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Genetic and environmental contributions to the association between anthropometric measures and IQ: a study of Minnesota twins at age 11 and 17

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Abstract

Associations of height and head circumference with IQ are well documented, but much less is known about the association of IQ with other anthropometric measures or the mechanisms behind these associations. We therefore analyzed the associations between IQ and several anthropometric measures using a twin-study design. Twins born in Minnesota were assessed at either age 11 (756 complete pairs) or 17 (626 complete pairs) and analyzed using genetic modeling. Head circumference and height showed the most consistent positive associations with IQ, whereas more detailed anthropometric measures were not significantly better predictors of IQ. These associations were mainly due to common genetic factors. Our results suggest that the same genetic factors have an effect on physical and cognitive development. Head circumference and height capture information on children's physical development, which is partly associated also with cognitive development.

Key words: IQ, genetic factors, height, head circumference, children, twins

Associations between cognitive function or intelligence (IQ) and different anthropometric measures have long attracted scientific interest. Previous studies have shown that head circumference is positively associated with childhood cognitive performance (Heinonen et al. 2008, Veena et al. 2009) and negatively with cognitive decline at old age (Lee et al. 2010). Tall stature has been found to be associated with higher IQ in childhood (Wheeler et al. 2004) and adulthood (Humphreys et al. 1985, Teasdale et al. 1989, Tuvemo et al. 1999) as well as with slower cognitive decline in old age (Abbott et al. 1998). Problems in physical development can thus have negative effect on cognitive development. Much less is known, however, about how measures of other body parts are associated with IQ. Leg (Mak et al. 2006, Kim et al. 2003), knee (Huang et al. 2008) and arm length (Jeong et al. 2005) have been found to be negatively associated with cognitive decline or risk of dementia at old age, but few previous studies have analyzed how they are associated with IQ at younger ages. Since growth of different body parts may show different susceptibility to the effect of environmental factors (Ali et al. 2000, Bogin et al. 2002), it is important to compare how they are related to IQ to find optimal anthropometric measures which would capture variation relevant to the cognitive development as well.

The mechanisms behind the associations between anthropometric measures and IQ are still poorly understood, and may also vary between different anthropometric measures. Head circumference can be an indicator of brain volume (Bartholomeusz et al. 2002), which is further associated with IQ (Lange et al. 2010). It has also been suggested that the association of IQ with height and its components, such as leg length, would reflect the effect of environmental factors during childhood. This is an intriguing hypothesis since environmental factors in childhood, such as malnutrition, are found to be associated both with IQ (Yehuda et al. 2006) and height (Silventoinen 2003). However, a previous Dutch twin study found that the association between IQ and height was explained by genetic factors, which suggests that factors other than childhood environment, for example endocrinological mechanisms, are behind this association (Silventoinen et al. 2006). The association between stature and IQ is also found in the tallest end of height distribution, suggesting that this association is not likely to be generated only by inadequate childhood living conditions (Teasdale et al. 1991).

Since there are few studies comparing the associations of different anthropometric measures with IQ, we decided to investigate this question in twins during late childhood and late adolescence. The twin-study design provided an opportunity to analyze how genetic and environmental factors contribute to these associations.

Data and methods

The data are derived from the Minnesota Twin Family Study including monozygous (MZ) and same-sex dizygous (DZ) twin pairs born in Minnesota (Iacono et al. 1999, Iacono & McGue 2002). Twin births from 1972 to 1984 were identified from Minnesota state birth records. Contact information was found for 91% of the families of these twins. Twins and their families were invited to a day-long assessment in a laboratory located in Minneapolis when the twins were approximately 11 (SD=0.43) or 17 (SD=0.46) years of age. Among invited families, 17% refused to participate. Over 95% of participating families had Caucasian heritage reflecting the ethnic composition in Minnesota in these birth cohorts. The combined sample comprised measures on 1512 twin children at age 11 (760 females) and 1252 at age 17 (674 females) including 756 (485 MZ) and 626 (411 MZ) complete twin pairs, respectively.

Full-scale IQ, performance IQ and verbal IQ were measured using an abbreviated version of the Wechsler Adult Intelligence Scale-Revised (WAIS-R) for 17-year olds or the Wechsler Intelligence Scale for Children-Revised (WISC-R) for 11-year olds. The short forms consisted of two Verbal subtests (Information and Vocabulary) and two Performance subtests (Block Design and Picture Arrangement). Previous research has shown that IQ estimated from this abbreviated form correlates 0.94 with IQ determined using all the Wechsler subscales (Sattler 1974). The scaled scores were prorated to determine Full-Scale IQ, Performance IQ and Verbal IQ. Detailed anthropometric measures were also obtained using the standardized protocol (Table 1). This protocol was administered by trained personnel using a specially constructed steel chair designed to keep participant body parts straight and fully extended as appropriate. IQ and anthropometric measures were approximately normally distributed. To take into account the effect of minor differences in the ages within each of the two cohorts at the time of the examination, we adjusted the IQ and anthropometric measures for the exact age at the time of the measurement. This was done by computing regression residuals with age as an independent variable in regression models separately for boys and girls and using these residuals in the subsequent analyses. In the younger cohort (11 years) age explained some of the variation in height measures (5.9-11.4% in boys and 7.4-13.8% in girls) but a more minor part of the variation of IQ (0.3-1.6% and 0.1-0.3%, respectively) and craniological measures (0-4.4% and 0.1-4.1%, respectively) whereas in the older cohort (17 years) it explained less than 1% of the variation in all of these measures in males and females. All analyses were done independently within these two cohorts (11 and 17 years of age).

(Table 1)

The effect of genetic and environmental factors on IQ and anthropometric measures was estimated using biometrical models for twin data (Neale & Cardon 2003). Whereas MZ twins are genetically identical, DZ twins share, on average, 50% of their segregating genes. On this basis, four sources of variation interpreted as latent variance components in a structural equation model can be defined: additive genetic variation (A), which is the sum of the main effects of all alleles affecting the trait, genetic dominance variation (D) caused by interaction between alleles at the same locus, environmental factors common to co-twins (C), and environmental factors unique to each twin individual (E). Our data include only twins reared together and therefore do not allow simultaneous modeling of genetic dominance and common environmental effects.

First, univariate models for each measure at age 11 and 17 were fitted to test the assumptions of twin models, find the best fitting model used for subsequent multivariate modeling and compute the proportions of variation explained by genetic and environmental factors. The fit of the models was tested by comparing the change of χ^2-goodness-of-fit statistics and degrees of freedom between nested models ($\Delta\chi^2_{\text{degrees of freedom}}$). The technical assumptions of twin models, i.e. equal means and variances for MZ and DZ twins, were tested by comparing genetic models to saturated models, which do not make these assumptions. In the saturated models, means and variances were estimated for first and second MZ and DZ twins as well as co-variances for MZ and DZ twins separately for males and females. Further, twin modeling makes the assumptions of random mating and lack of gene-environment interactions. To calculate the correlations between the IQ and anthropometric measures, we computed standardized regression estimates using the clustered samples option (svy) of the Stata statistical package, version 10.1 for Windows. This allows us to take account of the clustered sampling design, i.e. sampling twin pairs rather than non-related individuals, on standard errors. All statistically significant correlations were further decomposed into genetic and environmental correlations using bivariate Cholesky decomposition. We used 95% confidence intervals to test the statistical significance of the parameter estimates. Genetic modeling was carried out with the Mx statistical package, version 1.7.03, using the raw data analysis option (Neale 2003).

Results

Table 2 presents descriptive statistics of the IQ and anthropometric measures by sex and zygosity. Anthropometric measures were very similar in boys and girls at age 11, but at age 17 boys were clearly taller than girls. No major sex differences were seen in the IQ tests at either age.

(Table 2)

We started the genetic modeling by testing the equality of means and standard deviations between MZ and DZ pairs and selecting the best fitting model used in further analyses. DZ correlations were larger than half of the MZ correlations suggesting the presence of common environmental effects (Table 3). Thus we selected the additive genetic/ common environmental/ specific environmental (ACE) model as the starting point for genetic modeling. The fit of the ACE models did not differ significantly from the saturated models ($\Delta\chi^2_{11}$=7.0-29.3, p=0.875-0.003) after we had corrected the conventional alpha level ($p<0.05$) by Bonferroni correction of 26 tests ($p<0.002$). Further, no systematic differences were found in means and standard deviations between MZ and DZ twins (Table 2). Common environmental effects were found for all traits, but it was statistically significant for only some of them ($\Delta\chi^2_2$=0.5-23.6, p=0.77-0.0001). Because the non-significant common environmental effects can also be because of lack of power, we decided to use the ACE model in univariate modeling. Further we found that we were not able to equate the parameter estimates in males and females for all traits ($\Delta\chi^2_3$=0.5-18.9, p=0.93-0.0002). We decided to treat boys and girls separately for all traits to make our analyses systematic.

(Table 3)

Standardized variance components of genetic and environmental factors for all IQ and anthropometric measures are presented in Table 4. At age 11, the genetic and common environmental effects explained about equal portions of the variance in IQ tests in boys and girls. At age 17, however, the relative effects of genetic factors clearly increased and most of the common environmental effects became statistically non-significant. The same pattern was seen also in the anthropometric traits in boys. Especially for the cranial measures, the common environmental effects were substantial at age 11, but they clearly decreased at age 17 and most of them became statistically non-significant. For the measures of height, the common environmental effects were generally less important than for cranial measures and generally statistically non-significant at age 11; at age 17 these effects largely disappeared. Additive genetic factors were important for all traits in girls, and most of the common environmental effects were statistically non-significant.

(Table 4)

Table 5 presents the phenotypic correlations between full-scale IQ and the anthropometric measures. Head circumference was consistently correlated with full-scale IQ. The correlations with the other cranial measures were smaller in size but mostly still statistically significant. Height measures showed systematically weaker correlations with full-scale IQ when compared with cranial measures. Total height showed the strongest correlation but was statistically significant only in boys. Other height measures showed significant correlations with IQ only in boys at age 11, whereas these correlations were close to zero at age 17 in boys and at both ages in girls. The confidence intervals of the correlations were, however, so wide that the differences between boys and girls were not statistically significant. The correlations of anthropometric measures with performance IQ and verbal IQ were very close to the correlations with full-scale IQ (data not shown but are available from the corresponding author).

(Table 5)

Finally we decomposed all statistically significant correlations between full-scale IQ and the anthropometric measures using a bivariate Cholesky decomposition. We first tested common environmental correlations and found that they were not statistically significant when using the Bonferroni corrected alpha level ($\Delta\chi^2_1$=0-8.3, p=1-0.004), and thus we decided to drop common environmental correlations from all of the models. We also dropped additive genetic or specific environmental correlations if they were not statistically significant. We found that common genetic factors explained a large portion of the observed phenotypic correlations (Table 6). Specific environmental correlations were also found for some of the traits, but they explained a smaller part of the phenotypic correlations than additive genetic factors.

(Table 6)

Discussion

Consistent with previous studies from Asian American (Rushton 1997), Finnish (Heinonen et al. 2008) and Indian populations (Veena et al. 2009), we found that head circumference was correlated with IQ. It is possible that these associations partly reflect the effect of brain volume known to be correlated with head circumference (Bartholomeusz et al. 2002). However, detailed measures of gray matter, temporal white matter and frontal white matter volumes in a previous study were only slightly more strongly correlated with IQ than found in this study for head circumference (Lange et al. 2010). Since head circumference is only moderately correlated with brain volume, it is likely that its correlation with IQ also reflects factors other than those involved in brain volume.

Height also correlated with IQ, as has been found in several previous studies (Wheeler et al. 2004, Humphreys et al. 1985, Teasdale et al. 1989, Tuvemo et al. 1999). However in our study, height was only weakly associated with IQ in girls at 11 years of age and the correlation was weaker than between head circumference and IQ in boys and girls. The lack of correlation between height and IQ in girls may be because many of the girls had already initiated puberty by this age (Euling et al. 2008), and differences in the timing and tempo of puberty may have attenuated this association. Somewhat surprisingly, IQ showed a stronger association with total height than with the length of different body parts. There is some evidence that secular increases in height in a population owe more to growth in limb than trunk length, suggesting that limb length is more sensitive to environmental influence (Ali et al. 2000, Bogin et al. 2002). Further, leg length has been found to better predict risk of cardiovascular diseases than trunk length (Gunnell et al. 1998). Our results suggest that total height captures information on the physical development of a child relevant to the development of cognitive abilities and leg length or other components of body height are not better indicators of this variation. However the correlations between anthropometric measures and IQ were generally low suggesting that the major part of cognitive development is independent of physical development.

The twin-study design gave us an opportunity to analyze factors behind the observed associations between IQ and anthropometric measures. We found evidence that these associations were mainly of genetic origin. The exception was head circumference, where we found some evidence on the role of common environmental factors on this correlation. The role of common genetic effects are supported by previous Dutch twin studies, which found that the association of IQ with brain volume (Posthuma et al. 2002) and height (Silventoinen et al. 2006) were explained by genetic factors. Common hormonal pathways, such as secretion of growth hormone, between physical and cognitive development is a possible explanation for these results. The clinical syndrome of growth hormone deficiency is associated both with short stature and mental retardation (van Dam et al. 2005), but it is unknown whether there is an association between cognitive development and the secretion of growth hormone within the normal variation of growth hormone levels. Our results, however, do not exclude the possibility that environmental factors could also be involved in this association since there may be genetically-based differences in susceptibility to the effects of environmental stressors between children.

In addition to genetic factors, common environmental factors also had some effect on IQ and anthropometric measures at age 11, but most of these effects decreased and became statistically non-significant at age 17. A diminishing effect of environmental factors from childhood to adulthood is well known for IQ (Plomin & Spinath 2004). A shared environmental effect on height has been found in childhood (Silventoinen et al. 2007) and a small effect also in adulthood (Silventoinen et al. 2003). It is noteworthy that separating common environmental effects from genetic effects needs large twin data sets (Visscher 2004, Visscher et al. 2008), and thus if the most parsimonious model is used these effects would be eliminated in many cases if the data set is not very large. Since confidence intervals for common environmental effects were wide in this study, no firm conclusions could be drawn. Our results, however, suggest that common environment may not be insignificant for IQ and anthropometrical traits even in adolescence. However because of the wide confidence intervals, we cannot exclude the possibility that common environmental effects in this study might be attributable to sample error. Large twin data sets or meta-analyses would be needed to analyze this question in detail.

Twin modeling makes certain assumptions, and if they are violated it should be taken into account when interpreting the results. First random mating is assumed because non-random mating can generate a genetic correlation between spouses and thus increase the genetic correlation of DZ twins more than the 0.5 value assumed in twin models. This further inflates the estimates of common environmental variance. There is clear evidence for assortative mating both for height (Silventoinen et al. 2003) and IQ (Reynolds et al. 1996), and thus it may have contributed to common environmental variance in this study. However, it is noteworthy that a common environmental effect is usually not found for height (Silventoinen et al. 2003) or IQ (Silventoinen et al. 2006) in adulthood suggesting that this effect cannot be very strong. Second, in our study, genetic and environmental effects on the phenotype were modeled as independent effects. If gene-environment interaction exists, it would be modeled as part of an additive genetic effect if the environmental exposure is shared by the co-twins or as part of specific environment if the exposure affects only one co-twin. Thus we cannot rule out that the genetic component in our study may partly reflect, for example, different genetic susceptibility of DZ twins interacting with childhood living conditions. Testing this hypothesis would require direct measures of environmental exposure, which would allow disentangling gene-environment interactions from pure genetic effects.

Our data have strengths but also limitations. Our main strength is detailed anthropometric measures at two ages allowing for a comparison of how age affects the associations of anthropometric measures with IQ. Further, since we have information on twins, we can analyze potential mechanisms behind these associations. A weakness is that even though our sample size was relatively large, especially when taking into account the very detailed anthropometric measurement protocol and IQ tests, we still had somewhat limited power mainly because of two reasons. First, we needed to treat boys and girls separately because of statistically significant differences in some of the traits; further the different timings of puberty may have otherwise confused our analyses. Secondly, since we found moderate common environmental effects for many traits, we decided not to drop these effects from univariate genetic models, even when they were generally statistically non-significant. This led to wider confidence intervals not only for common environmental effects but also for additive genetic effects. However, the point estimates are probably less biased because if the AE model would have been used, all common environmental variation would have been modeled as part of additive genetic variation and thus have been artificially inflated. It is also noteworthy that inadequate power to separate additive genetic and common environmental effects is a general problem in many other twin data sets as well (Hopper 2000). Also the power to detect these effects can be increased by multivariate analyses and they thus could be the next step in these analyses.

To conclude, head circumference and total height showed stronger associations with IQ than anthropometric measures focused on specific body parts. We found some evidence that these associations were mainly genetic origin, which may indicate the role of endocrinological factors or genetically based susceptibility to environmental stressors shared by family members. Head circumference and height are both easy to measure and capture important information on child development which has some relevance also to the development of cognitive abilities, even when physical and cognitive developments are mainly independent. These measures are already part of the protocol of health check-up in many countries, and our results suggest that inclusion of more detailed anthropometric measurements may not be necessary.

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Table 1. Measurement protocol of anthropometric traits.

Trait	Measurement protocol
Craniological measures	
Head circumference	Metal tape was run around head immediately above eyebrows and ears
Face height	Measured from tip of chin to top of head using anthropometer
Head length 1	Maximum distance from the nasion to the back of the head measured using anthropometer
Head length 2	Maximum distance from the bottom of the nasion to the inion measured using anthropometer
Head breadth	Maximum breadth in the transverse plane measured using spreading calipers
Height measures	
Total height	Measured using anthropometer with participant standing heels together and stretching upward to the fullest extent
Sitting height	Measured from the bottom of the buttock to the top of the head using anthropometer and adding 1 cm
Buttock-knee height	Measured from the back of the chair to the front of the knee using anthropometer
Knee height	Measured from the bottom of the heel to the top of the leg with the thigh horizontal and adding 1 cm
Foot length	Mean of foot length measured from the back of the heel to the front of the big toe

Table 2. Means and standard deviations (SD) of IQ and anthropometric (cm) measures at 11 and 17 years of age in boys and girls by zygosity.

	Boys 11 years				Girls 11 years				Boys 17 years				Girls 17 years			
	MZ		DZ		MZ		DZ		MZ		DZ		MZ		DZ	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Intelligence measures																
Full-scale IQ	105	14	104	14	102	14	105	15	104	14	102	13	97	14	97	14
Performance IQ	108	15	107	15	107	16	109	17	109	17	107	17	102	17	102	17
Verbal IQ	102	14	101	14	97	13	100	13	99	14	98	13	94	13	94	13
Craniological measures																
Head circumference	54	17	54	18	54	18	54	17	57	15	57	16	55	16	55	17
Face height	21	1.2	21	0.9	20	1.2	20	1.0	23	1.2	23	1.0	21	0.9	21	1.0
Head length 1	19	0.7	19	0.7	18	0.8	18	0.8	20	0.7	20	0.8	19	0.8	19	0.8
Head length 2	17	0.9	17	0.8	16	1.0	16	1.0	18	0.9	18	0.8	17	0.9	17	0.8
Head breadth	14	0.6	14	0.6	14	0.5	14	0.5	15	0.6	15	0.6	14	0.5	14	0.5
Height measures																
Total height	149	7.1	150	6.7	151	7.3	151	7.3	177	6.7	177	6.4	164	6.0	164	6.0
Sitting height	77	3.6	77	3.3	78	4.1	78	4.2	97	66	97	6.4	87	3.5	87	4.2
Buttock-knee length	52	3.2	52	3.2	53	3.8	53	3.5	62	4.1	62	4.0	58	2.9	58	2.8
Knee height	47	2.9	47	2.8	47	2.8	47	2.8	54	2.8	54	2.7	50	2.6	50	3.5
Foot length	23	1.4	23	1.4	22	1.3	23	1.3	26	2.9	26	1.3	23	1.2	23	1.2

Table 3. Within-pair intra-class correlations for IQ and anthropometric measures by sex and zygosity at 11 and 17 years of age.

	11 years				17 years			
	Boys		Girls		Boys		Girls	
	MZ	DZ	MZ	DZ	MZ	DZ	MZ	DZ
Full scale IQ	0.73	0.57	0.78	0.56	0.80	0.51	0.79	0.48
Performance IQ	0.56	0.39	0.67	0.45	0.62	0.31	0.58	0.40
Verbal IQ	0.78	0.54	0.74	0.56	0.83	0.47	0.82	0.56
Head circumference	0.84	0.68	0.86	0.42	0.83	0.35	0.86	0.56
Face height	0.70	0.41	0.62	0.32	0.63	0.41	0.57	0.27
Head length 1	0.66	0.49	0.78	0.43	0.53	0.30	0.77	0.46
Head length 2	0.81	0.50	0.82	0.58	0.79	0.64	0.80	0.60
Head breadth	0.83	0.46	0.85	0.53	0.90	0.44	0.84	0.55
Total height	0.93	0.52	0.93	0.59	0.89	0.44	0.92	0.56
Sitting height	0.87	0.44	0.90	0.38	0.92	0.69	0.88	0.60
Buttock-knee height	0.82	0.65	0.86	0.53	0.82	0.35	0.84	0.43
Knee height	0.93	0.53	0.90	0.55	0.93	0.46	0.91	0.55
Foot length	0.93	0.50	0.89	0.55	0.91	0.50	0.91	0.39

Table 4. Relative variance component estimates with 95% confidence intervals (CI) for IQ and anthropometric measures by sex.

	Boys						Girls					
	Additive genetic factors		Common environment		Specific environment		Additive genetic factors		Common environment		Specific environment	
	a^2	95%	c^2	95% CI	e^2	95% CI	a^2	95% CI	c^2	95% CI	e^2	95% CI
11 years of age												
Intelligence measures												
Full scale IQ	0.35	0.14-0.61	0.38	0.13-0.57	0.27	0.22-0.33	0.49	0.30-0.73	0.29	0.06-0.47	0.22	0.18-0.27
Performance IQ	0.36	0.07-0.63	0.20	0.00-0.46	0.43	0.36-0.52	0.45	0.20-0.71	0.22	0.00-0.44	0.33	0.27-0.41
Verbal IQ	0.47	0.26-0.74	0.30	0.04-0.50	0.23	0.18-0.28	0.39	0.19-0.63	0.36	0.13-0.54	0.25	0.21-0.31
Craniological measures												
Head circumference	0.39	0.23-0.58	0.46	0.27-0.61	0.15	0.12-0.19	0.84	0.61-0.88	0.01	0.00-0.24	0.15	0.12-0.15
Face height	0.30	0.04-0.64	0.37	0.03-0.61	0.34	0.28-0.40	0.41	0.10-0.65	0.17	0.00-0.45	0.42	0.35-0.50
Head length 1	0.33	0.08-0.63	0.33	0.04-0.55	0.34	0.28-0.42	0.67	0.43-0.81	0.11	0.00-0.34	0.23	0.18-0.28
Head length 2	0.53	0.31-0.81	0.26	0.00-0.48	0.21	0.17-0.25	0.48	0.29-0.71	0.34	0.11-0.52	0.18	0.15-0.23
Head breadth	0.44	0.29-0.65	0.44	0.24-0.59	0.11	0.09-0.14	0.73	0.53-0.89	0.14	0.00-0.33	0.13	0.11-0.17
Height measures												
Total height	0.78	0.57-0.94	0.15	0.00-0.36	0.07	0.05-0.09	0.71	0.54-0.93	0.22	0.00-0.40	0.07	0.05-0.08
Sitting height	0.75	0.52-0.88	0.11	0.00-0.34	0.14	0.11-0.17	0.91	0.79-0.93	0.00	0.00-0.11	0.09	0.07-0.11
Buttock-knee height	0.39	0.22-0.61	0.44	0.22-0.60	0.17	0.14-0.21	0.73	0.53-0.89	0.14	0.00-0.34	0.13	0.10-0.16
Knee height	0.79	0.59-0.94	0.13	0.00-0.34	0.07	0.06-0.09	0.72	0.53-0.91	0.18	0.00-0.37	0.10	0.08-0.12
Foot length	0.85	0.63-0.94	0.08	0.00-0.30	0.07	0.06-0.09	0.62	0.43-0.86	0.26	0.02-0.45	0.12	0.10-0.15
17 years of age												
Intelligence measures												
Full scale IQ	0.53	0.29-0.82	0.26	0.00-0.50	0.20	0.16-0.26	0.63	0.39-0.82	0.16	0.00-0.39	0.21	0.17-0.26
Performance IQ	0.62	0.27-0.69	0.00	0.00-0.32	0.38	0.31-0.48	0.41	0.11-0.66	0.17	0.00-0.44	0.41	0.34-0.50
Verbal IQ	0.62	0.37-0.84	0.19	0.00-0.44	0.19	0.15-0.23	0.48	0.28-0.75	0.33	0.07-0.53	0.19	0.15-0.23

Craniological measures												
Head circumference	0.83	0.67-0.87	0.00	0.00-0.16	0.17	0.13-0.21	0.68	0.47-0.89	0.19	0.00-0.40	0.13	0.10-0.16
Face height	0.29	0.00-0.65	0.31	0.00-0.59	0.40	0.32-0.49	0.58	0.32-0.66	0.00	0.00-0.23	0.42	0.34-0.52
Head length 1	0.65	0.39-0.82	0.12	0.00-0.38	0.22	0.18-0.28	0.49	0.26-0.78	0.30	0.01-0.51	0.21	0.17-0.26
Head length 2	0.27	0.08-0.52	0.51	0.27-0.69	0.22	0.17-0.27	0.33	0.14-0.58	0.46	0.22-0.64	0.21	0.17-0.26
Head breadth	0.88	0.62-0.91	0.01	0.00-0.27	0.11	0.09-0.14	0.68	0.46-0.87	0.17	0.00-0.39	0.15	0.12-0.19
Height measures												
Total height	0.89	0.63-0.91	0.00	0.00-0.26	0.11	0.09-0.14	0.72	0.52-0.93	0.20	0.00-0.40	0.08	0.07-0.10
Sitting height	0.44	0.28-0.69	0.48	0.25-0.63	0.09	0.07-0.11	0.58	0.39-0.82	0.31	0.06-0.49	0.12	0.09-0.15
Buttock-knee height	0.82	0.65-0.86	0.00	0.00-0.16	0.18	0.14-0.23	0.82	0.56-0.87	0.02	0.00-0.27	0.17	0.13-0.21
Knee height	0.93	0.69-0.95	0.00	0.00-0.24	0.07	0.06-0.09	0.68	0.47-0.91	0.23	0.00-0.43	0.10	0.08-0.12
Foot length	0.87	0.63-0.93	0.04	0.00-0.28	0.09	0.07-0.11	0.90	0.73-0.92	0.00	0.00-0.18	0.10	0.08-0.12

Table 5. Phenotypic correlations between full-scale IQ and anthropometric measures with 95% confidence intervals (CI) in boys and girls.

	11 years of age				17 years of age			
	Boys		Girls		Boys		Girls	
	r	95% CI	r	95% CI	r	95% CI	r	95% CI
Craniological measures								
Head circumference	0.21	0.09-0.33	0.13	0.04-0.22	0.17	0.06-0.27	0.14	0.05-0.23
Face height	0.07	-0.02-0.15	0.04	-0.04-0.12	-0.05	-0.15-0.05	-0.02	-0.10-0.07
Head length 1	0.09	0.00-0.18	0.19	0.10-0.27	0.15	0.05-0.24	0.19	0.09-0.28
Head length 2	0.16	0.07-0.24	0.13	0.05-0.21	0.09	0.00-0.19	0.08	-0.01-0.17
Head breadth	0.10	0.00-0.19	0.16	0.07-0.25	0.11	0.01-0.21	0.05	-0.04-0.14
Height measures								
Total height	0.13	0.05-0.21	0.03	-0.06-0.11	0.10	0.00-0.20	0.07	-0.01-0.15
Sitting height	0.08	-0.01-0.16	0.01	-0.08-0.09	-0.03	-0.07-0.01	0.05	-0.04-0.13
Buttock-knee height	0.13	0.06-0.20	0.00	-0.07-0.07	0.02	-0.10-0.15	0.00	-0.09-0.08
Knee height	0.14	0.04-0.22	0.00	-0.09-0.09	0.13	0.02-0.23	0.06	-0.01-0.13
Foot length	0.09	0.01-0.17	0.01	-0.08-0.10	0.01	-0.07-0.09	0.07	-0.01-0.16

Table 6. Decomposition of statistically significant correlations between anthropometric traits and full-scale IQ into additive genetic and specific environmental factors.[1]

	Additive genetic correlation			Specific environmental correlation		
	r	95% CI	% explained	r	95% CI	% explained
Boys 11 years of age						
Craniological measures						
Head circumference	0.32	0.14-0.50	78	0.21	0.09-0.33	22
Head length 1	0.20	-0.03-0.51	100	-		
Head length 2	0.38	0.17-0.65	100	-		
Head breadth	0.26	0.06-0.51	100	-		
Height measures						
Total height	0.19	0.03-0.37	77	0.22	0.10-0.34	23
Buttock-knee height	0.34	0.13-0.62	100	-		
Knee height	0.24	0.09-0.43	100	-		
Foot length	0.17	0.01-0.36	77	0.19	0.07-0.32	23
Girls 11 years of age						
Craniological measures						
Head circumference	0.28	0.13-0.46	100	-		
Head length 1	0.34	0.20-0.53	100	-		
Head length 2	0.27	0.10-0.46	100	-		
Head breadth	0.22	0.08-0.38	84	0.15	0.02-0.27	16
Boys 17 years of age						
Craniological measures						
Head circumference	0.25	0.10-0.42	100	-		
Head length 1	0.24	0.08-0.43	100	-		
Head length 2	0.26	0.02-0.58	100	-		
Head breadth	0.15	0.01-0.32	100	-		
Height measures						
Total height	0.14	0.00-0.30	100	-		
Knee height	0.16	0.03-0.31	100	-		
Girls 17 years of age						
Craniological measures						
Head circumference	0.17	0.04-0.30	100	-		
Head length 1	0.25	0.11-0.41	100	-		

[1] ACE models without common environmental correlations were used for all traits.