–	(.07–	(.09–					
95% UCI	.26)	.31)	.28)	.37)					
Acrophase β_2	0.79	1.08	1.06	1.50					
Amplitude β_1	0.39	0.26	0.36	0.50					
α_3 (sin)	**-.07**	.06	***-.10***	**-.15**	n.s.	**-.09**	**-.07**	.01	n.s.
95% LCI	(-.15–	(-.07–	*(-.21–*	(-.29–		(-.17–	(-.15–	(-1.07–	
95% UCI	-.00)	.19)	*.01)*	-.01)		-.01)	-.00)	-1.10)	
α_4 (cos)	-.05	**-.12**	-.02	-.05	n.s.	-.06	-.06	-1.44	n.s.
95% LCI	(-.12–	(-.25–	(-.13–	(-.18–		(-.12–	(-.14–	(-2.42–	
95% UCI	0.02)	.01)	.09)	.09)		.15)	0.02)	-.46)	
Acrophase β_2	0.95	0.54	1.37	1.25		0.98	0.86	0.99	
Amplitude β_1	0.17	0.27	0.20	0.32		0.22	0.18	2.95	

Table 8.4. (continued)

Females	Minnesota death records					Minnesota twin study			
	Total	Cancer	Heart disease	Other natural	Non-natural	Birth weight ages 11-12	Birth weight ages 17-18	Systolic BP ages 11-12	Systolic BP ages 17-18
Periodicity	12+6	12+6	12+6	12	6		6	12+6	12
α_1 (sin)	-.05	.01	.02	**-.14**	n.s.	n.s.	n.s.	**2.08**	**1.90**
95% LCI	(-.12–	(-.14–	(-.12–	(-.26–-				(.17–	(.12–
95% UCI	.02)	.16)	.07)	.01)				3.99)	3.67)
α_2 (cos)	**.21**	**.24**	**.19**	*0.12*	n.s.	n.s.	n.s.	**3.04**	1.85
95% LCI	(.13–	(.08–	(.09–	*(-.01–*				(1.09–	(-.01–
95% UCI	.28)	.39)	.28)	*.24)*				4.99)	3.72)
Acrophase β_2	*.77*	*1.04*	*1.10*	*.14*				*0.60*	*0.80*
Amplitude β_1	*.43*	*.48*	*.38*	*.37*				*7.37*	*5.31*
α_3 (sin)	*-.06*	-.05	-.05	n.s.	-.28	n.s.	**-.07**	**-2.66**	n.s.
95% LCI	*(-.13–*	(-.20–	(-.15–		(-.83–		(-.13–	(-4.64–	
95% UCI	*.01)*	.09)	.04)		.26)		.00)	-.68)	
α_4 (cos)	**-.14**	**-.03**	**-.11**	n.s.	**-.56**	n.s.	-.03	-1.51	n.s.
95% LCI	(-.20–	(-.39–	(-.20–		(-1.11–		(-.11–	(-3.36–	
95% UCI	-.06)	-.09)	-.01)		-.01)		0.05)	.33)	
Acrophase β_2	*.41*	*1.03*	*.42*		*.46*		*1.16*	*1.05*	
Amplitude β_1	*.31*	*.12*	*.24*		*1.25*		*0.15*	*6.12*	

mortality, over 0.98 for birth weight of age group 17-18 (0.86 for age group 11-12) to 0.99 for systolic blood pressure at age 11-12 (Table 8.4).

For females the acrophases of the unimodal parts of the sinusoidal functions are 0.77 for total mortality and 0.80 for systolic blood pressure at age 17-18. The acrophases of the bimodal parts of the functions are consistent for cancer (1.03), birth weight of age group 17-18 (1.16) and systolic blood pressure at age 11-12 (1.05).

8.4 Conclusion

In the Minnesota twin data significant and consistent season-of-birth patterns exist in the four measures birth weight, current height, current weight and current systolic blood pressure. They are all consistent with patterns reported in earlier studies.

The season-of-birth patterns for measures related to current age are generally age dependent since they tend to become smaller or even to disappear with age. The large season-of-birth differences in current height and current weight that exist among the younger twins are generally absent at ages 17-18. There is one exception because current height among the older male twins still shows a seasonal month-of-birth pattern.

Recent studies suggest that at adult ages the spring-born men are taller. There is no information about females because the analyses are based on military conscript data. The differences found in these studies, however, are usually a few millimeters and therefore much smaller than those among the twins. Earlier studies have already suggested that the month-of-birth pattern depends on age. Inconsistencies in the results of studies of adolescents by Fitt, Mills, and Chenoweth and Canning were attributed to the different ages of the adolescents and that they were still growing at different rates. However, there is no study that particularly looked at the changes with age. The results from the twins suggest that the interaction between the seasonality in growth and the differences in the rate of growth with age is particularly strong at childhood while growth during puberty seems to have an equalizing effect.

A strong and consistent season-of-birth pattern with two troughs (summer and winter) and two peaks (spring and fall) exists for birth weight with the exception of the younger female twins. An important question is whether this pattern is caused by differences in gestational age and therefore by an increased risk of pre-term births, or whether it is caused by growth-retardation *in-utero*.

There is a general consensus that seasonal differences in birth weight in developing countries are due largely to intrauterine growth retardation. In studies on birth weight in developing countries, three main seasonal factors of intrauterine growth retardation are discussed. First, energy intake during the cold and dry period is about a third greater than during the pre harvest monsoon due to the availability of minor food crops (Brown et al. 1985). Second, rainfall and high temperatures influence disease prevalence during the hot and rainy period in that they have an effect on the incidence of infectious diseases such as gastrointestinal infections (Chen et al. 1979, Datta 1978, Trowbridge & Newton 1979), tuberculosis, measles, and whooping cough (Gordon 1965, Chambers 1981). Third, most agricultural activities are concentrated in the wet season, and the amount of work that women invest in the field increases by a factor of two to three (Brin 1984). The increase in work affects not only energy expenditure – it also reduces the time for social activities, including child rearing. There is an inverse relationship between the amount of time invested in farm work and time invested in activities in the household (Roberts et al. 1982).

There is no consensus yet as to whether the seasonal pattern in the birth weights of historic and contemporary western populations (including Japan) is due to differences in gestational age or to intrauterine growth retardation. The 1993 study by Matsuda et al. shows for Japan that, although the seasonal pattern is dampened, it nonetheless persists – even when corrected for gestational age.

Gestational age is not reported in the Minnesota twin family study, so it is not possible to control for gestational age. There is, however, a study of over 400,000 white singleton live births and stillbirths in Minnesota in the years 1967-1973 by Keller and Nugent (1983) which reports the seasonal pattern of preterm births (29-37 weeks gestational age). Like birth weight, it reveals two troughs and two peaks. The risk of a preterm-birth is particularly high in December and February. It reaches its minimum in March and another peak in July and August. The risk is higher in the autumn than in the spring. A highly significant correlation between the month-of-birth pattern in mean birth weight and the monthly probability of a preterm birth (ρ= -0.73, p=0.007) exists among the older female twins, whereas there is none among the younger female twins (ρ=0.091, p=0.78). For males a non-significant negative correlation exists for the older age group (ρ=-0.38, p=0.22), and there is a negative correlation of borderline significance for the younger age group (ρ=-0.54, p=0.07). The correlation coefficients thus suggest that the monthly differences in the birth weights of twins are partly the results of differences in gestational age. Since the correlation is modest, particularly among males, it also suggests that part of the differences are caused by growth retardation *in-utero*.

The comparison of the seasonal pattern in the risk of a pre-term birth reported in the study of Keller and Nugent and in birth weight reported by this study raises doubts about the validity of the results for the younger female twins. They are the only group without any significant seasonal differences in birth weight. It is highly unlikely that the seasonal differences in gestational age related to prematurity would not be reflected in seasonal differences in birth weight. The lack of any seasonality in the birth weight of the younger females twins is therefore most probably due to problems with the data.

A recent review (Huxley et al. 2002) questions the validity of the relationship between low birth weight and increased systolic blood pressure levels at adult ages. The authors show that the magnitude of the relationship depends on the size of the study population: the larger the population, the smaller is the correlation between birth weight and blood pressure. Furthermore, they point out that most of the studies are adjusted for current weight, which might produce a spurious inverse relationship even if current blood pressure and weight are uncorrelated (Luca et al. 1999, Kramer 1987).

In our study we find a significant positive correlation between the seasonal fluctuations in systolic blood pressure and birth weight for male twins aged 11-12. The correlation, however, is positive because the spring- and the winter-born have lower birth weight and lower systolic blood pressure. At age 17-18 the seasonal fluctuations in systolic blood pressure have disappeared among males. Among females of the same age they still exist but are not correlated with the pattern in birth weight. With regard to the season-of-birth fluctuations our study therefore does not find any support for a negative relationship between birth weight and current systolic blood pressure.

Birth weight, and systolic blood pressure at age 11-12 in the twins and total mortality (males) and cancer (females) in the US death records follow similar bimodal fluctuations. This suggests that the factors that caused the summer trough and autumn peak in the life spans of people born at the beginning of the 20th century could still cause differences in birth weights and systolic blood pressure among children at the end of the 20th century.

Table 8.5. Previous studies about season-of-birth patterns in birth weight, current weight, current height, and weight/height gain.

Topic	Authors	Country	Time period	Size of the sample	Minimum	Maximum	Peak-to-trough difference
Birth weight by month of birth	Adair & Pollit 1983, 1985	Taiwan	6-year time period	450	JUN-AUG (rainy season)	NOV-APR (mild winter)	152 g
	Bantje & Niemeyer 1984	Tanzania	1972-1981	7134	FEB-MAR (rainy season) JUN	SEP-NOV	37 g
	Fallis & Hilditch 1989	rural Zaire (Z) Ontario, Canada (C)	JAN 1972–31 DEC 1981 (Z), 1979–1983 (C)	8,815 (Z); 15,954 (C)	NOV (Z) (rainy season); no seasonality in (C)	JUN (Z) (dry season); no seasonality in (C)	(Z) 196 g
	Hellmuth & Wnorowski 1923	Hamburg, Germany	JAN 1912–SEP 1922	26,515	DEC-MAR (winter)	JUN-OCT	
	Kinabo 1993	Morogoro, Tanzania	1985–1989	19,783	FEB-MAR (rainy season)	AUG (dry season)	
	Matsuda et al. 1995	Japan	JAN 1974–DEC 1983	7,622,012	summer and winter	spring and autumn	
	Moore 1998	The Gambia	1949–cont.	3,102	JUL-DEC (hungry season)	JAN-JUN (harvest season)	200–300 g
	Otto & Glass 1959	Leipzig, Germany	1936–1956	53,638	spring	autumn	43 g

Table 8.5. (continued)

Birth weight by month of birth	Otto & Noack 1957	Berlin; Leipzig; Marburg, Wien, Odessa; Germany	1936–1953, 1937–1953, 1920–1922	48,497 (B) 52,947 (L) 39,000 (M, W, O)	DEC–JUN (B, L); NOV–JUN (M, W, O)	JUL–NOV (B, L); JUL–OCT (M, W, O)	(B, L) 35 g (M, W, O) 60 g
	Pollitt & Arthur 1989	Sui Lin, Taiwan		225	MAY-AUG (hot, rainy season), summer	FEB-MAY (dry season), spring	218.7 g
	Rousham & Gracey 1998	Kimberley region, Western Australia	1981–1993	4,508	JAN–MAR, (wet season))	JUL–OCT, (dry season)	
	Ward 1987	Vienna, Austria	1865–1930	12,700	winter and spring	SEP-DEC autumn	58 g
	Wendl-Richter 1997	North Western Burkina Faso	1987–1989	2,026	AUG (hunger season, field work)	APR-MAY (dry season)	
Length at birth by month of birth	Otto & Glass 1959	Leipzig, Germany	1936–1956	53,638	winter	SEP-OCT	1.92 mm
	Otto & Noack 1957	Berlin & Leipzig, Germany	1936/37–1953	101444 (48,497 + 52,947)	DEC, JAN; MAY-JUL	MAR–APR, OCT	1.5 mm
	Wohlfahrt et al. 1998	Denmark	1973–1994	1,166,206	DEC	APR	2.2 mm

Table 8.5. (continued)

Topic	Authors	Country	Time period	Size of the sample	Minimum	Maximum	Peak-to-trough difference
Weight gain in infants by current month	Brown et al. 1982	Bangladesh	APR 1978–JUN 1979	174	MAR–JUN	AUG–DEC	
	Xu et al. 2001	Shanghai, China	JAN 1980–DEC 1990	4,128	MAY-JUL (wet season), summer	AUG-JAN autumn and winter	
Height gain in infants by current month	Cole 1993	West Kiang, The Gambia; Cambridge, England	MAY1974–APR 1980 (G), 1984 -1988 (E)	686 (G), 191 (E)	JUN–OCT (hungry season) (G)	AUG (E)	
	Xu et al. 2001	Shanghai, China	JAN 1980–DEC 1990	4,128	autumn and winter	spring and summer	
Weight loss by current month	Cole 1993	The Gambia females	1978–1988	529	JUN-OCT (hungry season)	NOV-MAY (harvest season)	4 kg in 1978 2 kg in 1988
	Chen et al. 1979	Bangladesh	MAR 1976-SEP 1977	200	MAY-JUL	SEP-OCT	2 kg
Current weight by month of birth	Chenoweth and Canning 1941	Cincinnati, United States	birth cohorts 1904–1921	10,005 freshmen	AUG–NOV (SEP–DEC)	MAR–JUN (spring)	0.8 pounds
	Fitt 1955	New Zealand	army draft World War II.	21,177 men	MAY – JUN (late autumn)	DEC (early summer)	1.32 pounds
	Hillman & Conway 1972	United States	1966–1970	9,103	normal & underweight: JUN and JUL; overweight: OCT and NOV	overweight: MAR	

Table 8.5. (continued)

Current weight by month of birth	Mills 1955	Kentucky, Kansas, Wisconsin, North Carolina	1912–1939	45000 freshmen and women (ages 16–19)	OCT–DEC	APR–JUN	boys: 0.71 pounds; girls: 0.41 pounds
	Phillips and Young 2000	Hertfordshire, UK	1920–1930	1,750	JUL–DEC	JAN–JUN	
Current height by month of birth	Chenoweth and Canning 1941	Cincinnati, United States	1904–1921	10,005 freshmen	AUG–OCT	MAR-JUN spring	0.3 inch
	Mills 1955	Kentucky, Kansas, Wisconsin, North Carolina	1912–1939	45,000	OCT–DEC	APR–JUN	boys: 0.16 inches, girls: 0.04 inches
	Weber et al. 1998	Austria	1984–1993 (birth cohorts 1966–1975)	507,125 men	autumn	spring	0.6 cm
	Banegas et al. (2001)	Spain		2021, ages 35-64	males: winter	males: summer	1.7cm
Current systolic blood pressure	Banegas et al (2000)	Spain		572 men ages 45-64	MAY-JUN	OCT-NOV	11.1 mmHG