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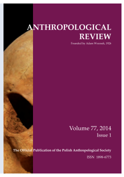

Understanding the links between month of birth, body height, and longevity: why some studies reveal that shorter people live longer – further evidence of seasonal programming from the Polish population

Piotr Chmielewski[1], *Krzysztof Borysławski*[2]

[1]Department of Anatomy, Faculty of Medicine, Wrocław Medical University, Poland
[2]Department of Anthropology, Wrocław University of Environmental and Life Sciences, Poland

Abstract: There is a lack of agreement in the literature as to whether adult height depends on month of birth and whether height affects lifespan. Additionally, the relationship between stature and longevity involves conflicting findings and the results remain mixed due to several confounders, such as: year of birth, somatotype, relative body weight, genetic inheritance, diet, diseases, etc. Here, we hypothesize that the season of birth effect can also be involved in shaping the mysterious link between body height and longevity. To assess the links between month of birth, adult height, and longevity in the Polish population, data on 848,860 individuals, of whom 483,512 were men (57%) and 365,348 were women (43%), born in the years 1896–1988 and died in the years 2004–2008, were collected from the 'PESEL' database and signalments in the censuses obtained from identity card offices throughout Poland. ANOVA and the LSD test were performed. A significant relationship between month of birth and lifespan was found. Individuals born in autumn and winter months lived significantly longer than those who were born in the middle of the year (May). The amplitudes of lifespan were 16 months in men and 14 months in women. As expected, subjects of both sexes born in autumn and winter months were significantly shorter than their peers born around the middle of the year. In conclusion, the results of the study not only corroborate the theory of seasonal programming of longevity and support the idea that some undetermined factors from early stages of ontogeny and associated with season of birth have long-term effects on phenotype in later life in terms of adult height and longevity, but also bear out the hypothesis that month of birth can be another important confounding factor with respect to the relationship between adult height and longevity.

Key words: month of birth effect, season of birth, body height, stature, lifespan, longevity

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Introduction

There is no agreement in the anthropological literature as to whether adult height depends on month of birth and whether body height affects lifespan. Additionally, the relationship between adult stature and longevity involves conflicting findings and the results remain mixed, presumably due to several confounding factors, such as: year of birth, somatotype, relative body weight, genetic inheritance of longevity, climate, diet, diseases, and socioeconomic status (Samaras 2007; 2014; Chmielewski et al. 2015b; 2016b; Chmielewski and Borysławski 2016; Perkins et al. 2016). Nevertheless, it has been established that factors acting upon the organism during early ontogeny are key determinants of future life events as well as healthspan and lifespan. Both extrinsic and intrinsic groups of factors during gestation and at early stages of infancy may play an extremely important role in shaping the phenotype and risk of adult diseases in later life (Barker 1998; 2006; Almond and Currie 2011). Here, we hypothesize that the season of birth effect is likely to be another important confounding factor with respect to the weak and unstable relationship between adult stature and longevity in humans (cf. Kemkes-Grottenthaler 2005; Samaras 2007; 2013; 2014; Paajanen et al. 2010; He et al. 2014; Özaltin 2012; Chmielewski and Borysławski 2016; Perkins et al. 2016).

A growing body of evidence suggests that adult stature (Weber et al. 1998), health (Bateson et al. 2004), lifespan and mortality (Gavrilov and Gavrilova 1999; Doblhammer and Vaupel 2001; Vaiserman et al. 2002; Lerchl 2004; Ueda et al. 2013; Vaiserman 2014; 2015; Chmielewski 2016), personality traits (Salib and Cortnia-Borja 2006), and even fertility or fecundity (Huber et al. 2004) may respond to prenatal programming in a seasonal fashion. Moreover, the long-lasting effects of early life conditions, which differ in both sexes, can also contribute to the well known sex disparities in late life. Therefore, it was established that certain fitness traits, i.e. biological characteristics that remain under strong and directional selection, show significant seasonal variation, which can be attributed to effects of seasonal programming. It has long been known that biological systems show a dynamic equilibrium and are subject to seasonality, which can be defined as regular, recurring fluctuations in the values of various biological features observed in a specified unit of time. Seasonality plays an important role in human biology and affects many morphological, physiological, and behavioral traits. Furthermore, its influence is not limited to ontogenetic development, but also has some important evolutionary aspects (Ulijaszek and Strickland 1993; Crews 2003; Chmielewski 2016). Huntington (1938) was probably the first researcher to demonstrate the relationship between the season of birth and lifespan in humans. He analyzed about 39,000 dates of birth and death in families from various regions of the USA and noted that individuals born in February or March (late winter/early spring) lived significantly longer than their peers born in July or August (summer). This serendipitous discovery has inspired many researchers and today the seasonality of different biological traits, including physiological and behavioral ones, is the subject of numerous studies. In the 1980s, Japanese researchers analyzed data on graduates of the medical university in Tokyo and data from mental hospital inmates and found that individuals born between May and July had a lower life expectancy after age 70 to 75 than their peers born in other months of the same year (Miura and Shimura 1980). Moreover, epidemiological studies carried out in the 1990s on rural children in Gambia demonstrated the higher mortality of individuals born in the dry season compared with those born in the wet season (Moore et al. 1997).

Searching for new predictors of longevity, gerontologists Leonid Gavrilov and Natalia Gavrilova analyzed 4,911 archive entries on lifespan in European aristocratic families. They assessed data from adult women born in the years 1800–1880, who at death were aged at least 30 years, and concluded that month of birth was a strong and good predictor of longevity in the studied population. Furthermore, it turned out that the month of birth effect was not an artifact, despite the initial assumptions (Gavrilov and Gavrilova 1999). To demonstrate this relationship, the researchers investigated the influence of factors such as the year of birth (due to the longer life expectancy in successive birth cohorts), lifespan of both parents (due to genetic inheritance and determinants of longevity), age of the mother and father at birth of the studied subjects, order of birth, nationality, causes of death, and loss of one or both parents before the age of 20 years. Their results indicated that women born in May (late spring) and December (late autumn/early winter) lived for about three years longer compared with their peers born in August (multiple regression analysis, $p<0.001$).

To date, several hypotheses have been put forward to elucidate the month of birth effect on various phenotypic traits and longevity. For example, confounding pathological effects, debilitation *in utero* and at early stages of ontogeny, unobserved social factors, and selective infant or adult survival were proposed as the plausible explanations (Doblhammer and Vaupel 2001). Nevertheless, the biological mechanisms and proximal causes involved in the process of seasonal programming of longevity in humans remain poorly understood. Interestingly, when researchers compared northern and southern hemisphere births and tried to establish whether the trend reverses due to the seasons being opposite in the two hemispheres, they found that the patterns of the relationship between month of birth and lifespan are very similar in geographically close populations, while the trends observed in the southern hemisphere are usually shifted by half a year (Doblhammer and Vaupel 2001). There are currently several hypotheses and models explaining the month of birth effect with respect to healthspan and longevity. Three concepts, however, are mentioned most frequently. These are: (1) The hypothesis of seasonal programming, also called the debilitation *in utero* hypothesis, which assumes that the amount and quality of nutrients and biologically active substances (e.g. vitamins, hormones, etc.) available to a fetus and newborn determines the adaptive programming of the child's metabolism in the whole of later life. This concept is derived directly from the Barker theory on fetal and infant origin of adult disease. In particular, this hypothesis concerns a situation where during a given critical period a seasonal shortage of some biologically active substances occurs, which may adversely affect the healthspan and lifespan (Almond and Currie 2011). The month of birth is therefore only an indicator of seasonal changes in environmental conditions, taking some effect during the early stages of ontogeny. (2) The hypothesis of unobserved social factors refers to situations in which women of lower socioeconomic status (SES) become pregnant more frequently in certain months of the year. Some studies conducted in the USA showed that women from poor families are more likely to become pregnant in spring. Therefore, a significant percentage of children born in winter are those which were exposed to a combination of unfavorable factors – mainly the biological condition of the mother, nutritional status, diet, stress level, stimulants, SES, and living conditions in the family. (3) The hypothesis of the natural connection between age and seasonality of deaths, also called the hypothesis of artifact, is based on the assumption that there is a natural link between mortality and the biological age of deceased individuals. This means that an individual born in April is simply older (and biologically weaker) than one born in December (younger and biologically stronger), when a seasonal factor further increasing the risk of death in older age takes its powerful effect – mainly temperatures below zero, heat waves, and, to a lesser extent, environmental pollution, smog, or peak incidence of influenza, as well as other infectious diseases. Accordingly, older and biologically weaker individuals are simply more likely to die, but the relationship does not necessarily have to be linear, because chronological age does not correspond to biological age of individuals. It should be emphasized that the relationship between the month of birth and lifespan deserves special attention, because the month of birth is currently used in epidemiology, medical anthropology, and gerontology as an important indicator of conditions at early stages of ontogeny that may have some long-term health effects, and thus can be an important predictor of the rate of aging and longevity in a given population, among other novel and important strong predictors of longevity (Friedman et al. 1974; Leng et al. 2005a; 2005b; Heidinger et al. 2012; Chmielewski et al. 2016a; Chmielewski 2016). The link between month of birth and lifespan encompasses the total impact of seasonal changes in other biological characteristics on the overall ability to survive. Moreover, information on the type of effect associated with month of birth for a particular geographic area (probably characterized by certain type of clinal variation) can be used for testing hypotheses on its direct causes, and even to predict the most favorable months for becoming pregnant from the point of view of the health and lifespan of offspring.

The present study aimed to explore the associations between month of birth, adult height, and lifespan in the Polish population with respect to the probable role of the month of birth effect in shaping the link between adult height and longevity. If the month of birth effect on height and longevity is proven, it will be important to determine and compare its character and significance in both sexes. It will also be necessary to compare our findings with other populations, based on data published by other authors, which is relevant for testing some of the hypotheses and models regarding the causes of these interesting effects. Although the study focuses on the relationships between the month of birth, adult stature, and lifespan, which have been well-investigated and repeatedly confirmed in numerous population-based studies conducted in Europe, Asia, and North America, especially in the context of determining the character and significance of month of birth as a strong and genuine predictor of longevity, these interesting links have not been systematically studied in the Polish population, especially with respect to the possible role in shaping the relationship between adult height and longevity. Moreover, our research can be a starting point for more sophisticated studies on biological and social causes, determinants, and consequences of the month of birth effect with respect to healthspan and longevity in the Polish population.

Materials and methods

Study material was provided by the Ministry of Internal Affairs and Administration in Warsaw, Poland, and comprised all death records of adults holding a Polish identity card in the years 2004–2008. This included 848,860 individuals, of whom 483,512 were men (57%) and 365,348 were women (43%), born in the years 1896–1988. The data came from two sources, i.e. the PESEL Universal Electronic System for Registration of the Population (sex, exact dates of birth and death) and from signalments in the censuses obtained from identity card offices throughout Poland (body height declared on the identity card).

To demonstrate the relationship between the month of birth and body height and lifespan, the analysis was carried out only for individuals who died aged at least 50 years (776,797 individuals of whom 427,872 were men and 348,925 were women). This was justified by the need to compare the study sample with data in the literature on other populations in which this age limit was adopted most frequently. Arithmetic means were compared using one-way ANOVA. The homogeneity of variance was analyzed using Levene's test. The least significant difference (LSD) was calculated from the *post-hoc* Fisher's test: LSD = $Q_{0.05}$; *a; df S*, where: *Q* is critical value at a confidence level of 0.05, *a* stands for number of groups, *df* denotes number of degrees of freedom, *S* represents standard error of the mean, i.e. sample standard deviation (s^2) divided by the square root of the sample size (*N*). All statistical calculations were performed using Microsoft Excel and Statistica 9.0 software from StatSoft.

The collected material has several important advantages. First of all, the sample is very large and representative for the whole studied population, which is fundamental for the analysis of such relationships. It is often pointed out that gathering a large sample of material representative for the whole population of the country is a *sine qua non* prerequisite in such studies. This is necessary because, for example, body height is an ecosensitive morphological trait determined by many biological and social factors, while the variation in lifespan as well as in body size is very large in each human population. Moreover, there are often numerous defined or unknown selection factors.

The next important characteristics of the study sample are heterogeneity and typical causes of death, i.e. the same as in the total population. Even randomly chosen data sets concerning ten to ninety thousand people are described by investigators of the month of birth effect as insufficiently large. It is believed that various local factors (mainly the level of pollution, smog, radiation and climatic factors, etc.), and above all different social and biological factors (mainly a history of childhood diseases, order of birth, age, health and lifestyle of parents, the biological condition of subjects, socioeconomic status, educational level, occupation, the cause of death and many others) can easily distort the image of the investigated relationships. Despite these reservations many epidemiological and anthropological studies are based on statistics from small geographical areas (i.e. cities or districts where the residents are affected by specific local factors, e.g. smog in Kraków), obtained in a short period of time, or concerning individuals that died of a specific disease (cardiovascular disease and cancer), which is justified for practical reasons but has a negative effect on the value of research and validity of conclusions.

Another advantage of the analyzed study material is the high reliability of data on dates of birth and death, proven by relevant documents. According to many authors, the use of the declared body height is also justified, or at least acceptable, in a situation when measurements cannot be taken. This is because in young and older adults there is a high and statistically significant correlation between the self-reported and measured values of this feature (usually at the level of $0.8 \leq r \leq 0.9$; $p < 0.001$), especially if body height is given for official purposes, not for matrimonial. On the other hand, some respondents tend to overestimate their body height (usually by 1-2 cm), and this more frequently happens with young men as well as with short individuals, while very tall people usually indicate slightly lower values of stature than actual (Brener et al. 2003; Sherry et al. 2007; Danubio et al. 2008; Krul et al. 2010; Bowring et al. 2012).

There is another extremely important criterion that should always be included in such investigations and that is met by our study material. Namely, for methodological reasons relating to extreme caution in the selection of empirical material and the choice of research methods, the study should be based solely on data gathered specifically to clarify the effect of month of birth on the analyzed biological characteristics, and not on the secondary use of material collected previously for another purposes, especially if the material is cross-sectional and there is a risk of the cohort effect (Kościński et al. 2009).

However, one disadvantage of the gathered study material is that the analysis did not consider potentially significant confounding factors which concern the investigated relationships and may modify them in various ways. For example, we did not consider somatotypes, body mass index (BMI), health status, diet and nutrition, socioeconomic status, specific causes of death, aging-associated alteration in body height, proximal causative factors proposed in the literature (e.g. hormonal profile, vitamin D_3 level, growth rate during progressive ontogeny, detrimental effects of catch-up growth, etc.), or even the type of the place of residence (i.e. urban or rural). Nevertheless, it seems that the relationship between the month of birth, adult height, and lifespan can be established based on the study sample used for the analysis.

Results

In both sexes, distributions of body height and lifespan in the whole sample, analyzed with the goodness of fit test χ^2, as well as cofactors of asymmetry and kurtosis, did not differ significantly from normal distribution. The analysis of the whole study data indicated that men were significantly taller than women (arithmetic mean ± standard deviation for men: 171.6±6.6 cm; for women:159.6±6.2 cm, $F=1.14$; $p<0.001$) and lived significantly shorter (67.9±13.8 years for men vs.75.0±12.7 years for women, $F=1.19$; $p<0.001$). In the statistical analysis of data on individuals who died aged at least 50 years, the values were 171.1±6.4 cm for men and 159.4±6.1 cm for women, and 71.1±10.8 years for men and 76.5±10.8 years for women, respectively, and the differences between all means were always significant (ANOVA, $p<0.001$). In the group of individuals who lived for at least 50 years, subjects born in autumn and winter months lived significantly longer than their peers who were born in the middle of the year, i.e. in spring and summer months (Figure 1; Tables 1 and 2). Differences between means were significant both in men ($F=38.31$; $p<0.001$) and women ($F=25.81$; $p<0.001$). For both sexes the longest lifespan was found for individuals born in December, and the shortest for those born in May. The amplitude of lifespan resulting from the month of birth effect was over 16 months in men and close to 14 months in women. The amplitude was similar

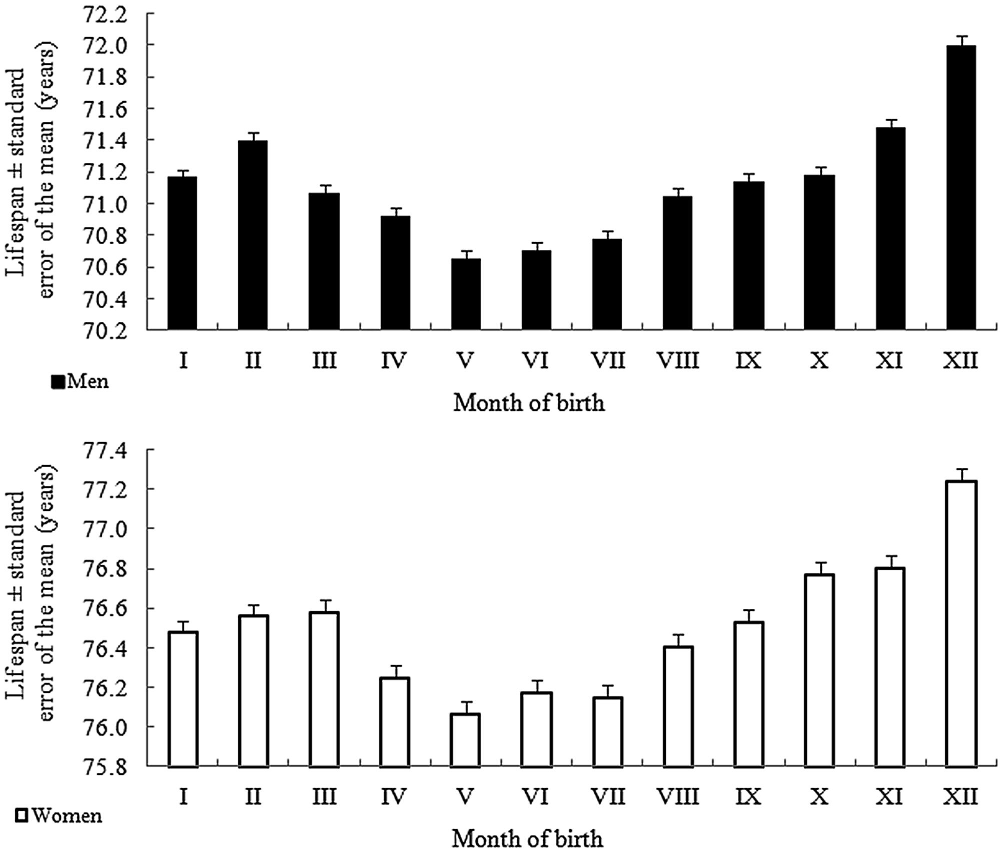

Fig. 1. Lifespan (arithmetic mean ± standard error of the mean) depending on the month of birth in subjects who died aged at least 50 years ($N=776{,}797$ individuals, including 427,872 men and 348,925 women)

Table 1. Baseline characteristics of men and women who died aged at least 50 years.

Month of birth	Men N=427,872			Women N=348,925		
	Lifespan Mean±*SD* (years)	Body height Mean±*SD* (cm)	*N*	Lifespan Mean±*SD* (years)	Body height Mean±*SD* (cm)	*N*
I	71.16 (10.53)	171.09 (6.36)	47591	76.48 (10.68)	159.51 (6.08)	35337
II	71.39 (10.80)	171.14 (6.43)	36146	76.56 (10.85)	159.43 (6.13)	29356
III	71.07 (10.83)	171.29 (6.44)	39775	76.58 (10.89)	159.50 (6.14)	32563
IV	70.92 (10.83)	171.29 (6.45)	36100	76.25 (10.96)	159.51 (6.13)	29134
V	70.65 (10.73)	171.17 (6.40)	36599	76.07 (10.81)	159.47 (6.11)	29469
VI	70.70 (10.74)	171.15 (6.44)	33094	76.17 (10.88)	159.37 (6.13)	26553
VII	70.77 (10.72)	170.93 (6.42)	34207	76.14 (10.83)	159.39 (6.11)	27945
VIII	71.04 (10.73)	170.94 (6.45)	34512	76.41 (10.78)	159.28 (6.11)	28323
IX	71.13 (10.82)	170.90 (6.47)	35245	76.53 (10.84)	159.40 (6.15)	28783
X	71.18 (10.92)	170.97 (6.41)	33271	76.77 (10.87)	159.25 (6.16)	27833
XI	71.47 (10.85)	170.91 (6.42)	32351	76.80 (10.71)	159.37 (6.19)	27051
XII	71.99 (10.96)	170.85 (6.47)	28981	77.24 (10.70)	159.33 (6.17)	26578

Table 2. Significance of differences between average lifespan (ALS) depending on the month of birth in men and women who died aged at least 50 years, assessed with the LSD test.

Women	Men	I 71.16	II 71.39	III 71.07	IV 70.92	V 70.65	VI 70.70	VII 70.77	VIII 71.04	IX 71.13	X 71.18	XI 71.47	XII 71.99
I	76.48	x	**	ns	***	***	***	***	ns	ns	ns	***	***
II	76.56	ns	x	***	***	***	***	***	***	***	**	ns	***
III	76.58	ns	ns	x	ns	***	***	***	ns	ns	ns	***	***
IV	76.25	**	***	***	x	***	**	ns	ns	**	***	***	***
V	76.07	***	***	***	*	x	ns	ns	***	***	***	***	***
VI	76.17	***	***	***	ns	ns	x	ns	***	***	***	***	***
VII	76.14	***	***	***	ns	ns	ns	x	***	***	***	***	***
VIII	76.41	ns	ns	*	ns	***	**	**	x	ns	ns	***	***
IX	76.53	ns	ns	ns	***	***	***	***	ns	x	ns	***	***
X	76.77	***	**	*	***	***	***	***	***	**	x	***	***
XI	76.80	***	**	**	***	***	***	***	***	**	ns	x	***
XII	77.24	***	***	***	***	***	***	***	***	***	***	***	x

x – blank field; ns – nonsignificant; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

in subsequent subgroups of individuals who died in subsequent years between 2004 and 2008.

In subjects who died in 2004 (N=75,541 individuals, including 44,826 men and 30,715 women), differences between mean lifespans were significant in men ($F=6.20$; $p<0.001$) and women ($F=4.17$; $p<0.001$). The longest lifespan was found in subjects born in December, and the shortest in those born in May, and the difference between the subgroups was slightly over 21 months in men and 18 in women. In the group of subjects who died in 2005 (N=114,096 individuals, including 66,488 men and 47,608 women), differences between means were significant in men

(F=4.51; p<0.001) and women (F=2.96; p<0.001), and in both cases the longest lifespan was found in subjects born in December. The shortest lifespan was found in men born in May and women born in April. The maximum difference resulting from the month of birth effect was 16 months in men and 13 months in women. In the group of subjects who died in 2006 (N=146,127 individuals, including 86,117 men and 60,010 women), differences between means were significant in both sexes, F=10.46; p<0.001 and F=4.65; p<0.001, for men and women, respectively. The longest lifespan was found in subjects born in December, and the shortest in those born in May (men) and June (women). The amplitude was nearly 20 months in men and nearly 14 months in women. In subjects who died in 2007 (N=198,852 individuals, including 115,539 men and 83,313 women) differences between means were significant (F=8.46; p<0.001 in men and F=5.13; p<0.001 in women). The longest lifespan was found in subjects born in December, and the shortest in those born in June (men) and May (women). The maximum difference was about 15 and 12 months, respectively. In the group of

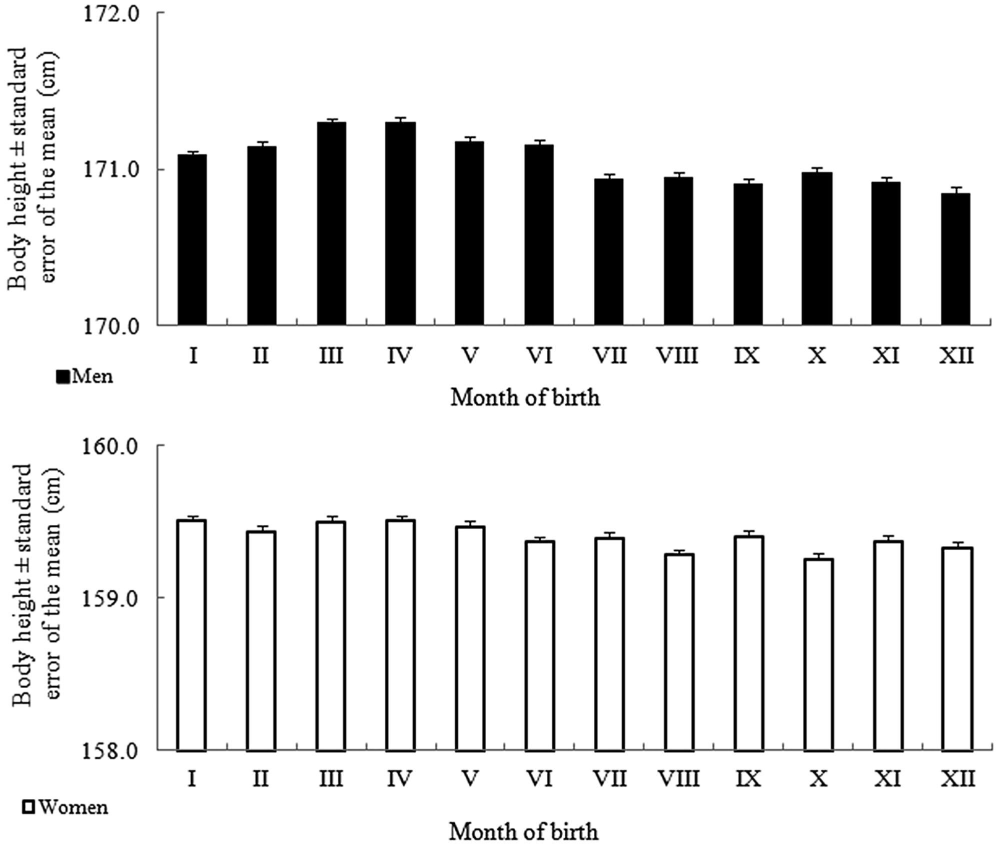

Fig. 2. Body height (arithmetic mean ± standard error of the mean) depending on the month of birth in subjects who died aged at least 50 years (N=776,797 individuals, including 427,872 men and 348,925 women)

Table 3. Significance of differences between average body height depending on the month of birth in men and women who died aged at least 50 years, assessed with the LSD test.

Women	Men	I 171.09	II 171.14	III 171.29	IV 171.29	V 171.17	VI 171.15	VII 170.93	VIII 170.94	IX 170.90	X 170.97	XI 170.91	XII 170.85
I	159.51	x	ns	***	***	ns	ns	***	***	***	**	***	***
II	159.43	ns	x	***	***	ns	ns	***	***	***	***	***	***
III	159.50	ns	ns	x	ns	**	**	***	***	***	***	***	***
IV	159.51	ns	ns	ns	x	**	**	***	***	***	***	***	***
V	159.47	ns	ns	ns	ns	x	ns	***	***	***	***	***	***
VI	159.37	**	ns	**	**	*	x	***	***	***	***	***	***
VII	159.39	**	ns	*	*	ns	ns	x	ns	ns	ns	ns	ns
VIII	159.28	***	**	***	***	***	ns	*	x	ns	ns	ns	ns
IX	159.40	*	ns	*	*	ns	ns	ns	**	x	ns	ns	ns
X	159.25	***	***	***	***	***	*	**	ns	**	x	ns	**
XI	159.37	**	ns	**	**	ns	ns	ns	ns	ns	*	x	ns
XII	159.33	***	*	***	***	**	ns	ns	ns	ns	ns	ns	x

x – blank field; ns – nonsignificant; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

subjects who died in 2008 ($N=314,244$ individuals, including 170,542 men and 143,702 women) differences between means were significant in men ($F=13.91$; $p<0.001$) and in women ($F=14.08$; $p<0.001$), and the effect was the same as in 2007. The maximum difference was about 17 months in men and 16 months in women. The relationship between the month of birth and body height was demonstrated in both sexes, and its pattern was very similar (Figure 2; Table 3).

As expected, men responded more strongly to the month of birth effect than women did, because differences in men were more frequently greater, and the trend of greater body height in subjects born in early spring was more constant and clear compared with women. In conclusion, the relationship between the month of birth and lifespan was found in both sexes, and the relationship was very similar in terms of the overall nature, significance and trend. Differences in mean lifespan (i.e. amplitude of variation) across cohorts were similar for their size. However, in men this relationship was stronger than in women, because the largest difference in lifespan in subjects who died aged at least 50 years of age was greater in men, and the differences in men were greater for 8 months, i.e. in January, February, April, July, August, September, November, and in December.

Discussion

The results of the present study suggest that the month of birth effect in the Polish population can also be an important confounding factor with respect to the unclear and tenuous links between adult height and lifespan. Numerous previous studies on the month of birth effect revealed its strong influence on human longevity (Gavrilov and Gavrilova 1999; Doblhammer and Vaupel 2001; Vaiserman et al. 2002; Lerchl 2004; Almond and Currie 2011; Vaiserman 2014; 2015; Chmielewski 2016). Interestingly, the results of only few studies supported the idea of seasonal programming and the month of birth effect with respect to final adult height (Weber et al. 1998), reproductive potential (Lummaa 2003; Huber et al. 2004, Cagnacci et al. 2005), mental and physical capacity and temperament (Chotai et al. 2001; Salib and Cortina-Borja 2006; Döme et al. 2010), incidence of certain illnesses, particularly schizophrenia (Torrey et al. 1997; Verdoux et al. 1997), Alzheimer's disease (Vézina et al. 1996), autism (Barak et al. 1995, Stevens et al. 2000), and some types of cancer, including breast cancer (Yuen et al. 1994); interestingly, for other types of cancer, which are strictly related to lifestyle (e.g. lung cancer) no such correlation was found (Kapitány et al. 2011).

The relationship between the month of birth and lifespan has been observed in many populations throughout the world, but nowadays it is known that there are some important inter-population differences in the significance and nature of this phenomenon. In other words, the strength and character of the month of birth effects varies between different populations and between different individuals from the same population (since socioeconomic status can also play an important role in shaping these interrelationships). Moreover, the month of birth effect is usually slightly more pronounced in men, as they are more sensitive to environmental factors compared with women. The results of other studies also corroborate the belief that men show generally greater ecosensitivity during the ontogenetic development than women do (Stini 1969; Stinson 1985; Stindl 2004; Chmielewski 2012; 2016; Chmielewski and Borysławski 2016; Chmielewski et al. 2015a; 2015b; 2016a; 2016b). To date, numerous anthropological and epidemiological studies have confirmed these findings.

In subsequent generations, however, the month of birth effect usually becomes weaker, which is explained by the fact that the healthier lifestyle and eating habits of pregnant women in many developed countries compensate for seasonal fluctuations in the supply of various biologically active substances, which to some extent could be responsible for the observed differences between various generations as well as between different populations. In general, the higher the socioeconomic status (SES) and educational attainment of mothers, the weaker the month of birth effect (Lerchl 2004; Chmielewski 2016).

To determine the possible causes of the month of birth effect on lifespan, some authors (Doblhammer and Vaupel 2001) compared its character and significance in selected populations, with a focus on the place of birth and death of individuals, and the typical pattern of the analyzed correlation in both hemispheres. In two countries of the northern hemisphere (Austria and Denmark) subjects born in autumn and winter months (from October to December) lived significantly longer than their peers born in spring months (from April to June). Data from Australia revealed a six-month shift in this effect in comparison to the countries of the northern hemisphere, but British people who emigrated to Australia and died there showed a pattern typical for the northern hemisphere (birthplace), and not for the southern hemisphere (place of death). This observation was based on a random sample of more than a million people, unaffected by any known selection factor (Doblhammer and Vaupel 2001).

Other researchers investigated the relationship between longevity and birth season based on a sample of 101,634 people who died in Kiev, Ukraine, in the years 1990-2000. The analysis revealed a very similar relationship in both sexes: the shortest lifespan in subjects born between April and July, and the longest in subjects born at the beginning or end of the year. The maximum difference resulting from the month of birth effect was 2.6 years (31 months) in men and 2.3 years (28 months) in women (Vaiserman et al. 2002). Considering the total mortality obtained by adding deaths due to known major causes in the study population, the analysis revealed the longest lifespan in subjects born in the fourth quarter of the year.

Studies conducted in a German population of 188,515 individuals who died in 1984 and 188,850 individuals who died in 1999, demonstrated the lowest life expectancy in subjects born between May and July, and the highest in subjects born between October and December Interestingly, the amplitudes of this effect (maximum differences) were greater in men than in women (Lerchl 2004), which is

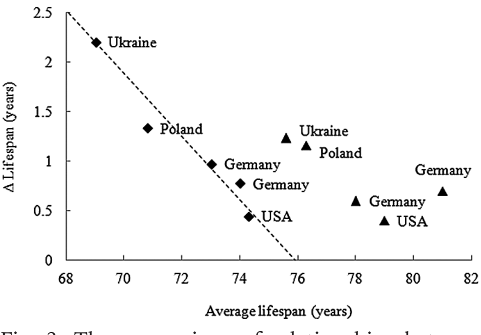

Fig. 3. The comparison of relationships between the average lifespan (ALS, *x* axis) and the differences between the highest and lowest ages at death between the respective months of birth (Δ, *y* axis), according to population and sex (men: ◊ – diamond; women: Δ – triangle), based on the results of previous studies (USA – Doblhammer & Vaupel, 2001; Ukraine –Vaiserman et al., 2002; Germany – Lerchl, 2004) and own data (Poland – Chmielewski 2016)

also in agreement with the results of the present study.

By comparing these findings with data concerning Ukraine and the USA, Lerchl (2004) was probably the first to notice a negative correlation between the average life expectancy of subjects and the maximum difference (amplitude) due to the month of birth effect. A comparison in this respect, carried out separately for both sexes, demonstrated a significant correlation in men ($r=-0.986$; $p=0.014$; Fig. 3, see dotted line), but not in women ($r=-0.675$; $p=0.325$). It has been found that the more difficult living conditions in a population are, which is roughly indicated or reflected in the value of average life expectancy for a given population, the stronger the month of birth effect is. Moreover, greater average life expectancy is correlated with lower differences between sexes in the amplitude of the analyzed effect (marked in the figure as delta). The largest differences were found in Ukraine, and the smallest in the USA as well as in Germany. In Poland, the differences were intermediate between those in Ukraine and Germany.

The analysis of the relationship between the month of birth and lifespan or longevity in a given population should always take into account the number of deaths in the subsequent months and the average lifespan within the group, for which no artificial factors limiting lifespan have been used. Such comparisons were conducted in the present study. These results clearly indicate a typical response of the Polish population to the month of birth, and very similar to that observed previously in other geographically close populations (Doblhammer and Vaupel 2001; Vaiserman et al. 2002; Lerchl 2004; Chmielewski 2016), and the significance of this effect is intermediate between that in the Ukrainian population and the German population analyzed at the end of the 20th century (see Fig. 3).

Considering the various plausible causes of the month of birth effect, researchers have emphasized that the overall pattern and character of this effect and factors that modify its strength indicate the decisive role of early programming in ontogeny, when during critical periods of development, some permanent, irreversible and long-lasting structural and functional changes can take place, especially the idea of seasonal programming of the metabolism in the developing fetus (Barker 1998; 2006; Gavrilov and Gavrilova 1999; Doblhammer and Vaupel 2001; Vaiserman et al. 2002; Gavrilova et al. 2003; Lerchl 2004; Stöger 2008; Almond and Currie 2011; Wells 2011; Vaiserman 2014; 2015; Zabuga et al. 2014; Chmielewski 2016). These changes are triggered by various environmental factors (climatic and environmental, such as radiation, insolation, food and its nutritional value), as well as intrauterine factors (hormone levels in the mother, levels of vitamins or antibodies in the blood). In particular, this hypothesis posits that some chronic and degenerative conditions of health in adulthood, including cardiovascular disease and type 2 diabetes, may be triggered by developmental conditions and circumstances during early stages of ontogenetic development. Interestingly, economists who investigated theses relationships have expanded on this hypothesis. Thus, the fetal origin hypothesis, originally proposed by an English physician and epidemiologist David Barker (1938-2013), has been corroborated by extensive research from other fields and has flourished (Stöger 2008; Almond and Currie 2011; Vaiserman 2014; Zabuga et al. 2014). The role of unobserved social factors, perinatal selection and birth seasonality is less likely, although it is possible that these processes and phenomena also impact, to a certain extent, this effect by slight modification of its local pattern. The occurrence of a pattern typical for the northern hemisphere, which is different from that seen in the southern hemisphere, indicates the role of global factors such as insolation, and consequently varying levels of vitamin D_3 biosynthesis in the skin of the mother. On the other hand, the differences in the type of this effect observed in Australians and individuals that were born in the United Kingdom but died in Australia, points to a 'footprint' of early stages of ontogeny (during gestation or in first few years after birth).

It is commonly believed that there are several critical periods in the child's development. In the first trimester of gestation, the fetus is most sensitive to teratogenic factors, xenobiotics, alcohol, tobacco, stress, and malnutrition of the mother. This is a particularly critical period of embryogenesis due to the high risk of malformations. The moment of birth and the first years of life are also regarded as critical. For example, if we assume that the first trimester of gestation is the most critical period of development, it can be noted that in the case of subjects born in December it coincides with the months characterized by the highest insolation, when the level of essential vitamin D_3 synthesis in the skin of the mother is sufficient, while in the case of subjects born in spring or summer – it coincides with months when this vitamin is deficient. The role of vitamin D_3 synthesis in the skin as a limiting factor (e.g. Czech-Kowalska et al.

2008) would explain the pattern of the month of birth effect and its universal character for the northern hemisphere, as well as the shift in this pattern by half a year in the southern hemisphere. The problem of causative factors and mechanisms of metabolic programming has not been finally dealt with (Taylor 2010). There is some speculation that persistent metabolic changes programmed at some stages of early ontogeny and having long-term effects on health, and thus on lifespan, result from genetic changes that are passed on to subsequent generations by means of the epigenetic mechanism. According to another hypothesis, the factors programming a child's metabolism affect the distribution of cells and their function, which may be associated with the arrangement of receptors in the fetus during the first trimester of gestation (Lucas 1998).

In the Netherlands, individuals who at the time of 'the Dutch Hunger Winter' in the years 1944–1945 were at a specific period of their prenatal development and exposed to considerable energy deficiency were consequently in adult life more vulnerable and susceptible to a number of diseases (e.g. obesity, hypertension, diabetes, cardiovascular disease, etc.). These individuals and their offspring were found to have significantly reduced methylation levels at *IGF*-2 gene, which is one of the genes subject to genomic imprinting. These findings showed that the environmental conditions at the early stages of development can cause epigenetic changes that will not only persist in individuals throughout their life, but are also passed on to subsequent generations (Heijmans et al. 2008).

The role of additional factors cannot be ruled out, such as the demographic upsurge of births in the fourth quarter of the year, because the seasonality of births was observed in the studied population. It is a well known effect that also occurs in other primates. Since Africa is the cradle of humankind, and the populations living in warm regions are more sexually active and have a higher birth rate than the populations living in colder areas, it can be assumed that there are also changes in activity and fertility within the population in subsequent months of the year, associated with temperature, insolation and cloud cover, seasonal changes in diet, etc. Increase in sexual activity typically starts in the spring months, which explains the upsurge in the number of births from January to March. The hypothesis of a holiday break in December and January refers to the second increase in the number of births, which takes place in September and at the end of the year.

The relationship between the month of birth and adult height is slightly more controversial since only a few studies have confirmed such links (Weber et al. 1998; Banegas et al. 2001; Kihlbom and Johansson 2004). According to reported data, in Europe the spring months of birth are the most favorable for adult body height, while birth in autumn and winter months is the least favorable. Therefore, the results from the present study conform with previous findings by other authors, although the observed differences are very small and are similar in size to changes in body height throughout the day in an individual, caused by postural compression. Nevertheless, they correspond to the pattern of the relationship between lifespan and body height revealed by some studies (Samaras 2007; 2014), and the relation between the month of birth and lifespan. It turns out that shorter individuals, usually born at the end of the year, live on average longer, which is in line with the hypothesis on the inverse relationship between adult stature and longevity (Bartke 2012; Salaris et al. 2012; He et al. 2014; Samaras 2014; Chmielewski 2016; Chmielewski and Borysławski 2016), as well as with the character of the month of birth effect in the studied population. Moreover, taller individuals, usually born in the spring, close to the middle of the year, are both significantly taller and live on average shorter. Currently, little is known about the causes of such disparities, but some researchers point to the potential role of changes in the level of vitamin D_3, as well as changes in the activity of the pineal gland and melatonin production (Kościński et al. 2009).

In order to elucidate as well as explain the observed relationships, one should point out some specific biological factors involved in development at early stages of a child's ontogeny, which can have long-term effects on the phenotype, health later in life, and longevity, e.g. hormones, vitamins, nutrients, infectious diseases or meteorological parameters. It is widely known that Polish pregnant women, as well as their offspring, are often vitamin D_3 deficient due to high latitude (49-55°N) and low vitamin D_3 intake. The effectiveness of the formation of previtamin D_3 (cholecalciferol) in the skin in the course of sunlight exposure becomes limited during autumn and winter in Poland (Czech-Kowalska et al. 2008), which fits our findings. Individuals born in the middle of the year were conceived in autumn. They were taller than their peers born in the autumn and winter months. Interestingly, vitamin D_3 stimulates cellular differentiation, but also has anti-proliferative effects on normal cells. Paradoxically, vitamin D_3 deficiency during gestation may contribute to the greater proliferation of cells and rapid growth in early ontogeny, with the result that the organism has more cells. Thus, the results of the present study can be interpreted in terms of higher susceptibility and vulnerability to certain diseases in adulthood (e.g. cardiovascular disease) in individuals born in the middle of the year, as well as the lower susceptibility and vulnerability of individuals born in autumn and winter months because of superior *in utero* nutrition during the first trimester of gestation in summer. In general, these results are in line with the findings of many previous studies on populations living in similar geographic areas (Weber et al. 1998; Vaiserman et al. 2002; Lerchl 2004).

According to traditional views, being taller and slimmer is a superior configuration for humans in respect of health, mortality, and risk of cardiovascular disease, while shorter stature often denotes lower biological condition due to congenital diseases, immunity disorders, poor diet, nutrition, socioeconomic status, and some health problems during early biological development (Waaler 1984; Holl et al. 1991; Herbert et al. 1993; Silventoinen et al. 1999; Engeland et al. 2003; Lawlor et al. 2004; Kemkes-Grottenthaler 2005; Song and Sung 2008; Paajanen et al. 2010). Nonetheless, some other investigations have contradicted the belief that taller people are healthier and live longer than their shorter peers (Samaras 2007; 2014). Samaras points to the inverse relationship between adult height and longevity within homogenous populations with relatively high socioeconomic status, which can result from relatively lower risk of cancer as well as lower risk of some other chronic diseases in shorter individuals compared with taller and stouter ones (Gunnel et al. 2001; Percik and Stumvoll 2009; Cairns and Green 2013; Kabat et al. 2013). In fact, these two completely different views may coincide because the biological causes and consequences of both very short and very tall stature can be deleterious to health in old age (Chmielewski et al. 2015a; 2015b; 2016b; Chmielewski 2016; Chmielewski and Borysławski 2016). For example, the findings that shorter people tend to live longer compared with taller ones are understandable in the light of the entropy hypothesis since smaller bodies are composed of fewer cells and contain relatively lower levels of growth hormone (GH) and IGF-1 which are involved in growth and cell proliferation (Samaras 2007; 2014; Bartke 2012; Bianconi et al. 2013; He et al. 2014). Therefore, such biological systems are at lower levels of entropy, which should be beneficial to their stability and survival. In taller individuals, cell proliferation is enhanced, which can be linked to higher risk of cancer in old age. In our sample, shorter people lived significantly longer than taller ones (ANOVA, $p<0.001$), although this interrelationship may have been caused by secular trends in body height, since people born in the past were shorter than those who were born in the next birth cohorts. However, after the elimination of the secular trend in height, the negative correlations between body height and longevity were very weak but still statistically significant (Chmielewski et al. 2015b; Chmielewski 2016; Chmielewski and Borysławski 2016). Taller individuals are believed to have higher socioeconomic status and better biological conditions, especially at early stages of ontogeny. Thus, they are supposed to live longer compared with shorter individuals. Body height might also be a confounding factor here because it also depends on month of birth. Moreover, some previous studies have revealed that taller stature is related to greater reproductive success in men (Mueller and Mazur 2001). The fact that taller men tend to have more offspring due to sexual selection can in part explain why people born in spring months (taller individuals) appear to be of greater fertility or fecundity. According to many authors, taller men are more attractive than shorter men and have more reproductive success (Mueller and Mazur 2001). This phenomenon brings to mind the handicap principle proposed by Zahavi (1975) in order to explain some evolutionary mechanisms involved in sexual selection. In men, taller stature may be an honest and reliable signal of 'good genes', but this trait can be eventually costly to its owner since it emerges now that it is often negatively correlated with longevity (Bartke 2012; Salaris et al. 2012; He et al. 2014; Samaras 2014; Chmielewski and Borysławski 2016; although see Chmielewski et al. 2015b; Perkins et al. 2016).

Conclusions

We found that lifespan and body height of men and women depend on month of birth and thus the existence of the month of birth effect was confirmed in the analyzed population. Individuals of both sexes born in the autumn and winter months (particularly in December) lived longer than their peers who were born in the middle of the year. The amplitudes of lifespan resulting from the month of birth effect were greater in men (16 months) compared with women (14 months). The relationship between the aforementioned difference and the average lifespan in the studied population, revealing the strength of the effect and environmental welfare, indicates that the Polish population has been exposed to conditions intermediate between those that prevailing in Ukraine and in Germany at the end of the 20th century. The character, pattern, and type of the relationships between the month of birth and lifespan are in line with findings obtained for Ukrainian and German populations, which suggests similarities between geographically close populations. The relationship between the month of birth and body height is weak and not always present, but is more pronounced in men. Individuals born at the end of the year are shorter than their peers born in spring (especially in March and April) and at the beginning of the year. Thus the results of the study not only corroborate the theory of seasonal programming of longevity and support the idea that some undetermined factors from early stages of ontogeny and associated with month of birth have long-term effects on phenotype in later life in terms of body height and longevity, but also back up our working hypothesis that month of birth can be another important confounding factor with respect to the weak and unstable relationship between adult height and longevity.

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Authors' contributions

PC designed the study, collected the data, performed all statistical analyses, interpreted the results, and wrote the paper; KB gave supervisory support and conceptual advice, collected and helped analyze the data, and commented on the initial draft of the manuscript. The final version of the manuscript was prepared by PC and approved by both authors.

Conflict of interest

The authors declare that there is no conflict of interests.

Corresponding author

Piotr Chmielewski, Department of Anatomy, Wroclaw Medical University, ul. T. Chałubińskiego 6a, 50-368 Wrocław, Poland
email address:
piotr.chmielewski@umed.wroc.pl

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