DOI: 10.17746/1563-0110.2019.47.3.145-157

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Secular Dynamics of Body Height and Weight in Russian Children Aged 0–17

This study deals with long-term temporal changes of body height and weight during various stages of ontogeny: newborns, infants, early age children, children of first childhood, children of second childhood, adolescents, and youths. Each age/sex group numbers ca 100 persons, the total sample size is ca 2000. The meta-analysis is based primarily on growth-standards for Russian children, regularly renewed by the Research Institute of Hygiene and Health Protection of Children and Adolescents and mostly relating to separate decades of the 20th century. The intensity of the secular trends was assessed through the analysis of scatter plots. The largest share in the secular increase of body dimensions belongs to intense growth during the second year of life and during the adolescent growth spurt. The smallest share is that of intrauterine growth, limited by the mother's body size, and that of growth during the juvenile age, when the mature body size has been virtually reached and growth rate is minimal. Boys, who are more eco-sensitive, demonstrate greater secular changes than girls, who are eco-resistant. Smaller secular changes in weight than in height in both boys and girls result in an increase of leptosomy. This heterochrony concerns mostly newborns, whose body mass is a standard example of stabilizing selection.

Keywords: *Secular changes, 20th century, body height, body weight, newborns, preschool children, school children.*

Introduction

A secular trend (lat. *secularis* – 'centenary'), also known as a temporal shift, is described in broad terms as an intergenerational shift in the body size of children and adults, as well as in the rate of biological maturation of children, or the biological markers of adults (age at menopause, life span, rate of aging). The term is also employed to refer to any directional non-racial change of physical type in modern humans, e.g. stature variation, brachycephalization or gracilization of the skull. Manifestations of the secular trend observed in the 20th century, which combine acceleration of biological maturation with deceleration of aging, do not fully comply with the "trunk line" of *Homo* evolution: simultaneous deceleration of both processes. An illustration of this scenario is long-lived populations; in particular, the Abkhazians before the conflict of the 1990s, which has irreversibly disrupted the mode of ontogeny of the Abkhazians—a combination of decelerated growth and aging.

Paleoanthropological data suggest that the morphofunctional status of the genus *Homo* was fluctuating, during the biological history of the genus, around some physiological norm. For instance, in ancient and medieval Europe, age at menarche was falling to the lowest physiologically possible level of 12 years of age, but later was increasing to 17.5–

18 years, in particular in northern Europe. Then, in the 19th century, there was a decrease to the modern values of 12–12.5 years in most European countries. Meanwhile, in some Asian populations, this age is still as high as 18 or even more years. Growth spurt in boys of the Angles tribe in the 1st to 6th centuries AD took place later than in modern European adolescents (14–16 years), though such a late age is still found at present in some high-altitude Himalayan groups (Khrisanfova, Perevozchikov, 1999: 161). Temporal fluctuations are typical of body height as well (Deryabin, 2009: 270–271). For example, the male stature of the ancient Lithuanians, reconstructed from the lengths of long bones, was approximately 172 cm during the 2nd to 12th centuries AD, which corresponds to this value in Lithuanians of the second half of the 20th century; in the 14th to 17th centuries, it was 166.8 cm, and in the late 20th century, in a sample of male military personnel, it averaged 175 cm. A similar picture is observed in the territory of Germany: from the 5th to the mid-19th century, there has been a gradual decline in the stature of males from 172 cm to 167 cm, followed by a "recovery" to ancient values by the middle of the 20th century, and then a continuing increase to more than 173 cm. The term "recovery" seems to be the most appropriate for the long-term secular trends described above. The situation with both the age at menarche and body height points towards a recovery in modern populations of the morphofunctional status of the Early Medieval Europeans. This stimulates a search for a global factor in such a large-scale (i.e. encompassing a long historical period) temporal change of body size and biological indicators. Supposedly, the cyclicality of human growth and development could be explained by adaptation to manifestations of cycles of solar activity, the peak of which coincides with a deceleration of growth, while the decline coincides with an acceleration (Nikityuk, Alpatov, 1979; Khrisanfova, Perevozchikov, 1999: 162). This observation might hold true even if we consider a much wider chronological scale, from Australopithecus to modern humans: we shall see similar temporal trends with a much wider "step". The stature of *A. africanus* was 130 cm, but two millions years later the Nariokotome *Homo erectus* was as tall as 180 cm. Neanderthals were much shorter (the estimated stature of La Chapelle-aux-Saints 1 was only 154–155 cm), while Upper Paleolithic modern humans were very tall (182 cm for Cro-Magnon 1) (Zubov, 2004: 250, 384). An exhaustive description of evolutionary dynamics of physical type of man, as well as a discussion of all accompanying and contributing circumstances and the hierarchy of acting factors, can be found in monographs by the leading Russian anthropologists: A.A. Zubov (Ibid.: 131–466) and E.N. Khrisanfova (1978: 5–183). We cannot agree more with the view of Zubov stating that the broadest morphological polymorphism in combination with extreme behavioral plasticity, based on the high brain development, is the asymptotic limit of human evolution (2004: 64).

The results of numerous and systematic studies of human growth carried out in the 20th century (Cole, 2000) get arranged in a rather mosaic picture of the temporal dynamics of the morphofunctional status of the modern population of the Earth, and show a wide variety of possible factors and specific manifestations of the temporal change. Taken together, those results finally spawned the concept of "secular trend".

The intensity and direction of the temporal dynamics of somatic indicators in children (inside the limits of the physiological structural norm) reflect important aspects of relationships between the body and environment, and the anthropogenic factor *per se*. These depend on the biological specifics of the period of ontogeny: tasks that the body has to perform, the degree of its eco-sensitivity, and the pattern of interplay between hereditary and environmental factors. By the anthropogenic factor we mean the complex of environmental factors relating to casual or intentional human activity. The anthropogenic activity of the last decades has resulted in global ecological disasters: the greenhouse effect, acid rains, deforestation, and desertification. Other factors of distress intensify as a direct result of human occupational activity: increased man-made pollution of atmosphere, soil, and water; increased information stress; increased level of hypokinesia; and long-term psychophysiological loads. Taken together, all these phenomena can be referred to as an "increase of anthropogenic pressure". Humanity changes the biosphere according to its needs, but then it has to adapt to the artificial environment it creates, which appears to be distressing in the modern civilized world. This cyclical and interactive biocultural interplay is crucial for the beginning of the 3rd millennium (Shell, 2014). The emergence of cities was an important critical point in human activity since the Paleolithic. It led to the emergence of an urban way of life and the resulting technogenic pollution, which represents a challenge for the adaptive capacities of our species (Ibid.). At that point, humanity became a unified system that opposed itself to biosphere. The urban ecological niche exerts a level of stress multiply exceeding that of any natural, even extreme, ecological niches. In terms of its strength of influence, it can be compared to the genetic factor, and represents an alternative to the environment in which the human genome was formed. In addition, in the 3rd millennium, technogenic pollution became the main factor affecting growth. In contrast, in growth surveys of the 20th century, other factors were considered the most important: social, family, climatic (temperature and latitude) factors, and the level of modernization of the society. The influence of climatic factors on growth points towards preservation of an evolutionarily meaningful relationship between life-cycle indicators and these factors (as immunity regulators), even in the modern technogenic world.

In the world literature, various aspects of somatic secular trends in children in relation to the period of ontogeny are discussed. The body size of newborns is considered a result of adaptation by the growing fetus, which is highly plastic, to relatively stable components of maternal phenotype (Wells, Figueiroa, Alves, 2018). Multiple regression analyses show that the main mediators of this adaptation are the size of the mother's pelvis (as a reflection of the general nutritive and morphological status of mother) and the circumference of the head of a newborn. The sensitivity of fetal growth to the size of the mother's pelvis decreases the probability of an adverse birth outcome. The result of this adaptation is synchronous secular changes of the circumference of the newborn's head and the size of the mother's pelvis. For example, the statistically significant deceleration of head circumference in Russia during the 1950–2010s coincides with the tendency in women in labor to have narrow pelvises, consistently found in different Russian regions since 1980s (Mogeladze, Shchurov, Kholodkov, 2009; Fedotova, Gorbacheva, 2016; Yatsyk, Malkova, Syutkina, 2007). Interestingly, from the 1880s to the 1960s, in Moscow newborns, an intense increase of the head circumference was observed, accompanied by a less pronounced acceleration in the height and weight of the body and a deceleration in the abdomen's circumference (Nikityuk, 1972). At the same time, the sagittal dimensions of the mother's pelvis were increasing. Such a sequence of secular trends for the head circumference of newborns confirms the views about the fluctuating nature of temporal trends of somatic dimensions as a part of general fluctuating change of biorhythms in humans (Khrisanfova, Perevozchikov, 1999: 162). An English anthropologist, J.C.K. Wells, performed a speculative (in his own opinion) attempt to reconstruct the trends of newborn body weight in the Paleolithic and Neolithic, basing solely on secular trends of adult stature and ignoring numerous ecological factors (2009). His results suggest a substantial decrease in body mass from the Paleolithic to Neolithic times and slighter fluctuations afterwards.

Importantly, the size of the newborn's body and the mother's pelvis got involved in an irreconcilable biological conflict from the very beginning of the evolutionary history of our species. The need for improvement in bipedal walking, which would provide certain energetic advances to our ancestors, conflicted with the need to deliver large newborns with voluminous brains. The once-achieved compromise and balance between the widening of the women's pelvis and the restriction of rate of intrauterine fetal growth, including the upper limit of somatic size of the newborn and a deceleration of brain growth (this development is "taken off the table" of fetal development), are maintained by a strict control of stabilizing selection throughout the biological history of our species. De Leon et al. (2008) expressed the opinion that the slight decrease in body- and brain-sizes observed in *Homo sapiens* during the last 30–40 millennia can be explained by an economy of the resources that a mother spends on the bearing, delivery, and feeding of a child, and was one of the factors of the rapid expansion of our ancestors into Eurasia. Maybe Neanderthals failed in attempts to overcome the consequences of the "biological conflict" mentioned above.

According to the results of a cohort-based study of children of Jimma, the largest city in southwestern Ethiopia, the body-fat mass of a newborn is not correlated with his/her stature, while in two-year old children the weight is positively correlated with height, and explains a substantial proportion of its variation (Admassu et al., 2017). Parallel analyses of secular trends of body height and weight have been carried out in Japan (1950–2010) and South Korea (1965–2005) during the last 50 years. The analyses employed one-year cohorts of children, adolescents, and youth (in general, from 1 to 20 years old), and showed substantial differences in growth patterns between the two ethnic groups, which can hardly be explained by their differences in national income, diet, or way of life. An accelerated growth of the long bones in infants is observed in both samples. Thus, marked secular differences in adult stature are established by 1.5 years of life (Cole, Mori, 2018).

A longitudinal study in Nepal has shown that the socioeconomic status of a newborn's family largely determines his/her body-fat mass in the first years of life, while higher education of the mother is associated with an increase in height to 0.6–0.7 units of standard deviation by 2.5 and 8.5 years (Devakumar et al., 2018).

An analysis of the secular dynamics of height in Dutch children of 0–21 years has demonstrated that stature in this world-tallest population got stabilized for a first time during 150 years of observations (since 1858). The definitive height remains 183.8±7.1 cm in boys and 170.7 ± 6.3 in girls since 1997 (Schonbeck et al., 2013). This observation can be explained both by the attainment of genetic optimum and by the stabilization of accelerating environmental factors in the last decade, which constricts the realization of genetic growth potential.

A study of the age dynamics of the relationships between hereditary and environmental factors in affecting parameters of physical development was carried out in Moscow, using data on twins (Khamaganova, 1979). According to its results, the role of genotype in the phenotypic variation of those parameters was increasing from 0 to 15 years. In general, in population variation of indicators of physical development, the role of genetic factors is high; higher than in the determination of neurophysiological parameters. At the same time, in individual variation, a substantial influence for environmental factors is detected: for stature in 7–9 years; for body weight in newborns, 4–6, and 10–12 years; for chest and head circumference in 7–9 years.

Among the aims of this study is a meta-analysis of the secular dynamics of two integral indicators of physical development (body height and weight) in a large number of samples of Russian urban children of the late 19th to early 21st centuries. Through the use of a wide age range spanning from newborns to juveniles, it is possible to assess the relative intensity of secular changes in relation to the period of ontogeny and its biological meaning. Owing to space limitations, it is not possible to consider thoroughly all one-year age and sex cohorts; thus the age groups that are most informative from the physiological and behavioral points of view (and which contrast to each other to an extent) were chosen in each period of ontogeny. Their succession describes the logic of ontogenetic change quite clearly. The age periodization employed in this study follows the methodical recommendations of modern age physiology (Bezrukikh, 2006). Newborns (first 1–10 days, or the period from umbilical cord dressing to 28 days of age, according to modern neonatology (Prakticheskoye rukovodstvo…, 2008: 10): body height and weight indicate the quality of intrauterine growth, they are limited by the morphology of the mother's body, and are an object for stabilizing selection. First year (or infant age, from 10 days to 1 year): body size is an indicator of the quality of the period of compensatory growth and a result of the intensive reshaping of the structure of individual and population variation of main anthropometric dimensions during the first year of life. Two years (early age, 1–3 years): body size describes the status of the individual, which is almost completely independent of the conditions of intrauterine growth and the maternal factor. Three years (second half of early age): a conditional boundary between physiologically and behaviorally dependent and autonomous individuals; body size at this age can be viewed as the starting point of the individual's stable developmental channel. Six years (first childhood, 4–7 years): the accumulation of morphofunctional changes leads to a substantial change of the general body plan and proportions, the emergence of new biomechanical properties, and acquisition of personal psychological traits; this is also the time of the second preschool growth spurt, which is however not observed in all growth studies. Nine years (second childhood, 8–12 years in boys, 8–11 years in girls): period of the lowest rate of somatic growth between the first and second growth spurts; minimal population variation of body size; this is accompanied by very active primary socialization. Thirteen years (adolescence, 13–16 years in boys, 12–15 years in girls): pubertal growth spurt, early stages of which are related to active secretion of growth hormone; this is a critical period of development associated with an intense activation of the genome and turbulent processes of differentiation. Seventeen years (juvenile age, 17–21 years in boys, 16–20 years in girls): the end of puberty and continuing (though not so rapid) biological development of the body. Morphofunctional stability is achieved by 21 years of age in females and by 25 years of age in males.

A large-scale analysis of secular change of definite stature of adult males and females was recently carried out by collective efforts of scientists around the world, excluding Russia and neighboring countries (the former members of the USSR) (NCD Risk Factor…, 2016). The results of 1472 population studies were compiled to answer the question of how human body height changed during the 20th century. The aim of this study is to assess the change of body height and weight in children of 0–17 years during the last century in the territory of the former USSR.

A difference with the study mentioned above is that in our work, mean values for cities and ethnic groups are used instead of means for countries.

The world-scale study has shown, inter alia, that the areas of high and low stature do not change between 1896 and 1996. The difference between the tallest and shortest population remains the same (19–20 cm for females) or even increases (in males) without a connection to social context. A similar geographic continuity of body size distribution in different time periods was observed in large-scale applied research of adult urban populations of the former USSR (Deryabin, Purundzhan, 1990: 121–167; Kurshakova, 1983). Such continuity is typical for children as well, but does not account for details of growth processes, and is usually broken for a variety of reasons: population differences in the age of maximal growth rate, an accumulation of stochastic changes due to the unequal social composition of samples, life conditions, etc. For instance, an analysis of the growth of children of the member countries of the CMEA (Bulgaria, Hungary, East Germany, Poland, Romania, Czechoslovakia, and the USSR) in the late 1960s has shown that only in 3-year old (and partially 17-year old) children do population differences completely replicate those in adults. At all other ages and for all other variables (chest circumference, trunk and limb lengths) the relative position of children's samples is changeable (Dunaevskaya, 1974). Notably, 3 years is the age of radical change in the immune system and the emergence of correlation systems between somatic dimensions. It was hypothesized that the three-year interval could be a "periodical step" in the immune function, which determines the advent of ontogenetic crises (Kurshakova et al., 1994). Somatic reaction to the crises is observed in the same year in children and a year later in adults.

Materials and methods

This study employs 193 territorial groups from the former USSR and Russia, measured in various decades of the 20th and 21st centuries. It represents a large number of ethnic groups: Adyghe, Azerbaijanis, Armenians, Bashkirs, Belarusians, Georgians, Dolgans, Kabardians, Kazakhs, Kalmyks, Kyrgyz, Karels, Komi, Russians, Tajiks, Tatars, Tuvinians, Turkmens, Udmurts, Uzbeks, Ukrainian, Khakas, Khanty, Mansi, Chukchi, Estonians, and Yakuts. Our dataset includes the following numbers of samples of various age cohorts: newborn (338 samples), one year (188 samples), two years (116 samples), three years (256 samples), six years (312 samples), nine years (418 samples), thirteen years (402 samples), and seventeen years (254 samples). The size of each sex-age cohort is ca 100 individuals. All samples are urban, which guarantees homogeneity of the data. Strictly speaking, the opposition of urban and rural populations is no longer valid in the modern world, but our study includes a substantial amount of retrospective data (50 and more years ago, when such a separation was of fundamental importance). For instance, it has been shown that the age at menarche (the most eco-sensitive indicator) differs systematically between urban and rural girls in a large number of ethnoterritorial groups of the former USSR, irrespectively of the ethnicity of the girls. The rate of maturation of dwellers of big cities was surprisingly uniform and in some sense conservative. For the Russian girls from Moscow, Arkhangelsk, Smolensk, Nizhniy Novgorod, Ulan-Ude, Omsk, Tomsk, Irkutsk, and Yuzhno-Sakhalinsk, this indicator varies between 12.9 and 13.1 years, while in rural girls of the same areas the range of variation is much wider—0.8 years (Godina, 2003: 157). A study of ethnoterritorial variation of the body size of newborns from the former USSR on the basis of 63 growth surveys has detected systematic differences between urban and rural populations of the same regions: the urban newborns were taller and larger (Borovkova et al., 2012).

Our dataset covers the period from 1880s to the present for preschool and school children (with ten year intervals); from 1920s to the present for newborns and infants; and from 1950s to the present for children in early childhood. The total sample-size exceeds 310,000 individuals. The main source of data is the materials on the physical development of children and adolescents of the former USSR and Russia collected according to a unified protocol, and thus completely comparable (Materialy…, 1962, 1965, 1977, 1986, 1988, 1998; Fizicheskoye razvitiye…, 2013, 2019). These composite volumes are published by the National Medical Research Center for Children's Health of the Russian Federation Ministry of Health (Moscow) about every 10 years, as substantial and significant secular somatic changes are not acquired faster than in a decade. We also used this "natural" time step (10 years) in our study. It is worth remembering that the body possesses a long-term ontogenetic and evolutionary memory; thus the somatic response of an organism to the influence of different factors reflects a systemic (holistic) type of reaction. Therefore, the body is the most informative object for an analysis of the specifics of development of living systems and the process of formation of their stability (Kurshakova et al., 1994). Some papers (Chuchukalo, 1929; Shtefko, 1925), dissertations (Bauer, 1900; Borovka, 1913; Gratsianov, 1889; Dik, 1883; Zak, 1982; Seiliger, 1900), and our own archive data were used as additional sources of information. Two main anthropometric parameters (body height and weight) were the object of our study as integral indicators of skeletal development and metabolism, respectively. A decrease in body weight accompanied by an increase in height, or leptosomization, is related to the attenuation of physical conditions and adaptive potential, which is confirmed by numerous auxological studies of children of various ages.

In the absence of available individual data and thus an opportunity to apply multidimensional statistics for assessing the level and direction of the correlation of anthropometric variables in children with the temporal factor, scatter plots were drawn for each of the age-sex cohorts. This graphical variety of correlation analysis for two variables in two-dimensional Cartesian space is an effective tool for exploring large sets of population means. The years of studies (1880s… 1920s… 2000s) were used as an independent variable, with body height and weight as dependent ones, for every age-sex cohort separately. In total, 32 diagrams were analyzed. In order to illustrate the intensity of the secular change, the mean rate of secular increase in stature or body weight in a decade (the ratio of total increase of a variable during the whole period to the number of decades in that period) was calculated for each of the cohorts.

Results

The direction of secular change in body height during the interval from birth to three years is identical for boys and girls of all age groups: this is a significant increase in size, or an acceleration of skeletal development (Fig. 1, *a–c*). The stature of newborns has increased by more than 2 cm from the 1920s to the 2010s (r = 0.27 for boys, r = 0.37 for girls, p = 0.00). The same figures for one-year old children from 1930s to 2010s are 4.7 cm for boys and 3.8 cm for girls (r = 0.4, p = 0.00), for two-year old children from 1950s to 2010s this is about 3 cm (r = 0.46 for boys and r = 0.47 for girls, p = 0.00), and for three-year old children during the same period about 2 cm (r = 0.27, p = 0.00). The slight decrease reflects the well-known fact of a gradual decrease in growth rate from birth to 3 years, though the rate of growth remains high in general (Deryabin, Krans, Fedotova, 2005).

From 6 to 17 years (Fig. 1, *d*), the weakest influence of temporal factor on the secular trend in stature is observed in six-year old boys (r = 0.19, p = 0.02) and girls (r = 0.42, p = 0.00). Later on, it increases by 9 years (r = 0.66 for boys, r = 0.61 for girls, p = 0.00) and 13 years (r = 0.76 for boys, r = 0.73 for girls, p = 0.00), but then decreases again by 17 years (r = 0.42 for boys, r = 0.62 for girls, p = 0.00). Clearly, the dynamics of the influence of the temporal factor, which determines secular changes of the indicators of physical development under increased anthropogenic pressure, is in general identical for both sexes. Surprisingly, this influence is higher in girls (typically less eco-sensitive than boys) at 6 and 17 years of age, probably as a result of distressing anthropogenic pressure. For instance, in extremely environmentally unfriendly areas of Moscow, as compared to more favorable areas of this city, a deceleration of skeletal development, accompanied by an increase in adiposity, is observed in children of 3–6 years. This trend is more pronounced in girls than in boys (Fedotova, Deryabin, 2006).

The mean rate of secular increase in stature in a decade is 0.32 cm in newborn boys, 0.38 cm in one-year old boys, 0.61 in two-year old boys, and 0.29 in three-year old boys. In girls of the same ages, the increases are the following: 0.23, 0.37, 0.60, and 0.37 cm. In boys of six years of age, about 1 cm; at 9 years, 0.9 cm; at 13 years, 1.7 cm; and at 17 years, 0.75 cm. In girls: 0.9, 0.9, 1.45, and 0.8 cm, respectively. Thus, the highest rate of secular changes in stature is typical of pubertal period (boys overtake girls), and the lowest for 17-year-olds. Consequently, the adolescent growth spurt has the main effect on the secular changes in body height during the interval from 6 to 17 years.

Secular changes in body weight (Fig. 2, *a–c*) are substantially different from those for stature. In newborns, no secular trend is observed. A slight decrease for girls (50 g in eight decades) is not statistically significant (r = 0.08, p = 0.33). Notably, weight of newborns represents a classic example of an object of stabilizing selection, while the main cause of its variation is the family factor—weight of parents and siblings at birth (Borovkova, 2012; Tanner, Lejarraga, Turner, 1972). This factor accounts for approximately 16 % of total variation of body size in newborns, while other factors explain only up to 1–4 %. The secular increase in weight in one-year-old children is slightly larger, 300–400 g in six decades, but also

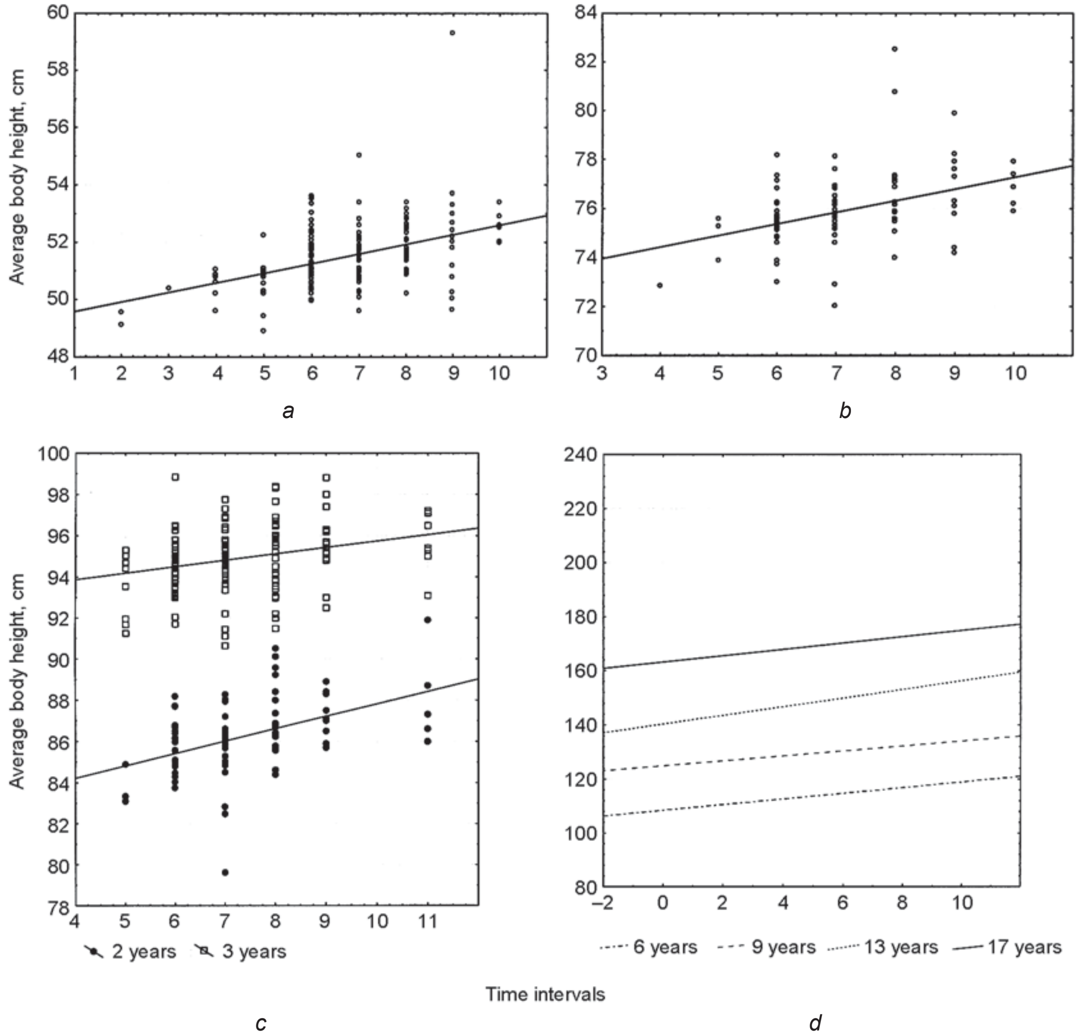

Fig. 1. Secular trend in stature in boys of Russian cities.
a – newborns; *b* – one-year old; *c* – early age children; *d* – preschool and school ages. Time intervals (10-year step): –2 – 1880s, 0 – 1900s, 2 – 1920s… 10 – 2000s.

not significant ($r = 0.03$, $p = 0.17$ for boys, $r = 0.33$, $p = 0.33$ for girls). The combination of the secular increase in stature with the stability of body weight reflects a trend to leptosomization in early ontogeny. In one-year old children of both sexes it is also accompanied by gracilization, i.e. a negative secular dynamics of the chest circumference (Fedotova, Gorbacheva, 2017). Later, in early childhood, the secular increase in body height and weight occurs in a more synchronous fashion. For instance, at two years of age, the absolute secular increase in weight approximates 700 g in six decades, and is statistically significant ($r = 0.32$, $p = 0.00$ in boys; $r = 0.27$, $p = 0.01$ in girls). In three-year old children, the increase approaches the level of significance as well. Summing up, the secular trend towards leptosomization is more pronounced in newborns and infants than in early childhood.

As with stature, the impact of the temporal factor on the change in body mass between 6 and 17 years (see Fig. 2, *d*) is the least at six years ($r = 0.31$ for boys, $r = 0.25$ for girls, $p = 0.00$). Then it gradually increases by 9 years ($r = 0.50$ for boys, $r = 0.46$ for girls, $p = 0.00$) and 13 years ($r = 0.65$ in boys, $r = 0.55$ in girls, $p = 0.00$). It decreases again by the age of 17 ($r = 0.37$ in boys, $r = 0.26$ in girls, $p = 0.00$). This indicator is generally higher in more eco-sensitive boys than in girls.

The mean rate of secular increase in body weight of boys per decade is 3 g in newborns, 30 g at one year, 100 g at two years, and 57 g at three years of age. The same figures in girls are 5, about 50, 125, and 63 g,

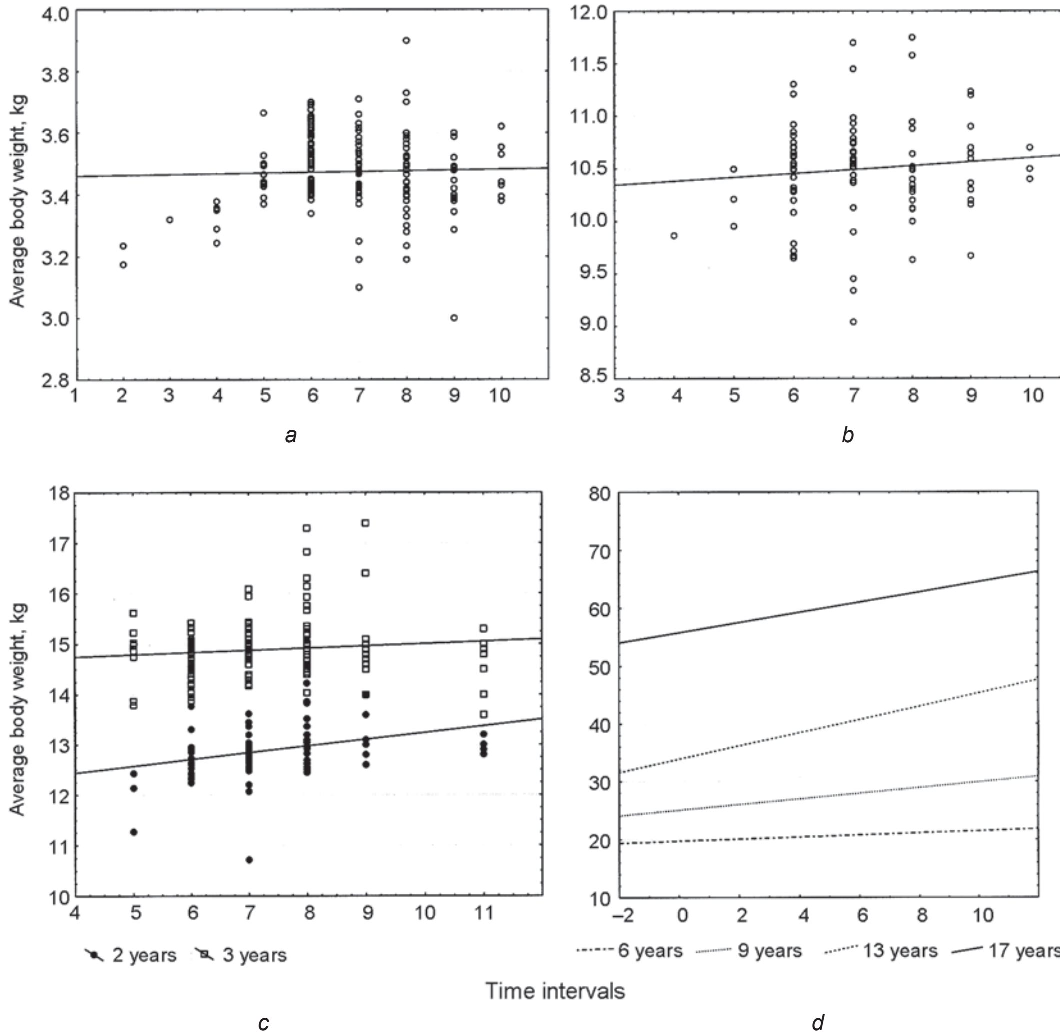

Fig. 2. Secular trend in body weight in boys of Russian cities.
a – newborns; *b* – one-year old; *c* – early age children; *d* – preschool and school ages. Time-intervals (10-year step): –2 – 1880s, 0 – 1900s, 2 – 1920s… 10 – 2000s.

respectively. In boys at six years it is 0.16 kg, at nine 0.50 kg, at thirteen 1.10 kg, and at seventeen 0.60 kg. In girls: 0.11, 0.48, 1.20, and 0.31 kg, respectively. Thus, the rate of secular change in body mass between 6 and 17 years is the highest at the pubertal growth spurt, and decreases substantially after 17 years, in girls in particular. This last observation may be explained by either an earlier attainment of definitive morphological status in girls, or by different sociocultural demands: physique stereotypes, diets, fitness, etc. These social trends affect girls more than boys.

Clearly, in the earlier age cohorts (0–3 years) the impact of the temporal factor on the secular dynamics of body weight is lower than in the later ages (6–17 years); moreover, it can cautiously be considered negligible. This is a contrast to the situation with stature, where the same factor is less influential between 0 and 3 years of life than in older children, but still is comparable to what is observed between 6 and 17 years of age.

Discussion

The impact of the temporal factor on the secular dynamics of body height and weight is gradually increasing from birth to two years of age. Afterwards, it is decreasing until three years, and then is increasing from 6 to 13 years. It decreases again at 17 years. Thus, the secular dynamics of the main indicators of physical development are non-linear, and are most clearly pronounced during the second year of life, the time of active search for an individual growth channel; and at puberty (13 years), when the growth trajectory is definitively corrected. These observations are in good agreement with the results of studies showing that the secular dynamics of definitive stature in adults are determined by an elongation of the leg during the first two years of life (Cole, 2003; Cole, Mori, 2018). An international twin-survey, which summarized the results of a number of European studies, has shown that the role of genetic factors in variation of stature increases from birth to adolescence, peaking at 13 years (Jelenkovic et al., 2016). The authors of the last-named study emphasize that the observed maximum for the environmental influence on stature-variation during the first years of life (50 % in the first year, less during childhood and adolescence) should be treated with caution, since the growth patterns of twins in early ontogeny differ substantially from those of single children. Secular trends are less clear during relatively "biologically neutral" periods (3, 6, or 17 years), when the rate of growth is lower. An increased intensity of secular changes at 9 years is in good agreement with the increased environmental influence on individual variation in body height and chest circumference at 7–9 years and body weight at 10–12 years (Khamaganova, 1979). The latter age cohort is conterminous between the groups of nine and thirteen-year old cohorts of the present study. Similar differences in the intensity of somatic secular trends were detected in the rural population of southern Mexico between 1968 and 2000. Those changes in body- and leg-lengths and sitting-stature were minimal in boys of 6–9 years and substantially higher in adolescents. In girls, otherwise, they were more intense between 6 and 9 years and between 10 and 13 years, rather than between 13 and 17 years. Finally, the secular increase in stature in young adults of both sexes was lower than that in the adolescents (Malina et al., 2004). In a national Chinese survey of pre-school children's growth and development in nine cities, an absence of statistically significant secular trends in body height and weight was observed before three years of age, but the trends were evident between 3 and 7 years (A National Survey…, 2018).

The effect of the temporal factor on the dynamics of stature is slightly higher than on those of body weight. Thus, the secular trends of the more genetically determined indicator of skeletal development are more pronounced as compared to body weight, which depends roughly equally on all the three somatic components (skeletal, muscular, and fat) and, consequently, on the way of life of children (level of physical exercise, nutrition, etc.). It should not be forgotten that the temporal dynamics of the skeletal somatic component is mediated by neurogenic mechanisms as a response to anthropogenic pressure, while transverse measurements of the body react to lifestyle more directly. For instance, the Fels longitudinal growth study (USA) has shown that the increase in the BMI in young men in recent years is largely dependent on fat-mass, but in young women on both fat- and lean-masses. The authors of the survey interpret this observation as a possible result of changes in the way of life and behavior patterns that have not involved the males yet and require further study (Johnson et al., 2013). A survey of children in Calcutta (India) in 1982–2011 shows that the increase in body height and the development of fat-mass are to a substantial extent independent of each other (Scheffler et al., 2018). This means that the former is fairly independent of nutrition and family income. A marked secular leptosomization of newborns and infants is correlated with similar morphological features in the girls who later became their mothers (manifest leptosomic adolescents of 1970–1990s), and points towards intergenerational correlations of the microevolutionary somatic changes.

Finally, the secular trends are generally better pronounced in boys rather than in girls. This corresponds to the fact of higher eco-sensitivity of males in the norm. As mentioned earlier, sexual differences in the secular trends were observed in rural population of Mexico (Malina et al., 2004). A higher eco-sensitivity was detected in healthy newborn boys in Japan in 1962–1988, the years of substantial social and economic progress, which somehow affected the physiology of prenatal growth (Oishi et al., 2004). The secular changes in body height and weight were the most evident, while the change in the chest circumference and head were not statistically significant.

It is of note, however, that while the general direction of secular trends in the main indicators of physical development is universal for all ethnoterritorial groups included in our meta-analysis, there are regional differences in their intensity/severity. This fact deserves special consideration, and points towards the need for development of local standards for growth.

Conclusions

The results of our study demonstrate that the secular change in body height and weight of children of both sexes are the highest during the periods of the most active growth and development, i.e. the second year of life and at 13 years (puberty). The influence of the temporal factor (which largely describes the increase in the level of anthropogenic stress) is the least in the periods of deceleration of growth processes: at 6, and particularly at 17 years of age. This influence on the dynamics of the main indicators of physical development is stronger in boys, who are more eco-sensitive than girls.

The less pronounced trend in body weight as compared to stature in children of both sexes and of all age cohorts suggests different factors of variation in longitudinal and transverse body dimensions. This, in turn, determines the secular trend in body shape: the increase in body weight relative to body height, resulting in an increased leptosomization. The process of leptosomization of children was most clearly detected in various regions of Europe in the second half of the 20th century.

It can be summarized that the secular increase in body size is mainly determined by intense growth during the second year of life and during the adolescent growth spurt. The least important segments of ontogeny from this point of view are: the intrauterine period, when the size of the fetus is restricted by mother's morphology, and youth, when the definitive level of morphofunctional maturation is almost achieved and the rate of growth is minimal. As girls reach the definitive morphofunctional status earlier than boys, sexual differences in the intensity of secular dynamics are most evident at 17 years of age.

The observations discussed in this paper are an aspect of studying the secular trends that can be called "superethnic" or "superpopulational". A similar algorithm of analysis of spatial somatic variation based on data from more than 70 child-growth surveys from the former USSR detected a western-eastern cline in the distribution of children's stature in various ethnoterritorial groups (Godina, 2001). For a more detailed examination of the temporal dynamics of somatic growth, including the consequences of experienced stresses, a stronger "magnification" is required: single populations and individual variation should be studied. This should include a consideration of the coefficient of variation, which is an informative marker of stress even in the absence of somatic changes *per se*. For instance, for a sample from Moscow it was demonstrated that girls born during the Second World War were able to realize the genetic program of growth and development, according to the evolutionary determined patterns of interchange of growth rates through early stages on ontogeny (Zadorozhnaya, 2018). According to the results of a survey of a long-lived Abkhazian population, the war of 1992–1993 and the stressing social consequences of the war have changed the "long-lived" rates of ontogeny typical of this population. In the 25 years from 1980 to 2004, the rates of skeletal maturation and somatic growth have substantially increased, though statistically significant changes are found not earlier than in children of 10–11 and 12–13 years, respectively (Batsevich et al., 2006). In recent decades, technogenic pollution, the result of industrial "race", is becoming the most important stressing factor, which might well have even more serious consequences than social cataclysms. For instance, the aggressive influence of combined radiation-toxic metabolites on children of the Bryansk Region leads to a deceleration of growth and development in children of 7–9 years, which is accompanied by adverse changes in cell immunity and an increased frequency of cytogenetic disorders (Korsakov, 2012). In the areas of the Belgorod Region, where critical ecological events have occurred during the last decades of the 20th century, significantly larger mean values of the main morphofunctional indicators in newborns were observed. In the same time, anthropometric dimensions of children of preschool and younger school ages were smaller in these areas than those of the children from areas with satisfactory ecological conditions (Krikun, 2006). The differences in the rates of the secular changes in children in various periods of ontogeny detected in this study are in a good agreement with the facts of differential age-related eco-sensitivity in the children mentioned above.

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Received November 13, 2018.
Received in revised form December 11, 2019.