Published in final edited form as:

J Pediatr. 2012 May ; 160(5): 762–768. doi:10.1016/j.jpeds.2011.11.002.

Eighty year trends in infant weight and length growth: the Fels Longitudinal Study

William Johnson, PhD¹, Audrey C Choh, PhD², Laura E Soloway, PhD³, Stefan A Czerwinski, PhD², Bradford Towne, PhD^{2,4}, and Ellen W Demerath, PhD¹

¹Division of Epidemiology and Community Health, School of Public Health, University of Minnesota, Minneapolis, MN

²Department of Community Health, Boonshoft School of Medicine, Wright State University, Dayton, OH

³New York State Cancer Registry, Albany, NY

⁴Department of Pediatrics, Boonshoft School of Medicine, Wright State University, Dayton, OH

Abstract

Objectives—To investigate secular trends in weight and length growth from birth to three years in infants born 1930–2008, and to assess whether these trends were associated with concurrent trends in pace of infant skeletal maturation and maternal Body Mass Index (BMI).

Study design—Longitudinal weight and length data from 620 (302 girls) infants were analyzed using mixed effects modeling for growth curves and predicted anthropometry for infants born 1930–1949, 1950–1969, 1970–1989, and 1990–2008.

Results—The most pronounced differences in growth occurred in the first year of life. Infants born after 1970 were ~450g heavier and ~1.4cm longer at birth, but demonstrated slower growth to one year, than infants born before 1970. Growth trajectories converged after one year of age. There was no evidence that relative skeletal age, maternal BMI, or maternal age together were associated with growth.

Conclusions—Recent birth cohorts may be characterized not only by greater birth size, but also by subsequent catch-down growth. Trends over time in human growth do not increase monotonically, and growth velocity in the first year may have declined compared with preceding generations.

Keywords

secular trends; infancy; catch-up growth; maternal BMI; longitudinal studies

A secular trend refers to a non-periodic change over time. The majority of studies investigating trends in human growth have focused on birth weight, childhood weight and height, and adult stature (1–6), with particular emphasis recently on trends in Body Mass

© 2011 Mosby, Inc. All rights reserved.

Corresponding Author: Ellen Demerath, Ph.D., Division of Epidemiology and Community Health, University of Minnesota, 1300 South 2nd Street, Suite 300, Minneapolis, MN 55454, Phone: (612) 624-8231, Fax: (612) 624-0315, ewd@umn.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Index (BMI).(1,7,8) Fewer data are available for trends in infant growth (i.e., birth to three years) (9–14), and studies that do exist have assessed trends over relatively short periods in the second half of the 20th century.(9–14) Greater infant weight gain is associated with later obesity and disease risk (15,16), so a secular trend in infant growth is indicative of more recent cohorts on a trajectory toward continued excess weight gain and increased disease risk.

Further, none of the reports on infant growth have accounted for the possibility that the observed trends in size may have occurred because the *tempo* of growth has changed over time (i.e., the age scale itself is shifting with time). It is possible that a trend in increasing size may be explained by a trend in the infant *maturational clock* as greater size is often a function of developmental pace. Our study describes trends in infant growth over an 80 year period in a single population, and examines whether these trends are explained by a change in the pace of skeletal maturation. Because upward trends in birth weight and infant growth are hypothesized to reflect the growing epidemic of maternal obesity (17), we also investigate whether growth trends are associated with concurrent trends in maternal BMI. The results provide a unique historical perspective for the current relationships between maternal obesity, infant growth, and the epidemic of childhood obesity.

METHODS

The sample consisted of 620 singleton European ancestry American infants (302 girls; 318 boys) participating in the Fels Longitudinal Study, which began in 1929 as a study of normative child growth and development and continues today as a study of the early life antecedents of chronic diseases of aging.(18) Mother-infant dyads living in Yellow Springs and nearby towns in southwestern Ohio have been enrolled from 1929 to present day. All protocols and informed consent documents used in the Fels Longitudinal Study were approved by the Wright State University Institutional Review Board.

Serial infant weight, length, and height were assessed using standard procedures, with target ages of birth and one month, every three months in the first year, and subsequently every six months until three years. Recumbent length was measured from birth to 24 months and height was measured from 30 months onward. Length and height will be referred to as “length”. Skeletal maturity was assessed using hand-wrist radiographs collected at the same study visits as the anthropometric measurements. For this analysis, the data closest to 1.5 years of age (range one to two years) were chosen as a measure of maturation pace during infancy. The radiographs were scored by trained anthropometrists using the Fels method (19) for skeletal age, and relative skeletal age was calculated by subtracting chronological age from skeletal age. Gestational age at birth and birth order were from birth records. Maternal age at infants’ birth was self-reported and non-pregnant BMI closest to birth was selected for analysis.

Infants had a minimum of three serial measurements for weight and length, including either a birth or one month measurement, with at least one measurement after 18 months. In addition, BMI data at 10 years of age ($\pm$ three months) were available for a sub-sample of children born at least ten years ago (i.e., prior to 2001) (n=480, 77.4%) and were used in the present study to provide additional information about secular trends in childhood size in the study sample.

Statistical Analysis

Gestational age was missing for 113 (18.2%) individuals and relative skeletal age was missing for 170 (27.4%) individuals, so these data were imputed five times using ICE in Stata. The imputation model included all measurements of weight and length, which had

been converted to Z-scores according to the WHO 2006 Standard (20) to avoid having to model a predefined function of age. Sex, birth year, birth order, relative skeletal age, gestational age, maternal age, and maternal BMI were also included in the imputation model. The distributions of the imputed relative skeletal age and gestational age data were similar to that of the observed data, providing some evidence that the missing data were missing at random. There were no differences in the goodness of fit or parameter estimates of the mixed effects growth models (see below) depending on which imputation dataset was used, thus the first imputation dataset was used in all subsequent analyses.

Mixed effects growth models were applied to the serial weight and length data. The Berkey-Reed 1st order function (21) provided a better fit for the data than other tested structured growth models, and resulted in the log likelihood, Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC) values closest to zero. Model convergence was achieved when random effects were specified for the intercept, age, and log age parameters, but not when inverse age was also allowed to have random effects. Growth models were built in steps. In step one, the Berkey-Reed function was fitted with sex, birth order, gestational age, and birth year as covariates. Birth year was categorized into four ~20 year cohorts to allow for nonlinear relationships between year of birth and infant growth. In step two, sex and birth cohort were interacted with the age terms to test whether the shape of the curve differed by sex and cohort, parity and gestational age were interacted with age, and sex was interacted with cohort. Each interaction was tested separately and was only retained if at least one of the parameters was significant ($p < 0.05$). In step three, relative skeletal age, maternal age, maternal BMI, and a maternal BMI-by-infant age interaction were added to test for possible mediation of the secular trend effect by these variables which may have changed over time. Relative skeletal age at 1.5 years of age was added to account for differences in the tempo of growth across birth cohorts, which were hypothesized to influence infant size.

The parameter and random effect estimates from step three models were used to calculate weight and length at birth; three, six, and nine months; and one, two and three years of age. These values were converted to Z-scores relative to the WHO 2006 Child Growth Standard (20), which were then plotted (sexes combined) by birth cohort. To account for the known negative association of infant growth with birth size, or regression to the mean, conditional gain measures were calculated over all cohorts as the residuals from sex specific linear regressions of weight (or length) Z-score at one year of age on weight (or length) Z-score at birth. Conditional weight and length Z-scores, along with birth weight and birth length Z-scores, were plotted (sexes combined) against birth cohort on the x-axis to more clearly assess secular trends in birth size and growth rate in the first year of life. Individual birth weight and birth length values from step two models were also calculated and converted to Z-scores, and are also plotted in this last set of figures to examine whether the trend in size at birth was perceptibly different when variations in maternal BMI (and maternal age and relative skeletal age) were not considered. Differences in weight and length Z-scores and conditional Z-scores between cohorts were tested using between-subjects analysis of variance (ANOVA), specifying a Bonferroni correction for multiple comparisons. Analyses were conducted using Stata IC10 (College Station, Texas).

RESULTS

Average birth year in the analysis sample was 1963, with a range of 1930 to 2008 (Table I). Mean imputed gestational age decreased over time, and birth weight and maternal BMI generally increased over time, with 17.9% of mothers in the 1930–1949 cohort being overweight or obese compared with 47.6% of mothers in the 1990–2008 cohort (p -values for trends < 0.01). Childhood BMI at 10 years of age also increased over time, with an increase

of approximately 3kg/m² occurring between the 1970–1989 and the 1990–2008 cohorts. Imputed relative skeletal age did not, however, demonstrate a significant trend over the study period.

Table II shows the parameter estimates from the mixed effects growth models. In step one, sex, gestational age, and birth cohort were significantly associated with weight and length growth. Weight and length increased in a stepwise fashion over successive birth cohorts; infants in the 1990–2008 cohort were 0.43kg heavier and 1.07cm longer than infants born between 1930 and 1949. In step two, we accounted for additional sources of variance in the shape of the growth curves by testing interactions of the independent variables with the age parameters of the Berkey-Reed model. The birth cohort-by-age (and by-log age and by-inverse age) interactions were generally significant, and cohort differences amplified with increasing age. The effect of birth cohort on growth of all dimensions did not differ significantly by sex and therefore this interaction was not included in the models. In step three, relative skeletal age was significantly associated with both weight and length, with a one year advancement in skeletal maturity being associated with a 0.12kg increase in weight and a 0.73cm increase in length. In addition, maternal age and the interaction between maternal BMI and age were significantly associated with weight, and maternal BMI was significantly associated with length. After adding these mediating variables, all but two of the same parameter estimates for birth cohort and the birth cohort-by-age interactions that were significant in step two retained significance. Moreover, the parameter estimates for birth cohort and birth cohort-by-age (and by-log age and by-inverse age) interactions were not substantially altered, suggesting that relative skeletal age, maternal age, and maternal BMI do not together mediate the association between birth cohort and growth.

To illustrate the trends in growth, predicted values from step three models were used to obtain Z-scores for weight and length, which were plotted by birth cohort (Figure 1). The differences in weight and length between cohorts were significant at all ages, except for length at two years of age. A clear pattern emerged, where infants born after 1970 tended to have higher birth weights and birth lengths than those born before 1970. The magnitude of this difference was approximately +0.75 Z-scores for both birth and birth length. All groups also exhibited decelerated growth relative to the WHO standard in the first three months, but those born after 1970 experienced a greater decline in Z-score values than those born before 1970. Between three months and one year of age, all groups grew faster than the standard, but those born before 1970 moved upward through the centiles at a greater pace, and achieved greater Z-scores at one year, than those born after 1970. After one year of age, the most recent cohort (1990–2008) demonstrated faster growth than the other cohorts, attaining final weight and length Z-scores at three years of age that were not significantly different (p-values >0.05) from those for the pre 1970 cohorts.

Figure 2 shows that birth weight and birth length have increased almost linearly over the 80 year period studied. Birth weight and length were approximately 1.0 Z-scores greater for infants born 1990–2008 compared with infants born 1930–1949. This represents a mean increase of approximately 600g in birth weight and 1.8cm in birth length. In contrast, conditional gain analysis showed that growth rate from birth to one year has declined over the study period. Infants in the first two birth cohorts showed catch-up growth in weight and length in the first year (i.e., conditional Z-scores at one year > 0.0), whereas those in the last two cohorts demonstrated catch-down growth.

DISCUSSION

We present the secular trends in the growth of European ancestry American infants over an 80 year period marked by large shifts in the prevailing food and energetic environment and

in maternal BMI. Unlike previous analyses (9–14), we were able to test whether any trends were changed by variations in the infant *maturational clock* and also maternal BMI and age.

A significant increase over time was observed for birth weight and birth length. Alberan (22) has reported that birth weight has changed little in some developed countries such as Norway, but in North America birth weight was still rising throughout the 1970s and 1980s. Using data from the annual natality volumes on the Vital Statistics of the United States, Chike-Obi et al (2) demonstrated that birth weight in Illinois has increased over a generation, such that white girls born 1989–1991 were on average 74g heavier than their mothers who were born between 1956–1976; the corresponding figure for males was 55g. The observed increase in birth weight in the present study of 600g was much larger, even after considering the longer study period of the Fels Longitudinal Study (i.e., 80 years) versus that of Chike-Obi et al (2) (i.e., 33 years). Historical data in the USA are lacking, although information from other countries show that trends in birth weight prior to 1950 have not necessarily been in a consistent direction or of the same magnitude.(12,23) We show that the greatest increases in birth weight and birth length occurred between the 1950–1969 and the 1970–1989 cohorts.

It is largely accepted that secular trends in length prior to two years of age are small and that mean childhood height has remained stable in industrialized countries since 1975 (17). We, however, found a 1.0cm increase in birth length between the 1950–1969 and the 1970–1989 cohorts (approximately 0.25cm per decade). Larger secular trends in neonatal length than those found in the current study have been observed in various developing countries (24,25), although comparative data from the USA are again lacking. The increasing trend in neonatal length presented here is, to our knowledge, novel.

It has been hypothesized that increasing birth weight in developed countries is the result of increasing maternal obesity.(17) We, however, found that, although maternal BMI increased by approximately 3.0kg/m² over the 80 year study period, inclusion of maternal BMI in our growth models did not perceptibly alter the observed trends in size at birth. Other factors that may have been responsible include changes in maternal biology and health (including a reduction in smoking prevalence and improved nutrition unrelated to maternal BMI or heights), an improvement in socioeconomic status and living conditions, and reductions in poverty and better provision of, and access, to health care and education.(26–28) A lack of detailed diet and other exposure data meant it was not possible to test the potential mediating effects of such factors, which is a limitation of the current study.

Beyond providing supporting evidence for cohort effects on size at birth, the present study clearly demonstrates a cross over in the postnatal growth trajectories of infants born before and after 1970 in the first year of life. Infants born earlier in the century appear to have experienced greater maternal constraint and fetal growth restriction, and thus demonstrated smaller sizes at birth, followed by catch-up growth. In contrast, infants born later in the century had greater body sizes at birth, followed by catch-down growth. The trend toward a greater prevalence of mothers choosing to formula rather than breast feed that generally persisted throughout the 20th century (29) may help explain this result, as formula feeding is associated with slower early infant weight gain and then faster later growth.(30) Again, this exposure was not assessed consistently and this hypothesis could not be tested with these data.

Results from the present study suggest that even though size at birth is clearly increasing over time, the effects of postnatal assortment of growth trajectories are large and predominate in the infancy period. As a result of this postnatal assortment, the growth of the cohorts tended to converge after 12 months of age. In addition, the significant trends

between cohorts in weight and length Z-scores at 36 months of age were driven by the lower Z-score of the 1970–1989 cohort compared with the other cohorts, who actually had values that were not significantly different from each other (p -values >0.05). We propose two distinct phases of secular trends in human growth: the fetal/infant phase and the childhood phase. In the first phase, prenatal factors affect fetal growth and size at birth, followed by postnatal growth assortment resulting in convergence of growth trajectories. In the second phase, nutritional factors acting on growth velocity at some point after infancy (including latent effects of earlier exposures) result in secular increases in size and adiposity in later childhood, adolescence, and adulthood. Evidence for the second phase is provided by numerous previous studies (1,7,8) and by the significant increase in childhood BMI and overweight or obesity prevalence that was observed in the present study.

An attractive explanation of the previous observed secular trends in infant growth (9–14) is that more recent cohorts are larger because they are more biologically advanced. We present data showing that secular trends in birth size and infant growth persist even after adjusting for a measure of the pace of infant maturation. The Fels Longitudinal Study stopped collecting hand-wrist radiographs from children under eight years of age in 1988, which meant that observed skeletal age data were not available for the most recent birth cohort. Although we can be confident in the quality of the relative skeletal data as a whole, we cannot comment on the quality of the imputed data for the most recent cohort, and this is a limitation of the present study. In a separate analysis not presented here we did, however, restrict the growth models to the first three cohorts and found that the effects of relative skeletal age on weight and length, and also the association of birth cohort with infant growth, remained the same as the results presented here.

The unique sampling strategy of the Fels Longitudinal Study has made it possible to present secular trends in longitudinal infant growth over an 80 year period, making appropriate adjustments for covariates and also testing for the potential mediating effects of relative skeletal age and maternal BMI on the association between birth year and infant growth. This study is the first to show that early postnatal growth trajectories have shifted from 1930 to the present day in a single regional United States growth study.

Pediatricians should be aware that, although early childhood growth rates are on the increase, leading to greater childhood BMI and obesity prevalence, growth velocity in the first year of life may actually have declined, representing catch-down growth following greater size at birth. After the first year of life, the greater growth of infants born between 1990 and 2008, observed in the present study, may be the beginning of a common trajectory among contemporary children who are on a course towards excess weight gain and increased risk for obesity compared with previous generations.

Acknowledgments

We acknowledge the life-long contributions of the Fels Longitudinal Study participants, and the study staff members, without whose commitment and enthusiasm the work of the study could never have been completed. In particular, we would like to thank Frances Tyleshevski (research data analyst at Wright State University) for her help in the creation of the dataset and the past and present Lifespan Health Research Center data collection team at Wright State University for their contributions.

Supported by grants from the National Institutes of Health: R01 HD012252 and R01 HD053685. The authors declare no conflicts of interest.

Abbreviations

BMI	Body Mass Index
------------	-----------------

AIC	Akaike Information Criterion
BIC	Bayesian Information Criterion
ANOVA	Analysis of Variance

References

1. Bua J, Olsen LW, Sorensen TI. Secular trends in childhood obesity in Denmark during 50 years in relation to economic growth. *Obesity*. 2007; 15:977–985. [PubMed: 17426333]
2. Chike-Obi U, David RJ, Coutinho R, Wu SY. Birth weight has increased over a generation. *Am J Epidemiol*. 1996; 144:563–569. [PubMed: 8797516]
3. Freedman DS, Khan LK, Serdula MK, Ogden CL, Dietz WH. Racial and ethnic differences in secular trends for childhood BMI, weight, and height. *Obesity*. 2006; 14:301–308. [PubMed: 16571857]
4. Komlos J, Lauderdale BE. The mysterious trend in American heights in the 20th century. *Ann Hum Biol*. 2007; 34:206–215. [PubMed: 17558591]
5. Larnkaer A, Attrup Schroder S, Schmidt IM, Horby Jorgensen M, Fleischer Michaelsen K. Secular change in adult stature has come to a halt in northern Europe and Italy. *Acta Paediatr*. 2006; 95:754–755. [PubMed: 16754562]
6. Wang YC, Colditz GA, Kuntz KM. Forecasting the obesity epidemic in the aging U.S population. *Obesity*. 2007; 15:2855–2865. [PubMed: 18070778]
7. Demerath EW, Li J, Sun SS, Chumlea WC, Remsberg KE, Czerwinski SA, et al. Fifty-year trends in serial body mass index during adolescence in girls: the Fels Longitudinal Study. *Am J Clin Nutr*. 2004; 80:441–446. [PubMed: 15277168]
8. Hulens M, Beunen G, Claessens AL, Lefevre J, Thomis M, Philippaerts R, et al. Trends in BMI among Belgian children, adolescents and adults from 1969 to 1996. *Int J Obes Relat Metab Disord*. 2001; 25:395–399. [PubMed: 11319638]
9. Carrascosa A, Yeste D, Copil A, Gussinye M. Secular growth changes. Weight, height and body mass index values in infant, children, adolescent and young adults from Barcelona population. *Med Clin*. 2004; 123:445–451.
10. Monteiro CA, Conde WL. Secular trends in postnatal growth in the city of Sao Paulo, Brazil (1974–1996). *Rev Saude Publica*. 2000; 34:41–51. [PubMed: 11428198]
11. Stein AD, Barnhart HX, Wang M, Hoshen MB, Ologoudou K, Ramakrishnan U, et al. Comparison of linear growth patterns in the first three years of life across two generations in Guatemala. *Pediatrics*. 2004; 113:e270–5. [PubMed: 14993588]
12. Takahashi, E. Growth standards for Japanese children- An overview with special reference to secular change in growth. In: Hauspie, R.; Lingren, G.; Falkner, F., editors. *Essays on Auxology Presented to James Mourilyan Tanner by Former Colleagues and Fellows*. Welwyn Garden City, Hertfordshire, UK: Castlemead Publications; 1995. p. 302-311.
13. Xu X, Wang WP, Guo ZP, Cheung YB, Karlberg JP. Secular change in growth over one decade (1980–1990) in Shanghai infants. *J Pediatr Endocrinol Metab*. 2000; 13:1603–1614. [PubMed: 11154156]
14. Zong XN, Li H, Zhu ZH. Secular trends in height and weight for healthy Han children aged 0–7 years in China, 1975–2005. *Am J Hum Biol*. 2011; 23:209–215. [PubMed: 21319250]
15. Ibanez L, Ong K, Dunger DB, de Zegher F. Early development of adiposity and insulin resistance after catch-up weight gain in small-for-gestational-age children. *J Clin Endocrinol Metab*. 2006; 91:2153–2158. [PubMed: 16537681]
16. Ong KK, Ahmed ML, Emmett PM, Preece MA, Dunger DB. Association between postnatal catch-up growth and obesity in childhood: prospective cohort study. *BMJ*. 2000; 320:967–971. [PubMed: 10753147]
17. Cole TJ. Secular trends in growth. *Proc Nutr Soc*. 2000; 59:317–324. [PubMed: 10946801]

18. Roche, AF. Growth, maturation and body composition: The Fels Longitudinal Study 1929–1991. Cambridge: Cambridge University Press; 1992.
19. Roche, A.; Chumlea, W.; Thissen, D. Assessing the skeletal maturity of the hand-wrist. Springfield, IL: Charles C Thomas; 1988.
20. WHO Multicentre Growth Reference Study Group. WHO Child Growth Standards: Methods and development: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age. Geneva: Word Heath Organisation; 2006.
21. Berkey CS, Reed RB. A model for describing normal and abnormal growth in early childhood. Hum Biol. 1987; 59:973–987. [PubMed: 3443447]
22. Alberman E. Are our babies becoming bigger? J R Soc Med. 1991; 84:257–260. [PubMed: 2041000]
23. Rosenberg M. Birth weights in three Norwegian cities, 1860–1984. Secular trends and influencing factors. Ann Hum Biol. 1988; 15:275–288. [PubMed: 3044272]
24. Davidson S, Litwin A, Peleg D, Erlich A. Are babies getting bigger? Secular trends in fetal growth in Israel--a retrospective hospital-based cohort study. Isr Med Assoc J. 2007; 9:649–651. [PubMed: 17939625]
25. Hop le T. Secular trend in size at birth of Vietnamese newborns during the last 2 decades (1980–2000). Asia Pac J Clin Nutr. 2003; 12:266–270. [PubMed: 14505988]
26. Kuh DL, Power C, Rodgers B. Secular trends in social class and sex differences in adult height. Int J Epidemiol. 1991; 20:1001–1009. [PubMed: 1800396]
27. Meyer HE, Selmer R. Income, educational level and body height. Ann Hum Biol. 1999; 26:219–227. [PubMed: 10355493]
28. Takahashi E. Secular trend in milk consumption and growth in Japan. Hum Biol. 1984; 56:427–437. [PubMed: 6489988]
29. Fomon S. Infant feeding in the 20th century: formula and beikost. J Nutr. 2001; 131:409S–20S. [PubMed: 11160571]
30. Griffiths LJ, Smeeth L, Hawkins SS, Cole TJ, Dezateux C. Effects of infant feeding practice on weight gain from birth to 3 years. Arch Dis Child. 2009; 94:577–582. [PubMed: 19019884]

Figure 1.

A, Weight-for-age and B, length-for-age Z-scores, relative to the WHO 2006 standard, from birth to three years of age, by birth cohort.

^aA separate ANOVA was applied at each age to test for differences between cohorts. All ANOVAs included a multiple comparison (with a Bonferroni correction) to test the difference between any two cohorts, although only the p-values for the overall models are given here.

Figure 2.

A, Weight and B, length Z-scores at birth and conditional Z-scores^a at one year, relative to the WHO 2006 standard, for each 20 year birth cohort.

^aConditional Z-scores were calculated as the residuals from sex specific linear regressions of Z-score at one year on Z-score at birth, and can be interpreted as change above or below that predicted by regression to the mean over the prior time interval.

^bA separate ANOVA was applied to each variable to test for differences between cohorts. All ANOVAs included a multiple comparison (with a Bonferroni correction) to test the difference between any two cohorts, although only the p-values for the overall models are given here.

Table 1

Description of study sample, by birth year cohort.

	Cohort 1 1930–1949	Cohort 2 1950–1969	Cohort 3 1970–1989	Cohort 4 1990–2008	P for trend ^a	Total
N	201	211	105	103		620
Percent (N) female	47.3 (95)	51.2 (108)	44.8 (47)	50.5 (52)	0.689	48.7 (302)
Mean (SD) birth weight (kg)	3.36 (0.48)	3.33 (0.52)	3.49 (0.45)	3.52 (0.59)	0.003	3.40 (0.51)
Percent (N) birth order first	33.3 (67)	28.4 (60)	48.6 (51)	39.8 (41)	0.003	35.3 (219)
Mean (SD) gestational age (weeks) ^b	39.89 (1.61)	39.88 (1.54)	39.83 (1.42)	39.16 (1.79)	0.001	39.76 (1.61)
<i>Gestational age using observed data (n=507)</i>	39.87 (1.60)	39.81 (1.49)	40.05 (1.36)	39.22 (1.81)	0.005	39.76 (1.60)
Mean (SD) relative skeletal age at 1.5 years (± 0.5 years) of age ^b	0.001 (0.46)	0.02 (0.48)	0.01 (0.46)	−0.01 (0.59)	0.948	0.01 (0.49)
<i>Relative skeletal age using observed data (n=450)</i>	0.003 (0.47)	0.03 (0.49)	−0.01 (0.49)	-	0.792	0.01 (0.48)
Mean (SD) maternal age (years)	30.15 (5.83)	27.15 (5.26)	27.67 (4.96)	29.58 (5.83)	<0.001	28.61 (5.65)
Mean (SD) maternal BMI (kg/m ²)	22.50 (4.38)	22.22 (3.41)	23.06 (4.32)	25.49 (5.35)	<0.001	23.00 (4.40)
Percent (N) mothers overweight or obese ^c	17.9 (36)	19.4 (41)	22.9 (24)	47.6 (49)	0.001	16.3 (150)
N for age 10 years sub-sample (% of total)	166 (82.6)	196 (92.9)	84 (80.0)	34 (33.0)		480 (77.4)
Mean (SD) BMI at 10 years of age	16.93 (1.97)	17.02 (2.48)	17.15 (2.91)	20.04 (4.78)	<0.001	17.23 (2.74)
Mean (SD) BMI Z-score ^d at 10 years of age	0.09 (0.96)	0.06 (1.07)	0.09 (1.06)	1.03 (1.38)	<0.001	0.14 (1.08)
Percent (N) overweight or obese ^e at 10 years of age	9.0 (15)	12.2 (24)	13.1 (11)	38.2 (12)	<0.001	13.1 (63)

^aContinuous variables were tested using between-subjects analysis of variance and categorical variables using a multidimensional Chi-square test.^bThe data shown are from the first of the five imputation runs.^cMaternal overweight and obesity were defined using internationally accepted cut-offs of $>25\text{kg/m}^2$ and $>30\text{kg/m}^2$, respectively.^dZ-scores were calculated according to the WHO 2006 Child Growth Standard.^eChildhood overweight and obesity were defined using the International Obesity Taskforce cut-off points.

Table 2

Mixed effects growth models of serial weight and length for 620 Fels Longitudinal Study infants aged zero to three years, testing for cohort effects and mediation of cohort effects by maturational pace and maternal age and BMI.

FIXED PART	Weight (kg)			Length (cm)		
	Step ^a 1	Step 2	Step 3	Step 1	Step 2	Step 3
Base model						
Constant	21.22 (0.35) ***	26.04 (1.16) ***	26.08 (1.16) ***	100.84 (1.03) ***	119.87 (3.29) ***	120.05 (3.29) ***
Age (decimal years)	3.32 (0.13) ***	3.67 (0.43) ***	3.68 (0.42) ***	10.90 (0.35) ***	14.95 (1.16) ***	14.98 (1.16) ***
Log age	-10.54 (0.51) ***	-13.53 (1.69) ***	-13.56 (1.68) ***	-22.59 (1.44) ***	-43.55 (4.73) ***	-43.63 (4.73) ***
Inverse age	-21.02 (0.46) ***	-26.37 (1.55) ***	-26.4 (1.55) ***	-59.23 (1.33) ***	-83.17 (4.41) ***	-83.25 (4.41) ***
Sex:						
male (referent)	--	--	--	--	--	--
female	-0.34 (0.04) ***	-4.84 (0.69) ***	-4.87 (0.69) ***	-1.51 (0.15) ***	-12.74 (1.95) ***	-12.85 (1.95) ***
Birth order:						
1 st born (referent)	--	--	--	--	--	--
2 nd born	0.02 (0.05)	0.01 (0.05)	-0.01 (0.05)	-0.30 (0.18)	-0.25 (0.20)	-0.30 (0.20)
3 rd born or higher	0.06 (0.05)	0.06 (0.05)	0.01 (0.05)	-0.14 (0.18)	0.08 (0.20)	0.02 (0.22)
Gestational age (weeks) ^b	0.12 (0.01) ***	0.12 (0.01) ***	0.12 (0.01) ***	0.54 (0.05) ***	0.62 (0.05) ***	0.59 (0.05) ***
Birth cohort:						
1930-1949 (referent)	--	--	--	--	--	--
1950-1969	0.14 (0.05) **	4.72 (0.82) ***	4.73 (0.82) ***	0.62 (0.18) **	10.23 (2.32) ***	10.26 (2.32) ***
1970-1989	0.32 (0.06) ***	2.10 (1.07)	2.15 (1.07) *	0.91 (0.23) ***	-11.59 (3.03) ***	-11.53 (3.03) ***
1990-2008	0.43 (0.06) ***	1.43 (1.06)	1.46 (1.06)	1.07 (0.23) ***	-22.18 (2.98) ***	-22.21 (2.98) ***
Interaction effects						
Sex:						
female * age		-0.74 (0.25) **	-0.75 (0.25) **		-2.15 (0.69) **	-2.16 (0.69) **

	Weight (kg)			Length (cm)		
	Step ^d 1	Step 2	Step 3	Step 1	Step 2	Step 3
FIXED PART						
female ^a log age		4.24 (1.00)***	4.26 (1.00)***		12.17 (2.81)***	12.23 (2.81)***
female ^a inverse age		5.41 (0.92)***	5.43 (0.92)***		13.90 (2.62)***	13.96 (2.62)***
Birth order:						
2 nd born ^a age					-0.05 (0.10)	-0.05 (0.10)
3 rd born or higher ^a age					-0.24 (0.10) [*]	-0.25 (0.10) [*]
Gestational age ^a age					-0.09 (0.03)***	-0.10 (0.03)***
Birth cohort:						
1950–1969 ^a age		1.22 (0.30)***	1.23 (0.30)***		1.63 (0.81) [*]	1.63 (0.81) [*]
1950–1969 ^a log age		-6.04 (1.19)***	-6.03 (1.19)***		-9.92 (3.33)***	-9.91 (3.33)***
1950–1969 ^a inverse age		-5.93 (1.10)***	-5.92 (1.10)***		-11.77 (3.12)***	-11.76 (3.12)***
1970–1989 ^a age		1.01 (0.39) ^{**}	1.00 (0.39) ^{**}		-3.68 (1.05)***	-3.68 (1.05)***
1970–1989 ^a log age		-4.34 (1.54)***	-4.39 (1.54)***		15.24 (4.34)***	15.16 (4.34)***
1970–1989 ^a inverse age		-2.79 (1.43) [*]	-2.84 (1.43) [*]		16.60 (4.06)***	16.52 (4.06)***
1990–2008 ^a age		1.44 (0.40)***	1.36 (0.40) ^{**}		-4.73 (1.08)***	-4.75 (1.08)***
1990–2008 ^a log age		-4.60 (1.57)***	-4.60 (1.57)***		24.40 (4.36)***	24.28 (4.36)***
1990–2008 ^a inverse age		-2.39 (1.43)	-2.40 (1.42)		28.99 (4.02)***	28.88 (4.02)***
Potential mediating effects						
Relative skeletal age at 1.5 years (± 0.5 years) of age			0.12 (0.04) ^{**}			0.73 (0.15)***
Maternal age (years) ^b			0.01 (0.00) [*]			0.01 (0.01)
Maternal BMI ^b			-0.01 (0.01)			0.04 (0.02) [*]
Maternal BMI ^a age			0.03 (0.00)***			0.01 (0.01)
RANDOM PART						
Sd[_constant]	1.25 (0.04)	1.18 (0.04)	1.18 (0.04)	2.63 (0.11)	2.45 (0.10)	2.44 (0.10)
Sd[age]	1.29 (0.05)	1.21 (0.05)	1.19 (0.05)	2.70 (0.12)	2.36 (0.11)	2.35 (0.11)

FIXED PART	Weight (kg)			Length (cm)		
	Step ^a 1	Step 2	Step 3	Step 1	Step 2	Step 3
	B(SE)	B(SE)	B(SE)	B(SE)	B(SE)	B(SE)
Sd[log age]	2.93 (0.11)	2.72 (0.10)	2.73 (0.10)	6.60 (0.27)	5.78 (0.25)	5.78 (0.25)
Sd[residual]	0.34 (0.00)	0.34 (0.00)	0.34 (0.00)	0.99 (0.01)	0.97 (0.01)	0.97 (0.01)
Log Likelihood	-4109.3	-4027.3	-3999.4	-9623.1	-9468.7	-9449.2
Akaike Information Criterion (AIC)	8254.7	8114.5	8066.8	19282.1	19003.5	18972.4
Bayesian Information Criterion (BIC)	8373.2	8312.0	8290.6	19400.6	19220.7	19216.0

* p<0.05,

** p<0.01,

*** p<0.001 (two tailed)

^a Models were built in steps: 1) Berkey-Reed 1st order function of age and basic covariates, 2) sex and year of birth were interacted with the three age terms (i.e., age, log age, inverse age), parity and gestational age were interacted with age, and sex was interacted with year of birth. For each interaction, all main effects for each variable were also included, and parameters were only kept in the model if at least one of them was significant (p<0.05), 3) relative skeletal age, maternal age, maternal BMI, and a maternal BMI-by-age interaction were added to examine their possible mediation of the birth cohort associations.

^b Gestational age, maternal age, and maternal BMI were centered about their means of 39.8 weeks, 28.6 years, and 23.0kg/m², respectively.