Characteristic Differences between the Growth of Man and the other Animals

Novák L.[1], Kukla L.[1], Zeman L.[2]
[1]Research Institute of Preventive and Social Paediatrics of the Medical Faculty, Masaryk University Brno, Czech Republic;
[2]Mendel University of Agriculture and Forestry Brno, Czech Republic

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Mailing address: Prof. Ludvík Novák, MD., DSc., Research Institute of Preventive and Social Paediatrics, Medical Faculty, Masaryk University, Bieblova 16, 613 00 Brno, Czech Republic; Phone: +420 549 248 363, e-mail: ludvik@iol.cz

Abstract: The method Dynamic Phenotype of Body Mass or of the body height was used for the interpretation of growth in children and adolescents from birth to the age of 18 years. Modelling of the body mass growth curve in boys by means of Dynamic Phenotype of Body Mass is expressed in the form of three individual curves which are compatible with the three I, C, P, components of Karlberg's body height growth curve. However the Dynamic Phenotype of Body Mass is based on the direct use of the measured biological values as input parameters of the simulated growth curve e.g. body mass in the origin of the growth curve (G0, kg), the genetic limit of body mass (GLi, kg) inherited from parents and the inherited physiological potency to produce the appropriate body mass increase (dG max, kg/d) in conditions of adequate nutrition and in convenient environment. The components I, C, P, of children and adolescents growth curve do exhibit principal difference in comparison with the growth curves of the other mammals. This difference is characterized by the long lasting (C) component with extremely slow body mass increase indicating the very low growth velocity of body mass growth. This long lasting (C) component of childhood postpones the puberty component (P) from the infancy component (I). This phenomenon makes the principal difference between the body mass growth in man and that of other mammals where immediately after the short episode of postnatal growth follows puberty, sexual and corporeal maturity. Some primates carry out the body mass growth similar to man. The method of Dynamic Phenotypes may be helpful for investigation of the brain's function ontogeny in relation to neural and humoral regulatory mechanisms of body mass growth during childhood and transition into puberty.

Introduction

Body mass growth is a phenomenon of each individual's physical development from conception up to the time when it reaches the stage of sexual and corporeal maturity. Growth curves of measured values do represent the formal expression of the growth process. The growth of body mass in auxologic longitudinal studies are evaluated by comparing the growth data of the studied individuals or averages of the examined groups with the percentile graph set [1, 2] or on statistically evaluating the group average differences [3, 4, 5]. Such approach allows imagining the individual's studied phenotype trait in relation to reference population. However it gives us no feedback for quantitative evaluation of recorded growth divergences of the studied individual growth curves, which are determined by the genetic growth potential acquired from parents and modified by the environment. For the quantitative assessments of body mass growth curves many various mathematic formulas and functions have been used [6, 7, 8, 9]. However Ludwig [6], after evaluating many various approaches and formulas postulated that "the body mass growth function has to be generated from the physiologic processes, they form the basis of the growth processes, otherwise the formal coincidence

between the calculated and the experimental data of the growth curve is nothing more than a mathematics exercise". Mathematic description is an important condition for the evaluation of the individual's development after the birth and it enables quantitative comparison of the individual growth curve with growth curves of other individuals of the same or different sex or species. Making the comparison of man's growth curves with growth curves of laboratory or farm animals**,** precise mathematic constants unequivocally defining the growth curve trajectory from the beginning up to the asymptote of the curve are needed. The logistic growth curve and the Gompertz growth curve are, according to our opinion, suitable for the assessment of the body mass growth. The logistic growth curve and the Gompertz growth curve do have a slightly different shape, however according to Winsor [7] each of them is unequivocally determined by three mathematic constants, the asymptote (A), the constant of specific growth (a, b) and the integration constant (c). For a biologist or a physician these mathematic constants are hard to be understood, because they are not directly concordant with the phenotype's expression values of growth e.g. the body mass (G, kg) the statures dimension (D, cm) or the maximum increase of measured parameter (dGmax,kg/day) or (dDmax,cm/day). To define the mathematic constants of growth curves in relation to their physiological background, the method of Dynamic Phenotype of body mass was elaborated.

Methods

The body mass growth is a result of two contradictory processes; anabolism and catabolism [10] and has a form of S-shaped curve. The body mass increase (dG/dt) can be expressed by simple differential equation

$$dG/dt = a.G - b.G.G \qquad [kg/d] \qquad (1)$$

a – anabolism coefficient, b – catabolism coefficient, both with the dimension [$time^{-1}$]

By integration of (1) we receive the equation of the logistic growth curve

$$Gt = GLi/ (1+c.exp(-a.t)) \qquad [kg] \qquad (2)$$

GLi – genetic limit of body mass growth = the asymptote (A) of the growth curve.

From equilibrium condition of equation (1) it follows that dG/dt=0 if G=GLi, e.g. if the body mass reaches the asymptote of the growth curve than a = b.GLi.

In the inflexion point the body mass (Gi) of the logistic growth curve, Gi = GLi/2 and the body mass increase reaches its maximum (dGmax). Expressed by equation (1) adjusted according [11, 12] in the form dGmax = a.Gi.(1-Gi/GLi) it follows that a = 4.dGmax/GLi and b=4.dGmax /GLi^2. If we put the ordinate of G0 equal to the birth weight and set the time of birth (t_0, d) we receive the integration constant

c=(a-b.G0)/(b.G0). The integral path of the logistic growth curve is than defined by three biological parameters of Dynamic Phenotype of Body Mass (G0, GLi, dGmax). The calculation of the logistic growth curve and the search for the best growth curve fit with experimental values is in the spreadsheet supplied with graphic easily managed directly by the biologically comprehensible values of the Dynamic Phenotype of Body Mass. The parameters of the Dynamic Phenotype of Body Mass can be than used directly for comparison of differences observed between individuals of the same breed or compared with individuals of other races, breeds, lines or hybrid combinations.

The catabolic processes in the Gompertz's growth curve do not increase proportionally to the body mass (G) but proportionally to the natural logarithm of the body mass (lnG), then the differential equation (1) takes on a shape

$$dG/dt = a.G - b.G.\ln G \qquad [kg/d] \qquad (3)$$

a – anabolism coefficient and b – catabolism coefficient. In this Gompertz body mass increase interpretation the asymptote A=lnGLi and the coefficients in the equilibrium are defined a = b.lnGLi.

By integration of (3) we receive the equation for calculation of the Gompertz growth curve

$$Gt = GLi.\exp(-c.\exp(-b.t)) \qquad [kg] \qquad (4)$$

Body mass in the inflexion point (Gi) of the Gompertz growth curve Gi = GLi/e the integration constant c=ln(GLi/G0) and the constant of specific growth (b) calculated from the diferential equation (3) adjusted to the form dGmax = b.Gi.(ln(GLi) – ln(Gi)) yields b=e.dGmax/GLi.

The integral path of the Gompertz's growth curve is than also defined by three biologic parameters of Dynamic Phenotype of Body Mass (G0, GLi, dGmax).

The same mathematic interpretation may be used to evaluate body length and body height parameters noted as distances (D, cm) e.g. (D0, cm) body length at birth, (DLi, cm) the genetic limit of body height and (dDmax, cm/d) the maximum body length increase in the inflexion point (Di, cm). The relation of the Dynamic Phenotype parameters of body mass growth to the mathematic constants of the Logistic or of the Gompertz growth curves are presented in Table 1.

Table 1 – The relation of the Dynamic Phenotype parameters of body mass growth to the mathematic constants of the Logistic and the Gompertz growth curves

Phenotype parameters	G0	GLi	dGmax
Logistic growth curve	a = 4.dG max/GLi	b = a/GLi	c = (a-b.G0)/(b.G0)
Gompertz growth curve	a = b.ln(GLi)	b = e.dGmax/GLi	c =ln(GLi/G0)

Use of the Dynamic Phenotype for modelling of the body mass growth in man from the conception up to the maturity

The human growth curve from birth till maturity differs significantly from growth curves of other warm-blooded mammals [13]. While body mass of laboratory animals, farm animals and poultry grows from birth or hatching till maturity according to one logistic or Gompertz growth curve, body length growth of newborns, infant children and pubescent adolescents is composed, according to Karlberg [14] of three separate, additive and partially overlapping components.

The first, infancy growth curve component (I – infancy) lasts from birth until one year of age and fades away until two to three years of age. It is expressed by an exponential function.

The second, child growth curve component (C – childhood) begins during the first year of age, slows down gradually till maturity and is described by a second-degree polynomial.

The third, pubertal growth curve component (P – puberty) represents growth acceleration related to the sexual maturation hormonal activity and lasts till reaching genetically limited value. This third component is described by a logistic growth function. However the constants in these functions used by Karlberg are pure mathematic constants without the direct concordance with the physiologic values (D0, DLi dDmax), which in the Dynamic Phenotype of body height do express the whole logistic growth curve.

The growth of body length and body height in children and adolescent

Simulation of newborn body length data and body height of children and youth published in Brno growth study [4] using the "Dynamic Phenotype" for construction of the growth curves is shown in Figure 1.

All three human growth components from the newborn body length growth till one year of age, child body height growth till puberty onset and pubertal spurt till 18 years of age are very closely approximated by the Gompertz and the logistic growth curves calculated by means of the Dynamic Phenotype of body length. Timing of the individual components of the growth curve corresponds with the ICP body height growth components established by Karlberg [14]. Constants of the Dynamic Phenotype (D0, DLi, dDmax) for particular component of the growth curve together with the corresponding mathematic constants (a,b,c) are shown in the Table 2. The onset of the growth curve (C) component in our graph at 0.75 years is in agreement with data of Karlberg (0.74 $\pm$ 0.16 years) and the asymptote of the growth curve (I) component (DLi = 85 cm) is also close to the value of Karlberg [14].

Body mass growth in newborns, children and adolescent

Carrying out weight data analysis of the children and youth published in the Brno growth study [4] using the "Dynamic Phenotypes" we found out that the curve

describing average body mass growth of boys from birth till 18 years of age can be approximated with minimum differences by the calculated growth curve only if the whole set of body mass growth data is divided into three segments [15]. The average body mass of boys and their respective smoothed fit with growth curves calculated for individual components of measured data are shown in Figure 2 and Table 3. It is apparent that the extrapolated path of the logistic growth curve segment of component (C) in the Figure 2. will reach slowly the genetic body

Table 2 – Dynamic Phenotype parameters and coefficients for calculation of body lenght growth curves

Components of the curve	Age. year	D0. cm	Dli. cm	dDmax. cm/year	Curves coefficients	a	b	c
Infancy (I)	0.0	50.9	85.0	55.0	Gompertz	7.81413	1.75889	0.513
Childhood (C)	0.75	77.8	180.0	8.5	Logistic	0.18889	0.00105	1.313
Puberty(P)	13.0	161.8	180.0	30.0	Logistic	0.66667	0.00370	0.113

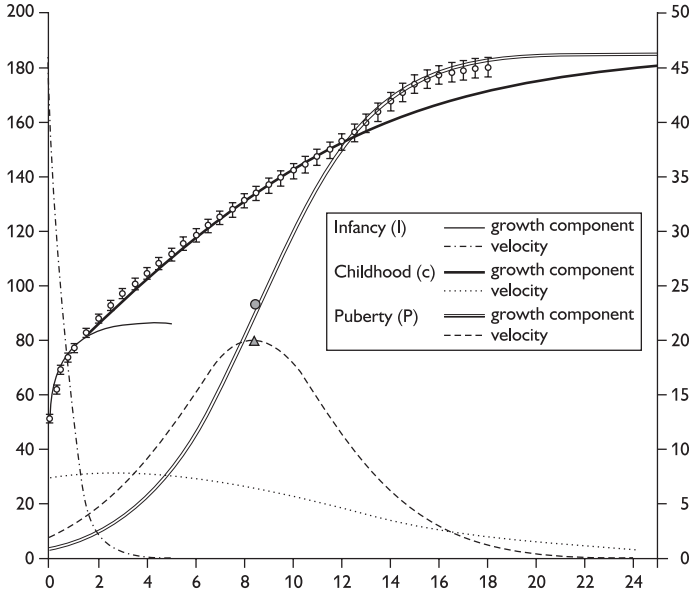

Figure 1 – Fitted curve for average body height of boys with experimental data Infancy (I) growth component (continuous simple line) and velocity (dotted and dashed line), with Childhood (C) growth component (heavy line) and velocity (dotted line); Puberty (P) growth component (double line) and velocity (dashed line). The Dynamic Phenotype Parameters for Height (D0), (DLi), (dDmax) see Table 2. Maximum body height increase of the Puberty component (P), (dDmax) triangle and value of the inflexion point (Di) – circle. Variation coefficient abscissae Cv = 2.0 %. Abscissa: age [year]. Ordinate: to left, posture height (D) [cm], to the right body height growth velocity (dD) [cm/year].

mass limit of 75 kg approximately in the age of 29 years without the spurt in puberty. However the pubertal spurt shortens the time interval in the segment of the (P) component of the growth curve to the age of 18 years.

"Dynamic Body Mass Phenotype" parameters of individual human growth curve components from embryo till 25 years of age are shown in the Table 3 and in Figure 2. The first growth curve component (I) is directed by the Gompertz growth function with GLi=9.0 kg and a maximum body mass increase

Table 3 – Dynamic Phenotype parameters and coefficients for calculation of body mass growth curves

Components of the curve	Age. year	G0. kg	DLi kg	dDmax. kg/year	Curves coefficients	a	b	c
Infancy (I)	0.0	3.3	9.0	12.5	Gompertz	12.60898	5.73859	1.003
Childhood (C)	0.75	9.0	75.0	3.5	Logistic	0.18666	0.00248	7.447
Puberty(P)	12.5	43.5	75.0	8.5	Logistic	0.45333	0.00604	0.722

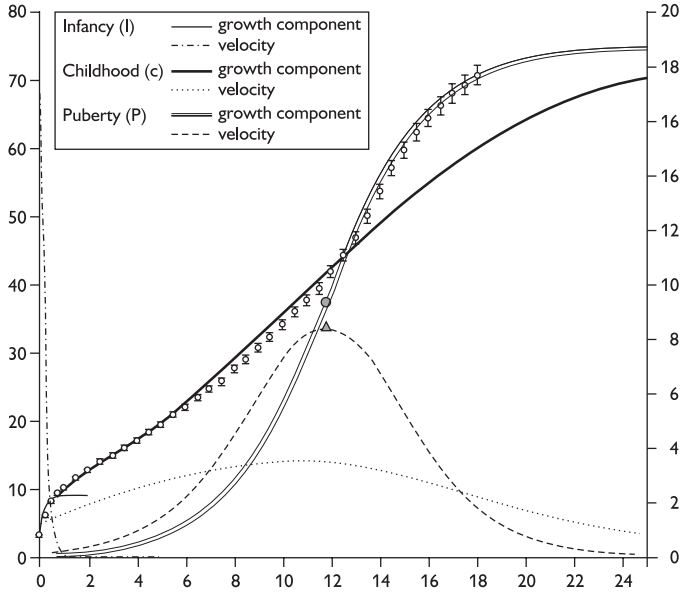

Figure 2 – Fitted curve for average body mass of boys with experimental data Infancy (I) growth component (continuous simple line) and velocity (dotted and dashed line), with Childhood (C) growth component (heavy line) and velocity (dotted line); Puberty (P) growth component (double line) and velocity (dashed line). The Dynamic Phenotype Parameters for Body mass (G0), (GLi), (dG max), see Tab. 3. Maximum body height increase of the Puberty component (P), (dGmax) – triangle and value of the inflexion point (Gi) – circle. Variation coefficient abscissae Cv = 2.0 %. Abscissa: age [year]. Ordinate: to left, body mass growth (G) [kg], to the right body mass growth velocity (dG) [kg/year].

dGmax = 12.5 kg/year – the curve is labelled continuous simple line. The second segment, component (C) is directed by the logistic growth function with GLi = 75 kg and dGmax = 3.5 kg/year and is labelled heavy line. The third growth curve segment component (P) is also directed by the logistic growth function with a higher maximum of body mass increase (dGmax = 8.5 kg/year) and is labelled double line. Kg/year simulates well the whole path of the exponential curve with the asymptote of 75.0 kg. The heavy line indicates the onset of the component (C) of the growth curve and fits also perfectly with the experimental data.

The first Gompertz segment of the body mass growth curve, the infancy component (I) according to Karlberg [14] is presented in detail in Figure 3. To show the whole image of the first development phase the infancy component (I) in detail the data of Bouchalová were completed with data of Florián [16] and Lisá [17] which describe the foetus growth in utero from embryo until birth. It is apparent that the Dynamic Phenotype of the Gompertz growth curve with

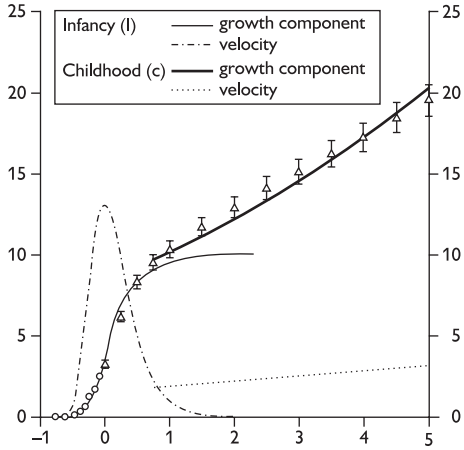

Figure 3 – Fitted curve for average body mass growth of boys with experimental data Infancy (I) growth component (continuous simple line) and velocity (dotted and dashed line), with Childhood (C) growth component (heavy line) and velocity (dotted line). The Dynamic Phenotype Parameters for Body mass (G0), (GLi), (dG max), see Tab. 4. Abscissa: age [year]. Ordinates: to left, body mass (G) [kg], to the right body mass increase (dG) [kg/year]. Data Florián Lisá (circles), data Bouchalová (triangles). Variation coefficient abscissae Cv = 5.0 %.

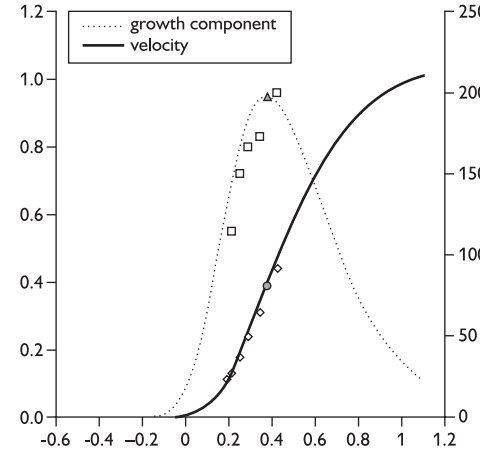

Figure 4 – Fitted curve for average body mass growth of pigs with experimental data. Curve components Infancy (I), Childhood (C), Puberty (P), are in the monotone course of the growth curve not visible as it is to be observed in the growth curve of man. The Dynamic Phenotype parameters of Body mass growth (G0), (GLi), (dG max), see Tab. 5. Body mass growth (G) (diamonds), body mass increase (dG) (squares). Maximum body mass increase (dGmax) – triangle and the inflexion point (Gi) – circle. Abscissa: age [year]. Ordinates: to left, body mass increase (dG) [kg/day] (continuous simple line); to the right body mass growth (G) [kg] (dotted and dashed line).

constants G0 = 2.5E–5 kg, GLi = 10.0, kg and maximum body mass increase dGmax = 12,5 kg/year, simulates well the whole path of the Gompertz curve continuous simple line. The heavy line indicates the onset of the component (C) of the growth curve and fits also perfectly with the experimental data. The dotted and dashed bell shaped line expresses the body mass increase of the foetus in utero. The dotted linear line from approximately 0.75 year of age than indicates the transition of the (I) component growth velocity into the very low growth velocity of the (C) component.

Body mass growth in pigs

With pigs hybrid PIC the experiment was focused to the influence of nutrition on the live body mass growth in the optimum environmental conditions. The experiments were carried out at the Mendel University of Agriculture and Forestry Brno, in the University farm Žabčice. [20, 21] The experimental data together with the simulated growth curves calculated by means of the Dynamic Phenotype of body mass growth are shown in the Figure 4 and Table 5.

The exponential Gompetz growth curve (dotted line) copies the path of experimental averages of the live body mass growth of pigs. Evidently the exponential shape of the growth curve exhibits a continuous course without separable components (I, C, P). The inflexion point of the Gompertz growth curve is positioned in the age of 20 weeks (140 days, 0.383 years). At the same age the experimental pigs reach the peak velocity of growth (dG max = 0.95 kg/day). The Dynamic Phenotype of Body Mass Growth together with mathematic constants of the Gompertz growth function is presented in the Table 5. On the instant after the short episode of postnatal growth follows puberty, sexual and corporeal maturity. Component (C) with abrupt very low growth velocity doesn't appear.

Table 4 – Dynamic Phenotype parameters and coefficients for calculation of body mass growth curves

Components of the curve	Age. year	G0. kg	DLi kg	dGmax. kg/year	Curves coefficients	a	b	c
Infancy (I)	-0.767	2.50E-06	10.0	12.5	Gompertz	8.136	3.533	15.202
Childhood (C)	0.75	3.64	75.0	75.0	Logistic	0.186	0.00248	7.447

Table 5 – Dynamic Phenotype parameters and coefficients for calculation the body mass growth curve of pigs

Components of the curve	Age. year	G0. kg	DLi kg	dGmax. kg/day	Curves coefficients	a	b	c
Not identified	0.0	1.4	220	0.95	Gompertz	0.06331	0.01173	5.057

Comparing the pig's body mass growth with the (I) component of human's growth curve

The human (I) component of the body mass growth from embryo to the age of one year after birth is presented in Figure 3. The constants of the Dynamic Phenotype of body mass growth are presented in Table 4. The human growth curve has – in the time from conception to the age of one-year – Gomperz's growth curve form. Similarly like the growth curve of the pig ends the infancy component of the growth curve with the asymptote. In the case of the infant this asymptote is however only the interim step to further specific growth of the child and adolescent. The substantial difference between the growth curves of infancy component (I) and the growth curve of the pig however is to be seen in the quantity of the living body mass accumulated during the comparable time of growth. The peak velocity of the human growth in (I) component of the growth curve is positioned around the time of birth e.g. approximately 10th lunar months after conception (280 days, 0.75 year). The asymptote of the (I) component of the human growth curve (GLi ≐ 10.0 kg) is reached during one year after birth. The peak velocity of the (I) component in the human growth (dGmax = 12.5 kg/year = 0.034 kg/day) is however approximately 45 times smaller than that of the pig and performs no sign of sexual maturation. In the same time the body mass growth of the pig reaches its asymptote.

Discussion

The body mass growth represents expression of the genotype inherited from parents. The expression of genotype to its phenotype appearance is modified by conditions of nutrition and the impact of all stressing factors present in the environment. The body mass increase (dGmax) reflects the deposition of the gained net energy in the formed mass of proteins, lipids and sugars together with the bound minerals and water [11, 12]. The body mass growth reflects the physiological processes of energy accumulation and dissipation influenced in men by their lifestyle profiles. Attention deserves the fact that the (C) component of the body mass growth curve is present in some primates. Auxologist Tanner [18] expresses the opinion "that the characteristic shape of the human growth curve is shared only with the apes and monkeys, not with the other members of the order *Primates"*.

In other warm-blooded mammals the growth curve has a single genetic limit of body mass (GLi) and a constant maximum body mass increase (dGmax). The (C) component between weaning and puberty is lacking, and no visible adolescent spurt occurs. The growth velocity between birth and maturity has – in good environmental conditions – the constant maximum body mass increase (dGmax) and constant genetic limited body mass growth (GLi).

On the contrary the (I) component of the growth curve of man has its own separate asymptote defined by the genetic limited body mass (GLi) between 9 to 11 kg, different from the genetic limited body mass of man in the C and P components of the growth curves see in Fig. 2 (GLi = 75 kg). During the (I)

component of the growth curve the infant has not yet fully developed the brain, the muscles and the legs. Until the onset of the (C) component of the growth curve the child is unable to move independently as Homo erectus. Tanner [18] (page 23) states: "The prolongation of time between weaning and puberty appears to be an evolutionary step taken by the primates reaching its most pronounced development in Man. The increased time necessary for the maturing of the primate brain has been sandwiched into this period. It is probably advantageous for learning, especially learning co-operation in-group and family social life, to take place while the individual remains relatively docile and before he comes into sexual competition".

Neuroontogeny is a long lasting process that is in Man not finished with formation of basic anatomic structures of the brain. Development of brain function, the complex of movement reflexes is build up in the first year after the birth. The specific humans brain-functions expressed in the development of speech and of thinking are formed during the long lasting period of the (C) childhood component of the growth curve. The question remains open what is the primary cause of the extremely low velocity of body mass growth during the (C) childhood component of body mass growth in children. Maybe the human brain behaves in sense of plasticity definition [19] e.g. "as a special endowment of the nervous system to develop, to react or to adjust to the internal and external environmental changes both in physiological and pathological conditions". Maybe the brain is exploiting the yielded opportunity of low body mass growth velocity for comfortable development of specific human neural functions, as are the speech and ability of thinking. Would it be possible to anticipate that the neural and hormonal regulatory steps, that in comparison with other animals during the phylogeny have depressed the body mass growth velocity to the low rate of the childhood growth component (C), may repeat their role also during the ontogeny?

Conclusion

The Dynamic Phenotype of Body Mass Growth formed by three parameters (G0, GLi and dGmax) enables to visualize the expression of body mass genotype in the form of the Logistic or the Gompertz growth curve. This methodical approach opens new ways for the accurate evaluation of individual body mass growth in man and warm-blooded animals with respect to their genetic basis inherited from parents. This methodology may be also used for evaluation of nutrition and defined stressing factors they do influence the maximum body mass increase (dGmax). That means in men and women to evaluate their life-style conditions including the effects of harmful substances present in the environment.

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