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Changes in the Genetic Variance and Heritability of the Body Mass Index and Skinfolds among Polish Twins Aged 8–18 Years

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A B S T R A C T

Body Mass Index (BMI) and skinfolds are common indicators of adiposity. Many studies have shown relationships between the BMI in childhood and adolescence and the BMI in adulthood. Similar correlations were observed for the skinfolds, although they tend to be lower. The aim of this study was to estimate changes with age in the genetic variance and heritability of the BMI and skinfolds among Polish twins born between 1959 and 1965. Observations involved male and female monozygotic (MZ) and dizygotic (DZ) twins, who were measured annually between 8 and 18 years of age. Body Mass Index and skinfold thicknesses at the triceps (TSF), subscapular (SSF) and suprailiac (SIF) sites were measured. Genetic variance and heritability were estimated for individual skinfold thicknesses, the sum of three skinfolds (SUMSF) and BM, separately by age classes for both sexes. Intraclass correlations were significantly higher for MZ twins than for DZ twins in both sexes and across all ages. Heritability estimates were significant for all indicators of adiposity, but varied with age and had different ranges for boys and girls. Estimates of genetic variance were significant for all indicators of adiposity and were higher for girls than for boys.

***Key words**: adiposity, twin studies, genetic variation, longitudinal studies, youth*

Introduction

Excess adiposity in the form of overweight and/or obesity is associated with elevated morbidity and mortality from a variety of conditions in adults[1–4]. In spite of growing concern for the health consequences, the prevalence of overweight and obesity has increased considerably in all segments of populations throughout most of the world[5–7]. Among Polish children and adolescents, for example, the prevalence of overweight and obesity nearly doubled between 1971 and 2000 from 7.5% to 15.2% in boys and from 6.5% to 11.8% in girls[8]. Similarly, the percentage of obese individuals (BMI>30.0 kg/m^2) 40 to 50 years of age in the city of Wroclaw has increased twofold between 1986 and 1996[9].

Longitudinal studies of children and adolescents indicate that measures of body fat track reasonably well. Correlations between the BMI at various ages during childhood and adolescence and the BMI in adulthood are moderate during childhood, but increase with age during adolescence[10,11]. Correlations between the sum of four skinfolds during childhood and in young adulthood are lower than corresponding correlations for the BMI, but the pattern of change in correlations across age is reasonably similar for skinfolds and the BMI. Data from a variety of studies using the BMI, relative body weight, weight-for-height, and skinfolds have been comprehensively summarized by Power et al.[12]. Based on data from 12 studies, inter-age correlations between measures incorporating body mass (BMI, relative weight, weight-for-height) during childhood (<13 years) and adulthood (25–36 years) were generally low (~0.30), while correlations between measures during adolescence (13–14 years) and in adulthood (25–36 years) ranged from moderate to high, 0.46 to 0.91 in males and from 0.60 to 0.78 in females[12]. Corresponding correlations for skinfolds were less extensive (four studies) and were limited largely to the triceps and subscapular skinfolds. Allowing for varia-

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tion among skinfolds and intervals between observations, inter-age correlations overlapped those for indicators of adiposity based on body mass. Correlations for skinfolds measured during adolescence and in adulthood tended to be higher than corresponding correlations for skinfolds taken during childhood. However, in studies including both the BMI and skinfolds, inter-age correlations for measures in childhood and adulthood were higher for the BMI[12].

Evidence from nuclear families, adoptive families and twins indicates a significant genotypic contribution to measures of body fat content[13]. Data from twin studies provide higher estimates of heritability than other designs. Twin studies, though providing valuable information, rarely consider longitudinal changes in the genetic variance of indicators of adiposity across childhood and adolescence and perhaps into adulthood in males and females[14–22]. For example, one of the first studies on this topic among twins aged 3–15 years showed a greater contribution of the genetic component for skinfold thickness after 10 years of age, accounting for about 98% of the variance; before 10 years, the estimated genetic influence was about 50%[23].

The purpose of this study is to estimate changes in the genetic contribution to several indicators of adiposity between 8 and 18 years in the Wroclaw Longitudinal Twin Study. Studying changes in the estimated genetic influence on adiposity across childhood through adolescence may indicate variation in estimates during the transition into adolescence and the interval of rapid growth and pubertal maturation; the latter, of course, vary among individuals in timing and tempo.

Materials and Methods

The sample included 51 male and 45 female pairs of monozygotic (MZ) twins, and 53 male and 41 female pairs of dizygotic (DZ) twin pairs from the Wroclaw Longitudinal Twin Study[24]. Zygosity was based on three independent methods: (1) diagnosis of similarity based on a battery of morphological traits, under the assumption that polygenic traits are concordant in MZ and discordant in DZ twins[25]; (2) probability of monozygosity based on discriminant function for a complex index of dermatoglyphic similarity, an algebraic sum of numerical values of similarity and dissimilarity between twin pairs for 64 specific indicators on the fingers, palms, soles and first toe[26]; (3) analysis of blood group concordance with calculation of the probability of monozygosity by means of the method of Maynard-Smith and Penrose using tables of pD values elaborated for the Polish population[27]. Anthropometric variables were not used in the assessment of zygosity.

The twins were born between 1959 and 1965 and were measured annually from 1967 to 1983, about 8 to 18 years of age. In 1983 year when the youngest cohort born in 1967 reached the age of 18 years the study was completed. Parents provided informed consent for the participation of their twins in the study. All measurements were taken by professional anthropologists using the same protocol and measuring instruments in the laboratory of the Institute of Anthropology of the Polish Academy of Sciences in Wroclaw. The study started with 233 pairs but at the conclusion included data for 190 pairs. The number of observations per twin pair varied from 6 to 13, with a mean of 10. Mean ages at first and last measurements were, respectively, 8.6±1.3 and 18.0±1.3 years for boys, and 8.4±1.0 and 17.5±1.7 for girls.

Height, body mass, and skinfold thicknesses at three sites were measured at each observation. A Lange skinfold caliper was used to measure the triceps (TSF), subscapular (SSF) and suprailiac (SIF) skinfolds. A standardized protocol was used throughout the study. The triceps skinfold was measured as a vertical on the back of the arm midway between acromion and olecranon, while the subscapular skinfold was measured one cm below the inferior angle of the scapula following the natural cleavage lines of the skin. The suprailiac skinfold was measured approximately 1 cm above and 2 cm medial to the anterior superior iliac spine. It was assumed that inter- and intra-observer errors were in an acceptable range. The three skinfold thicknesses were summed (SUMSF) to provide an estimate of overall subcutaneous adiposity. The body mass index (BMI, kg/m^2) was calculated and used as an indicator of weight-for-height and proxy for overall adiposity[28,29]. Distributions of all measurements and derived indicators were non-normal. All were thus transformed to a normal distribution and standardized with the LMS method[30,31].

Genetic variance and heritability of the three individual skinfold thicknesses, SUMSF, and BMI were estimated in single year age groups and also three combined age groups by sex according to the model of Christian et al.[32]. The combined age groups approximated late childhood and the transition into adolescence (girls, 8–10 years; boys, 8–12 years), the interval of the adolescent growth spurt (girls, 11–13 years; boys 13–15 years), and later adolescence (girls, 14–18 years; boys, 16–18 years).

Two independent estimates of genetic variance were calculated using between and within twin pair mean squares:

$\hat{G}_{WT}$ = within DZ mean square – within MZ mean square, and

$\hat{G}_{AT}$ = between MZ mean square – among DZ mean square.

When the total mean squares of MZ and DZ twin pairs do not differ significantly, $\hat{G}_{WT}$ is an adequate measure of genetic variance. When this assumption is violated, the arithmetic mean of $\hat{G}_{WT}$ and $\hat{G}_{AT}$ can be used as an unbiased estimate of twin genetic variance[32].

Differences in total variance between MZ and DZ twins were tested using a modification of the t-test adapted for twin data[32]. Equality of environmental co-variances within twin pairs was assumed. The presence of the genetic component in the variance in the indicators of adiposity was tested with the F-test[32].

Coefficients of heritability (h^2) were calculated as follows:

$$h^2 = \frac{r_{1_{MZ}} - r_{1_{DZ}}}{1 - r_{1_{DZ}}};$$

where $r_{1_{MZ}}$ and $r_{1_{DZ}}$ are intra-class correlation coefficients for MZ and DZ twins, respectively.

Results

Means, medians and standard deviations for each skinfold, SUMSF and BMI by age, sex and zygosity are presented in Tables 1 and 2. Medians differ between MZ and DZ twins within each sex for some indicators. Standard deviations for SUMSF and individual skinfolds are slightly higher for MZ boys at most ages. After transformation and standardization, results of t-tests adapted for twin comparisons do not show any significant differences in means by age in males and females for all indicators.

Tables 3 and 4 present the genetic variances and F values for all indicators of adiposity by age group in males and females, respectively. The BMI appears to be subject to greater genetic control than SUMSF in boys (Table 3). The genetic component for the BMI in boys varies, 0.200 to 0.285, between 8 and 15 years but in-

TABLE 1
MEANS, MEDIANS AND STANDARD DEVIATIONS OF THE VARIABLES ANALYSED FOR MALE TWINS BY ZYGOSITY AND AGE

	BMI [a] (kg/m²)				SSF [a] (mm)				TSF [a] (mm)				SIF [a] (mm)				SUMSF [a] (mm)			
Age	MZ (N=22)		DZ (N=24)		MZ (N=22)		DZ (N=24)		MZ (N=22)		DZ (N=24)		MZ (N=22)		DZ (N=24)		MZ (N=22)		DZ (N=24)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
8	16.1	2.00	15.4	1.13	64.0	45.87	49.3	12.27	80.9	38.84	67.1	17.52	64.2	56.80	41.6	23.37	209.2	133.68	158.0	47.51
9	16.7	2.00	15.7	1.16	72.8	68.77	53.3	16.22	81.5	39.98	71.2	17.75	72.3	80.52	45.0	21.31	226.6	182.90	170.5	50.26
10	17.1	2.22	16.2	1.60	79.4	63.84	56.3	19.47	91.5	41.69	78.4	25.94	87.1	41.69	52.9	35.72	257.0	200.22	187.6	76.85
11	17.5	2.38	16.4	1.58	85.5	86.76	60.1	24.24	96.0	58.07	83.3	31.86	103.4	137.55	56.6	35.87	284.9	275.90	200.1	83.22
12	17.9	2.57	17.0	1.83	93.8	87.61	70.1	31.50	107.4	65.39	88.2	33.42	108.5	111.77	62.9	47.40	309.7	256.22	221.1	101.19
13	18.4	2.53	17.5	1.97	94.1	91.78	74.0	37.35	102.2	55.02	91.8	37.06	100.2	98.46	76.3	87.76	296.5	236.80	242.1	150.66
14	19.2	2.78	18.1	2.13	95.8	77.44	70.8	30.20	99.4	55.71	87.7	50.12	107.5	100.57	82.5	95.45	302.7	227.39	240.9	164.04
15	20.7	2.69	19.2	2.11	98.0	79.98	75.8	28.90	97.3	52.42	82.5	28.94	118.0	118.43	74.3	34.73	313.3	242.39	232.5	84.32
16	20.6	2.48	20.2	2.36	91.0	54.11	86.3	34.52	90.0	41.21	93.3	37.03	101.8	92.72	88.5	73.08	283.3	181.01	268.1	138.14
17	21.8	2.68	20.7	2.39	109.3	86.70	95.8	53.51	101.0	46.36	93.3	44.79	111.4	108.12	95.8	83.44	321.7	234.80	284.9	174.08
18	21.8	1.96	21.1	2.21	97.8	46.42	99.0	47.84	98.7	40.30	91.9	37.54	104.0	79.72	91.8	90.45	300.5	144.72	282.8	165.89

[a] BMI – body mass index, SSF – subscapular skinfold, TSF – triceps skinfold, SIF – suprailiac skinfold, SUMSF – sum of skinfolds

TABLE 2
MEANS, MEDIANS AND STANDARD DEVIATIONS OF THE VARIABLES ANALYSED FOR FEMALE TWINS BY ZYGOSITY AND AGE

	BMI [a] (kg/m²)				SSF [a] (mm)				TSF [a] (mm)				SIF [a] (mm)				SUMSF [a] (mm)			
Age	MZ (N=25)		DZ (N=16)		MZ (N=25)		DZ (N=16)		MZ (N=25)		DZ (N=16)		MZ (N=25)		DZ (N=16)		MZ (N=25)		DZ (N=16)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
8	15.2	1.37	15.7	1.73	56.23	17.54	65.8	29.64	83.1	26.91	85.2	26.04	57.21	41.23	59.2	33.59	196.5	79.09	210.3	83.10
9	15.4	1.56	16.1	2.00	65.7	29.77	76.6	41.87	82.4	28.63	93.8	38.22	58.0	33.90	84.0	63.02	206.1	86.76	254.5	135.08
10	15.9	1.83	16.3	2.21	76.8	46.82	78.8	40.46	95.7	40.24	97.5	33.28	74.7	69.80	71.4	40.50	247.2	151.82	247.8	106.94
11	16.5	2.20	16.9	2.49	86.8	60.41	86.2	45.64	101.7	50.62	107.0	41.20	83.2	76.20	98.9	81.76	271.7	183.30	292.2	161.12
12	17.1	2.21	17.7	2.94	89.6	58.03	91.7	49.56	101.8	45.19	109.3	51.89	83.3	73.53	108.0	131.28	274.7	170.69	309.0	222.44
13	17.9	2.67	18.6	3.20	97.7	78.90	115.8	61.10	109.6	64.92	125.2	52.16	89.3	62.59	136.9	108.27	296.6	199.35	377.9	207.47
14	19.0	2.69	19.4	2.75	110.6	66.46	122.6	65.08	125.5	56.81	136.1	53.54	106.3	68.90	145.8	128.75	342.5	182.50	404.4	228.22
15	19.5	2.31	20.0	2.57	111.3	54.55	131.8	60.0	134.3	42.49	148.9	57.83	107.7	62.55	130.3	70.31	353.3	152.26	411.0	167.55
16	20.2	2.33	20.2	2.73	125.8	48.98	141.5	61.01	155.1	53.75	157.7	62.07	126.8	70.49	168.5	96.49	407.7	165.01	467.7	200.17
17	20.7	2.91	20.9	2.69	142.7	82.12	158.7	66.57	163.8	65.83	173.8	54.88	131.7	74.35	195.2	108.60	438.3	210.06	527.6	196.10
18	20.5	2.97	19.8	1.89	142.0	91.14	140.2	57.27	159.1	65.85	150.0	47.10	121.8	67.91	160.8	90.47	422.9	205.17	451.0	163.04

[a] BMI – body mass index, SSF – subscapular skinfold, TSF – triceps skinfold, SIF – suprailiac skinfold, SUMSF – sum of skinfolds

TABLE 3
ESTIMATED GENETIC VARIANCE BASED ON THE CHRISTIAN ET AL. (1974) MODEL FOR INDICATORS OF ADIPOSITY IN SINGLE YEAR AGE GROUPS OF BOYS (MZ N=22; DZ N=24)

Age	BMI [a]		SUMSF [a]		SSF [a]		TSF [a]		SIF [a]	
	$\hat{G}_{WT}$	F	$\hat{G}_{WT}$	F	$\hat{G}_{WT}$	F	$\hat{G}_{WT}$	F	$\hat{G}_{WT}$	F
8	0.239	2.39*	0.002	1.01	0.040	1.28	0.153	2.07*	0.037	1.23
9	0.200	2.81**	0.057	1.64	0.034	1.33	0.115	1.96	0.063	1.37
10	0.264	2.60*	0.109	1.80	0.147	2.43*	0.216	2.34*	0.122	1.64
11	0.265	3.46**	0.166	2.23*	0.232	3.78**	0.253	2.79**	0.111	1.73
12	0.255	2.61*	0.264	2.94**	0.264	2.89**	0.366	3.03**	0.181	2.28*
13	0.285	3.11**	0.225	3.06**	0.172	2.61*	0.421	4.62***	0.267	2.91**
14	0.229	2.10*	0.116	1.62	0.280	3.36**	-0.195	0.67	0.274	2.06*
15	0.225	2.61*	0.231	2.53*	0.183	2.03*	0.308	3.23**	0.146	1.70
16	0.299	3.49**	0.296	2.88**	0.361	4.14**	0.286	2.56*	0.008	1.03
17	0.335	5.46***	0.147	1.76	0.112	1.70	0.288	2.65*	0.071	1.21
18	0.338	4.10***	0.459	4.74**	0.083	1.28	0.486	4.03**	0.304	2.22*

*p<0.05; **p<0.01; ***p<0.001; [a] BMI – body mass index, SUMSF – sum of skinfolds, SSF – subscapular skinfold, TSF – triceps skinfold, SIF – suprailiac skinfold

TABLE 4
ESTIMATED GENETIC VARIANCE BASED ON THE CHRISTIAN ET AL. (1974) MODEL FOR INDICATORS OF ADIPOSITY IN SINGLE YEAR AGE GROUPS OF GIRLS (MZ N=25; DZ N=16)

Age	BMI [a]		SUMSF [a]		SSF [a]		TSF [a]		SIF [a]	
	$\hat{G}_{WT}$	F	$\hat{G}_{WT}$	F	$\hat{G}_{WT}$	F	$\hat{G}_{WT}$	F	$\hat{G}_{WT}$	F
8	0.188	2.64*	0.160	3.18**	0.156	1.72	0.206	2.91**	0.136	2.32*
9	0.134	2.29*	0.200	2.81**	0.037	1.23	0.094	1.56	0.234	2.62*
10	0.194	2.63**	0.250	3.95**	0.181	2.30*	0.169	2.21*	0.208	2.74**
11	0.279	3.65**	0.460	6.80***	0.216	2.96**	0.566	7.20***	0.368	4.05***
12	0.195	3.12**	0.331	3.37**	-0.035	0.81	1.287	8.58***	0.033	1.21
13	0.142	2.75**	0.126	3.05**	0.138	2.84**	0.344	4.31**	0.015	1.20
14	0.114	1.91	0.266	3.47**	0.290	3.45**	0.449	3.44**	0.124	2.01*
15	0.176	2.57*	0.290	4.05***	0.217	2.48*	0.342	3.59**	0.378	4.86***
16	0.270	2.95**	0.327	4.62***	0.194	2.34*	0.521	4.41***	0.310	4.20**
17	0.325	3.75**	0.243	3.25**	0.268	2.55*	0.276	2.45*	0.198	2.45*
18	0.232	2.60*	0.468	4.71***	0.353	3.53**	0.833	4.90***	0.557	5.12***

*p<0.05; **p<0.01; ***p<0.001; [a] BMI – body mass index, SUMSF – sum of skinfolds, SSF – subscapular skinfold, TSF – triceps skinfold, SIF – suprailiac skinfold

creases in later adolescence reaching 0.338 at 18 years; the genetic component for SUMSF among boys varies with age with lowest and highest values at 8 years (0.002) and 18 years (0.459). In girls, the genetic component for the BMI varies between 0.114 and 0.325 with no clear age trend, although the highest estimate occurs at 17 years; SUMSF in girls appears to have a somewhat higher degree of genetic control reaching value of 0.460 at age 11 years (Table 4).

Estimates of genetic variance for individual skinfold thicknesses and SUMSF in males are not consistently significant in late childhood (8–10 years), but during the transition into adolescence (11–12 years) and the interval of the spurt (13–15 years), estimates of genetic variance for individual skinfolds and SUMSF are significant. SIF is the most variable of the individual skinfolds and shows the lowest estimated genetic variance at most ages in males (Table 3). Estimates of genetic variance for the BMI, SUMSF, and individual skinfolds are significant at most ages in females and are consistently higher than estimates for males (Table 4).

Intraclass correlations are shown in Tables 5 and 6. They are significantly higher among MZ than DZ twins in both sexes across all ages. There does not appear to be

TABLE 5
INTRA-CLASS CORRELATION COEFFICIENTS FOR MZ (N=22) AND DZ (N=24) TWINS AND ESTIMATED HERITABILITIES (h^2) FOR INDICATORS OF ADIPOSITY IN SINGLE YEAR AGE GROUPS OF BOYS

Age	BMI [a]			SUMSF [a]			SSF [a]			TSF [a]			SIF [a]		
	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2
8	0.839	0.468	0.70**	0.885	0.773	0.49	0.813	0.725	0.32	0.873	0.688	0.59*	0.848	0.733	0.43
9	0.892	0.508	0.78**	0.942	0.734	0.78**	0.918	0.843	0.48	0.909	0.615	0.76**	0.744	0.602	0.43
10	0.848	0.546	0.67*	0.900	0.648	0.72**	0.911	0.676	0.72**	0.856	0.526	0.70**	0.836	0.646	0.54
11	0.898	0.558	0.76**	0.909	0.575	0.79**	0.931	0.663	0.80**	0.904	0.516	0.80**	0.871	0.637	0.64*
12	0.870	0.516	0.73**	0.914	0.501	0.83***	0.883	0.540	0.75**	0.886	0.376	0.82***	0.888	0.597	0.72**
13	0.880	0.578	0.72**	0.914	0.659	0.75**	0.915	0.679	0.74**	0.900	0.416	0.83***	0.871	0.670	0.61*
14	0.828	0.593	0.58*	0.819	0.773	0.20	0.908	0.724	0.67*	0.504	0.661	–0.46	0.766	0.635	0.36
15	0.866	0.624	0.64*	0.877	0.532	0.74**	0.854	0.614	0.62*	0.876	0.480	0.76**	0.854	0.478	0.72**
16	0.863	0.615	0.64*	0.852	0.545	0.67*	0.896	0.475	0.80**	0.808	0.525	0.60*	0.748	0.671	0.24
17	0.926	0.622	0.80**	0.797	0.680	0.37	0.860	0.741	0.46	0.793	0.548	0.54	0.750	0.620	0.34
18	0.830	0.543	0.63*	0.897	0.423	0.82**	0.745	0.608	0.35	0.888	0.358	0.83**	0.792	0.404	0.65*

*p<0.05; **p<0.01; ***p<0.001; [a] BMI – body mass index, SUMSF – sum of skinfolds, SSF – subscapular skinfold, TSF – triceps skinfold, SIF – suprailiac skinfold

TABLE 6
INTRA-CLASS CORRELATION COEFFICIENTS FOR MZ (N=25) AND DZ (N=16) TWINS AND ESTIMATED HERITABILITIES (h^2) FOR INDICATORS OF ADIPOSITY IN SINGLE YEAR AGE GROUPS OF GIRLS

Age	BMI [a]			SUMSF [a]			SSF [a]			TSF [a]			SIF [a]		
	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2
8	0.877	0.716	0.57	0.911	0.715	0.69*	0.708	0.696	0.04	0.877	0.652	0.65*	0.902	0.745	0.62
9	0.869	0.774	0.42	0.899	0.723	0.63*	0.837	0.831	0.04	0.860	0.813	0.25	0.877	0.618	0.68*
10	0.864	0.725	0.51	0.934	0.560	0.85***	0.895	0.616	0.73*	0.874	0.649	0.64*	0.912	0.566	0.80**
11	0.901	0.686	0.68*	0.929	0.556	0.84**	0.902	0.694	0.68*	0.906	0.424	0.84***	0.886	0.621	0.70*
12	0.915	0.810	0.55	0.866	0.669	0.59	0.827	0.856	–0.20	0.820	0.214	0.77**	0.826	0.848	–0.15
13	0.926	0.859	0.48	0.938	0.869	0.53	0.925	0.825	0.57	0.894	0.663	0.69*	0.913	0.935	–0.33
14	0.879	0.828	0.30	0.903	0.770	0.58	0.882	0.750	0.53	0.842	0.551	0.65*	0.891	0.840	0.32
15	0.867	0.777	0.40	0.907	0.714	0.67*	0.862	0.715	0.52	0.846	0.726	0.44	0.900	0.558	0.78**
16	0.815	0.693	0.40	0.903	0.710	0.67*	0.845	0.752	0.38	0.832	0.580	0.60	0.904	0.678	0.76*
17	0.880	0.629	0.68*	0.889	0.737	0.58	0.837	0.675	0.50	0.816	0.650	0.47	0.844	0.754	0.37
18	0.858	0.660	0.58	0.879	0.466	0.77**	0.890	0.628	0.70*	0.811	0.187	0.77**	0.858	0.403	0.76**

*p<0.05; **p<0.01; ***p<0.001; [a] BMI – body mass index, SUMSF – sum of skinfolds, SSF – subscapular skinfold, TSF – triceps skinfold, SIF – suprailiac skinfold

a consistent pattern in correlations by age. Correlations also do not consistently differ for the BMI and SUMSF, but are more variable for individual skinfolds.

Heritability estimates are low to moderately high and are significant for almost all indicators in boys. Corresponding estimates in girls in many and perhaps most the age groups, (depending on adiposity measure) are not significant and range from low to moderate (Tables 5 and 6). Heritability estimates show no consistent pattern across ages in both sexes. Estimated heritabilities for the BMI range from 0.58 to 0.80 in males and 0.42 to 0.68 in females; estimates for SUMSF range from 0.37 to 0.83 in males and 0.53 to 0.85 in females. Estimated heritabilities are more variable among individual skinfolds.

Intraclass correlations and estimated heritabilities for all indicators of adiposity in the three broader age groups are summarized in Table 7. Among males, estimated heritabilities of the BMI and SUMSF are lower during the interval of the growth spurt. Estimated heritability of TSF is also lowest during the interval of the growth spurt in males, while heritabilities for the two trunk skinfolds are lowest in late adolescence. Estimated heritability of the BMI reaches its highest value during interval of spurt and is lowest in late adolescence in females. A different pattern is suggested for SUMSF in females; the highest estimate occurs in late childhood and the lowest during interval of the growth spurt. Estimated heritabilities of the individual skinfolds show no

TABLE 7
INTRACLASS CORRELATION AMONG MZ ($r_{1_{MZ}}$) AND DZ ($r_{1_{DZ}}$) TWINS AND ESTIMATED HERITABILITIES (h^2) FOR INDICATORS OF ADIPOSITY IN THREE BROADER AGE GROUPS: LATE CHILDHOOD (BOYS 8-12 YEARS, GIRLS 8-10 YEARS), THE INTERVAL OF ADOLESCENT GROWTH SPURT (BOYS 13-15 YEARS, GIRLS 11-13 YEARS) AND LATE ADOLESCENCE (BOYS 16-18 YEARS, GIRLS 14-18 YEARS).

Age intervals	N/N	BMI [a]			SSF [a]			TSF [a]			SIF [a]			SUMSF [a]		
		$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2	$r_{1_{MZ}}$	$r_{1_{DZ}}$	h^2
Boys																
8–12	110/120	0.86	0.51	0.72***	0.89	0.68	0.65***	0.88	0.54	0.75***	0.84	0.64	0.55***	0.91	0.63	0.75***
13–15	66/72	0.85	0.59	0.64***	0.89	0.68	0.66***	0.75	0.52	0.48**	0.83	0.61	0.56**	0.87	0.67	0.61***
16–18	66/72	0.89	0.58	0.74***	0.80	0.67	0.40	0.85	0.45	0.72***	0.76	0.58	0.51*	0.84	0.55	0.65**
Girls																
8–10	75/48	0.86	0.70	0.54*	0.81	0.71	0.35	0.87	0.69	0.59**	0.88	0.64	0.67***	0.90	0.65	0.72***
11–13	75/48	0.90	0.78	0.56**	0.86	0.78	0.36	0.86	0.40	0.77***	0.86	0.80	0.29	0.89	0.70	0.63**
14–18	125/80	0.86	0.72	0.49**	0.85	0.70	0.50**	0.82	0.56	0.59***	0.87	0.66	0.60***	0.89	0.69	0.65***

*p<0.05; **p<0.01; ***p<0.001; [a] BMI – body mass index, SSF – subscapular skinfold, TSF – triceps skinfold, SIF – suprailiac skinfold, SUMSF – sum of skinfolds

consistent pattern across the three age groups in females. For TSF heritabilities tend to be higher in interval of growth spurt, whereas those for SSF and SIF decrease in this interval.

Discussion

Changes in estimated genetic variance and heritability of BMI, sum of three skinfolds and individual skinfolds (triceps, subscapular, suprailiac) were evaluated between 8 and 18 years of age in participants in the Wroclaw Longitudinal Twin Study. Overall, degree of resemblance in the indicators of adiposity was significantly greater in MZ than DZ twins in both sexes. Heritabilities for the BMI, an indicator of weight-for-height in surveys of overweight and obesity, varied from 0.58 to 0.80 and 0.30 to 0.68 for boys and girls, respectively. Corresponding estimates for SUMSF, a proxy for subcutaneous fat, were variable in boys, 0.37 and 0.83. The contribution of heredity to SUMSF was somewhat greater in girls, 0.53 to 0.85.

Results from the study of Polish twins were generally consistent with a relatively strong genetic influence on indicators of adiposity in twins[21,33–37]. Previous estimates of heritability in most studies of twins were based on adolescents and adults, whereas corresponding data for the children were relatively limited. Estimated heritabilities for the BMI in adolescent twins ranged from 87 to 93% and were considerably higher than observed in adults[36,37]. Among 105 MZ and DZ twin pairs 10–14 years, estimated heritabilities of the BMI were in the same range[37]. In a much larger sample of twins and sibling pairs 11–20 years of age, estimated heritabilities of the BMI were 41% in females and 75% in males[38]. More recent data have shown that during adolescence additive genetic factors may explain 90–96% of the BMI phenotypic correlations[21]. Nevertheless, limitations of the BMI as an indicator of adiposity during adolescence should be noted. It may be more appropriately viewed as indicator of »heaviness« rather than of fatness; the genetic effect in the BMI could also reflect contributions of skeletal muscle mass, skeletal mass and other tissues[35].

Similar studies of twins using the SUMSF during childhood and adolescence are limited. Using a sum of six skinfold thicknesses, evidence suggested a heritability of about 88% in adults[34] but sex differences were not indicated. Evidence for a ratio of trunk to extremity skinfolds (TER, an indicator of relative subcutaneous fat distribution) in adolescence indicated relatively strong genetic control (>75%) in both males and females[20].

Results for individual skinfolds in Polish twins suggested that heredity plays a somewhat greater role in the accumulation of subcutaneous fatness on the trunk than on the extremities in girls more so than in boys. This was also suggested for 222 twin pairs 3–15 years of age[23]. The results for Polish twins also suggested higher heritability for subscapular (upper trunk) compared to suprailiac (lower trunk) subcutaneous fat in males; corresponding estimates were nearly equal in female twins. The estimates were generally consistent with earlier observations of a sex difference in genetic influence in the suprailiac skinfold thickness, about 7%[18].

Changes in genetic contribution and/or heritability to indicators of adiposity during specific transitional periods in growth and maturation have not been systematically studied within a broader age ranges. Reduced heritability during the interval of the growth spurt was suggested in the male twins (Table 9); however, the reduction was due to increases in intra-class correlations for DZ twins. Individual skinfolds behave differently during the adolescent spurt and height and weight also differ in timing of maximal growth[39]. Among male twins, the estimated importance of genotype decreased with age and reached a lowest value in late adolescence only for trunk subcutaneous fatness; corresponding estimates for

girls were stable at earlier ages but increased in late adolescence. The apparent sex differences appeared during the interval of adolescent growth spurt. BMI, subscapular skinfold (upper trunk) and triceps skinfold (extremity) tended to be under greater genetic control in girls than in boys, in comparison to the other developmental periods, i.e. late childhood and late adolescence. It has also been reported that pooled heritability estimates for the triceps and subscapular skinfolds were higher for children older than 10 years compared to children younger than 10 years of age, 98% versus 50%[23].

It might be expected that estimated heritability would decrease with age due largely to enhanced effects of shared environmental factors in children and adolescents, assuming constant heritability with age. During childhood and adolescence twins are to great extent dependent on parental resources, but in early adulthood they are more self-reliant (e.g., weight control behaviors) and under greater influence of non-shared environmental factors. Thus, increasing heritability with age may be attributed to the influence of additive genetic factors. That may contribute to the interpretation of increasing heritability in trunk subcutaneous fat in girls and in overall fatness and triceps skinfold in boys in late adolescence.

Genome-wide association studies (GWAS) have confirmed 16 loci associated with the genetic susceptibility to obesity in adults[40], while studies of anthropometric traits related to obesity in children and adolescents have shown similar genetic associations[41]. It is important to note differences between genetic variants for changes in BMI and skinfolds at different ages and of genetic variants affecting specific particular levels of BMI and skinfolds. Such a difference between changes and levels of BMI has been noted in a longitudinal study of adult twins[42] and adolescents[21]. Observations from the Wroclaw Longitudinal Twin Study focused on levels of BMI and skinfolds from late childhood to late adolescence but did not consider changes in BMI and skinfolds with age across childhood through adolescence. Similarly, individual differences in the timing of sexual maturation and the growth spurt were not considered. These obviously represent topics for further analysis.

The Wroclaw Longitudinal Twin Study started with nearly 200 twin pairs, but a relatively small number of pairs had complete data from 8 to 18 years of age. Such a limitation is common in longitudinal studies and interpretation of the results should recognize this limitation.

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PROMJENE U GENETIČKOJ VARIJANCI I NASLJEĐIVANJE INDEKSA TJELESNE MASE TE KOŽNIH NABORA U POLJSKIH BLIZANACA OD 8-18 GODINA STAROSTI

S A Ž E T A K

Indeks tjelesne mase (engl. body mass indeks BMI) te kožni nabori uobičajeni su pokazatelji adipoznosti. Mnoge studije pokazale su povezanost između BMI u djetinjstvu i adolescenciji te BMI u odrasloj dobi. Slične, premda nešto niže, korelacije primijećene su za i kožne nabore. Cilj je ovog istraživanja procijeniti dobne promjene u genetskoj varijanci i nasljeđivanju BMI i kožnih nabora u poljskih blizanaca rođenih u periodu od 1959 do 1965. Istraživanje uključuje muške i ženske monozigotne (MZ) i dizigotne (DZ) blizance koji su mjereni godišnje u razdoblju od njihove 8. do 18. godine. Mjereni su indeks tjelesne mase i debljina kožnog nabora na tricepsu (TSF) te na subskapularnom (SSF) i suprailijačnom (SIF) mjestu. Genetska varijanca i nasljeđivanje procjenjeni su za pojedine kožne nabore, za zbroj svih triju nabora (SUMSF) te za BM, odvojeno po dobnim kategorijama za oba spola. Korelacije su bile značajno više za MZ blizance nego za DZ blizance kod oba spola te u svih godina starosti. Procjena nasljeđivanja bila je značajna za sve indikatore adipoznosti, ali je varirala s dobi i imala je drugačije raspone za dječake i djevojčice. Procjene genetske varijance bile su značajne za sve indikatore adipoznosti te su bile više za djevojčice nego za dječake.