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Zygosity Differences in Height and Body Mass Index of Twins From Infancy to Old Age: A Study of the CODATwins Project

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A trend toward greater body size in dizygotic (DZ) than in monozygotic (MZ) twins has been suggested by some but not all studies, and this difference may also vary by age. We analyzed zygosity differences in mean values and variances of height and body mass index (BMI) among male and female twins from infancy to old age. Data were derived from an international database of 54 twin cohorts participating in the COllaborative project of Development of Anthropometrical measures in Twins (CODATwins), and included 842,951 height and BMI measurements from twins aged 1 to 102 years. The results showed that DZ twins were consistently taller than MZ twins, with differences of up to 2.0 cm in childhood and adolescence and up to 0.9 cm in adulthood. Similarly, a greater mean BMI of up to 0.3 kg/m^2 in childhood and adolescence and up to 0.2 kg/m^2 in adulthood was observed in DZ twins, although the pattern was less consistent. DZ twins presented up to 1.7% greater height and 1.9% greater BMI than MZ twins; these percentage differences were largest in middle and late childhood and decreased with age in both sexes. The variance of height was similar in MZ and DZ twins at most ages. In contrast, the variance of BMI was significantly higher in DZ than in MZ twins, particularly in childhood. In conclusion, DZ twins were generally taller and had greater BMI than MZ twins, but the differences decreased with age in both sexes.

■ **Keywords:** twins, height, BMI, zygosity differences

Twinning rates vary considerably across the world, ranging from 6–9 per 1,000 maternities in South Asia, South-East Asia, and Latin America, 11–20 per 1,000 maternities in Europe and North America, to above 18 per 1,000 maternities in Central Africa (Hoekstra et al., 2008; Smits & Monden, 2011). In addition to regional differences, there are secular differences as well. Rates of twinning started to decline from around the year 1900 to the mid-20th century, but began to increase again in the late 1970s in most developed countries, including the United States, Japan, South Korea, and Western European countries (Hur & Song, 2009; Imaizumi, 2005; Macfarlane & Blondel, 2005; Martin et al., 2015). In developing countries, however, changes in twinning rates over time are small and not in a specific direction (Smits & Monden, 2011).

Since monozygotic (MZ) twinning generally occurs at a constant rate of about 4 per 1,000 maternities worldwide, the variation in twinning rates is mostly due to differences in dizygotic (DZ) twinning (Blickstein et al., 2005; Bulmer, 1970). Spontaneous DZ twinning is influenced by genetic, maternal, and environmental factors (Campbell, 2005; Hoekstra et al., 2008). Maternal age has played a major role in twinning rate fluctuations during the past 100 years, following demographic trends (Bulmer, 1970; Hoekstra et al., 2008), but the rise in DZ twins seen in developed countries during the past two or three decades has been related to the increase in the use of fertility treatments (Fauser et al., 2005; Martin et al., 2015; Tandberg et al., 2007). Moreover, some studies have found that mothers of DZ twins are significantly taller and heavier and smoke more often before the twin pregnancy than mothers of MZ twins (Corney et al., 1979; Hoekstra et al., 2010; Nylander, 1981; Reddy et al., 2005). Although MZ twinning has been

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considered an essentially random event, it has also been observed that the odds of producing MZ twins associated with fertility treatments are higher than in natural conception (Vitthala et al., 2009).

Approximately two-thirds of MZ twins are monochorionic and share the same placenta and nutritive source, and thus may have higher risk of experiencing intrauterine growth restriction as indicated by lower birth weight in MZ than in DZ twins (Boomsma et al., 2005; Corney et al., 1979; Johansson & Rasmussen, 2001; Loos et al., 2001; Ramos-Arroyo et al., 1988). Twin studies from infancy to adulthood have reported non-significant or very small mean differences in height and relative weight by zygosity; however, a closer look at these results indicates a trend toward greater body size in DZ compared with MZ twins (Antoniades et al., 2003; Boomsma et al., 2005; Estourgie-van Burk et al., 2006; Hur et al., 2008; Jelenkovic et al., 2011; Lajunen et al., 2009; Schousboe et al., 2003; Silventoinen et al., 2003, 2007a, 2007b, 2008b). It is largely unknown how these differences vary by age. Studies on age-dependent zygosity differences in height and body mass index (BMI) are scarce, and insufficient sample sizes make comparisons of the existing results problematic. Further, whether the variance of height and BMI differs between MZ and DZ twins has not been systematically studied previously.

Using international data obtained from twin cohorts in 22 countries, the present study aims to analyze zygosity differences in mean values and variances of height and BMI among males and females from infancy to old age, and to determine how these zygosity differences vary with age.

Materials and Methods

Sample

This study is based on the data from the COllaborative project of Development of Anthropometrical measures in Twins (CODATwins; Silventoinen et al., 2015). Briefly, the CODATwins project was launched in 2013 and was intended to recruit all twin projects in the world with information on zygosity and height and weight measurements. The present study included a total of 54 twin cohorts from 22 countries: one cohort from Africa (Guinea-Bissau Twin Study), three cohorts from Australia (Australian Twin Registry, Peri/Postnatal Epigenetic Twins Study, and Queensland Twin Register), nine cohorts from East-Asia (Guangzhou Twin Eye Study, Japanese Twin Cohort, Korean Twin-Family Register, Mongolian Twin Registry, Osaka University Aged Twin Registry, South Korea Twin Registry, Qingdao Twin Registry of Adults, Qingdao Twin Registry of Children, and West Japan Twins and Higher Order Multiple Births Registry), 22 cohorts from Europe (Adult Netherlands Twin Registry, Berlin Twin Register, Bielefeld Longitudinal Study of Adult Twins, Danish Twin Cohort, East Flanders Prospective Twin Survey, Finnish Older Twin Cohort, FinnTwin12, FinnTwin16, Gemini Study, Genesis 12–19 Study, Hungarian Twin Registry, Italian Twin Registry, Murcia Twin Registry, Norwegian Twin Registry, Portugal Twin Cohort, Swedish Twin Cohorts, Swedish Young Male Twins Study of Adults, Swedish Young Male Twins Study of Children, TCHAD-study, Twins Early Developmental Study, TwinsUK, and Young Netherlands Twin Registry), three cohorts from South-Asia and Middle-East (Longitudinal Israeli Study of Twins, Sri Lanka Twin Registry, and Turkish Twin Study) and 16 cohorts from North-America (Boston University Twin Project, California Twin Program, Carolina African-American Twin Study of Aging (CAATSA), Colorado Twin Registry, Michigan Twins Study, Mid-Atlantic Twin Registry, Minnesota Twin Family Study, Minnesota Twin Registry, NAS-NRC Twin Registry, Quebec Newborn Twin Study, SRI-International, Texas Twin Project, University of British Columbia Twin Project, University of Southern California Twin Study, University of Washington Twin Registry, and Vietnam Era Twin Study of Aging). From these cohorts, 35 are longitudinal and included from two to more than 10 measurements. A more detailed description of the participating twin cohorts was presented previously (Silventoinen et al., 2015).

In the original database, there were 960,859 height and weight measures from MZ and DZ (the same sex and opposite sex) twins, at ages ranging from 1 to 103 years. Most of the height and weight measures were self-reported (67%) or parentally reported (19%), and only a minority was based on measured values (14%). Age was classified to single-year age groups from age 1 to 19 years (e.g., age 1 refers to 0.5–1.5 years range) and decade age groups from age 20 to 103 years (e.g., 20–29, . . . , 70–79, and age ≥ 80 years). BMI was calculated as follows: weight (kg)/height (m^2). Impossible values and outliers were checked by visual inspection of histograms for each age and sex group. Outliers were removed to obtain an approximately normal distribution of height, whereas the distribution of BMI was allowed to be positively skewed. The number of observations removed represented less than 0.2% of the whole database. For the purpose of this article, we restricted the analyses to one observation per individual in each year/decade age group. In the final database, we had 842,951 observations for both height and BMI, and the maximum age at measurement was 102 years.

Statistical Analyses

Equality of mean values between MZ and DZ twins by age group and sex was tested using linear regression adjusted for birth year and cohort, and corrected for clustering of twin pairs. Equality of variances was tested using the Levene's clustered test based on the 10% trimmed mean as proposed by Iachine et al. (2010). This clustered version of the Levene's test is robust under the non-normality of outcomes. Percentage difference (%) between DZ and MZ twins in mean values [(DZ mean/MZ mean) × 100 - 100] and standard deviations (*SD*) [(DZ *SD*/MZ *SD*) × 100 - 100] of height and BMI were calculated. Statistical analyses were conducted using the Stata statistical software package (version 12.0; StataCorp, College Station, Texas, USA).

Results

Descriptive statistics by zygosity, age, and sex are listed in Tables 1 and 2 for height and BMI, respectively. Sample size for each zygosity, age, and sex group ranged between 1,154 and 11,426 individuals from age 1 through 19 years, and between 970 and 32,777 individuals in adulthood (≥20 years). The 6 and ≥80-year age groups had the smallest sample sizes. Briefly, mean height increased with age in childhood and adolescence and slightly decreased over adulthood (Table 1). Males were expectedly taller than females; only at the age of 11 and 12 years were girls slightly taller than boys. The *SD* of height was highest at 13 years in boys and 12 years in girls. Mean values for BMI declined slightly from the age of 1 to 5 years and then started to increase; these mean values were higher in males than in females from age 1 to 6 years and from the age of 16 years onwards (Table 2). The *SD* of BMI increased with age but slightly decreased for the oldest age groups.

Dizygotic twins were consistently taller than MZ twins, demonstrating zygosity differences in mean height. Statistical significance was attained particularly in adulthood because of the larger sample size, but also at many ages during childhood and adolescence (Table 1). Figure 1 illustrates the percentage difference (%) in the mean value and *SD* of height between DZ and MZ twins. DZ twins presented up to 1.7% greater height than MZ twins; the greatest differences were observed in middle and late childhood and decreased with age to <0.6% in adulthood. The *SD* of height was not significantly different between MZ and DZ twins at most ages, and the greatest zygosity differences were observed at the age of 1 and 2 years (higher *SD* in MZ twins) and at the age of 6 (higher *SD* in DZ twins) for both sexes.

In contrast to the observations for height, mean BMI was not significantly different between MZ and DZ twins at young ages (Table 2). Significantly higher mean values in DZ than in MZ twins were observed at some ages from 11 to 30–39 years in males and from 10 to 50–59 years in females. The greatest mean differences between DZ and MZ twins ranged from 1.3–1.7% in males (at the age of 11, 14, and 17 years) and reached 1.9% in females (at the age of 6, 8, 9, and 11 years), and then decreased with age (Figure 2). The *SD* of BMI was significantly higher in DZ than in MZ twins, particularly in middle and late childhood; the highest difference was observed at the age of 6 years for females (24%) and was below 20% for the rest of the age groups. MZ twins presented a slightly greater *SD* at the age of 4 and 18 years in females and 1 and 50–59 years in both sexes. Finally, because of the positively skewed distribution of BMI, we tested the equality of mean values and variances for the log-transformed data, which produced very similar results (results not shown).

Discussion

The present study, based on an international database of twin cohorts with 842,951 measurements from infancy to old age, revealed zygosity differences in mean height and BMI in both male and female twins. Although zygosity was not associated with variance differences in height in most age groups, the variance of BMI was significantly different in MZ and DZ twins, particularly in childhood. However, these zygosity differences in mean values and variances of height and BMI were generally modest and age-dependent.

Zygosity differences have been analyzed previously for several health-related outcomes. For example, Oberg et al. (2012) reported no substantial differences in cumulative morbidity in cardiovascular disease (CVD) and overall cancer in adult Swedish MZ and DZ twins. Some studies have reported higher risks of breast and testicular cancers in DZ than in MZ twins (Swerdlow et al., 1997; Verkasalo et al., 1999), but this has not been corroborated with data from the Nordic Twin Cancer project (Hjelmborg et al., 2014). Large-scale register studies found no zygosity differences in the risk of diabetes (Johansson et al., 2008; Kaprio et al., 1992; Lehtovirta et al., 2010; Petersen et al., 2011), and although some studies have suggested that MZ twins have more adverse levels of glucose metabolism-related traits (Poulsen & Vaag, 2006; Poulsen et al., 2002), the findings are inconsistent (Benyamin et al., 2007; Lehtovirta et al., 2000; Rahman et al., 2009; Souren et al., 2007). Regarding height and BMI, a trend toward greater mean values in DZ than in MZ twins has been observed in several studies. In Swedish males from birth to 18 years, although MZ twins tend to be taller at the age of 2 and 4 years, DZ twins showed slightly greater height at later ages (Silventoinen et al., 2007b) and BMI in most age groups (Silventoinen et al., 2008b). A study of 5-year-old children from the Netherlands found that MZ twins were significantly shorter than DZ twins, but inconsistent differences were found for weight and BMI (Estourgie-van Burk et al., 2006). Finnish DZ twins at the age of 12, 14, and 17 years showed slightly higher values for height and BMI in both sexes (Jelenkovic et al., 2011; Lajunen et al., 2009). In a comparative study between Caucasian and East Asian adolescent twins of 13–15 years of age, a trend toward greater height in DZ twins was observed in Caucasian populations, but not in East Asians (Hur et al., 2008). Hur et al. (2008) found no differences for BMI in either ancestry group. In adulthood, Dutch DZ twins were significantly taller (Boomsma et al., 2005), and DZ women from the United Kingdom showed greater height, weight, and BMI than MZ twins (Antoniades et al., 2003). Accordingly, twin studies in seven European populations and Australia found that DZ men and women had slightly greater height and

TABLE 1

Number of Twin Individuals, Mean, and *SD* of Height (cm) by Zygosity, Age, and Sex

		Males					Females				
		N	Mean	*p*-value[a]	*SD*	*p*-value[b]	*N*	Mean	*p*-value[a]	*SD*	*p*-value[b]
Age 1	MZ	5,791	74.2	.009	4.12	<.001	6,104	72.9	.002	4.14	<.001
	DZ	10,128	75.0		3.84		9,685	73.6		3.85	
Age 2	MZ	4,682	86.7	.046	4.31	<.001	4,748	85.5	.001	4.33	.013
	DZ	8,350	87.5		4.14		7,751	86.4		4.20	
Age 3	MZ	5,908	95.9	.001	4.39	.477	6,572	94.9	.005	4.42	.124
	DZ	11,426	96.7		4.40		11,030	95.6		4.54	
Age 4	MZ	3,421	102.1	.011	5.29	.977	3,436	101.1	.497	5.29	.449
	DZ	6,697	102.8		5.33		6,406	101.6		5.30	
Age 5	MZ	2,816	110.7	.003	5.87	.845	2,934	110.1	.008	6.12	.466
	DZ	5,439	111.9		5.98		5,050	111.0		6.21	
Age 6	MZ	1,365	114.7	.084	6.38	.005	1,154	113.5	.424	5.77	<.001
	DZ	1,957	116.2		6.90		1,698	115.4		6.86	
Age 7	MZ	4,996	123.5	.001	6.65	.065	5,396	122.8	.002	6.54	.777
	DZ	8,771	124.6		6.61		8,547	123.8		6.63	
Age 8	MZ	2,519	127.8	.052	6.32	.607	2,526	127.0	.680	6.59	.896
	DZ	3,983	129.5		6.52		3,634	128.3		6.72	
Age 9	MZ	2,805	133.4	.068	6.93	.204	2,734	132.2	.022	6.88	.095
	DZ	4,261	134.8		7.11		4,012	134.0		7.15	
Age 10	MZ	4,364	139.9	<.001	7.18	.476	4,575	139.6	<.001	7.49	.065
	DZ	7,167	141.5		7.15		6,870	141.0		7.34	
Age 11	MZ	3,566	143.7	.001	7.22	.530	3,742	144.4	.015	7.56	.209
	DZ	5,583	145.3		7.42		5,220	145.6		7.87	
Age 12	MZ	4,860	151.3	.047	8.22	.044	5,039	152.3	.052	8.08	.303
	DZ	7,280	152.4		7.90		7,243	153.3		8.28	
Age 13	MZ	1,967	158.1	.045	9.50	.310	1,862	157.6	.032	7.43	.309
	DZ	3,141	159.4		9.17		2,999	158.8		7.75	
Age 14	MZ	3,572	165.6	.134	9.04	.552	3,976	161.8	<.001	6.77	.801
	DZ	6,115	166.0		8.84		6,245	162.7		6.80	
Age 15	MZ	2,263	171.2	.012	8.67	.774	2,300	164.1	.001	6.91	.478
	DZ	3,641	172.3		8.71		3,520	165.0		6.89	
Age 16	MZ	3,118	175.5	.054	7.50	.637	3,785	164.5	<.001	6.48	.679
	DZ	5,627	175.9		7.55		5,826	165.4		6.53	
Age 17	MZ	4,447	176.0	.001	7.63	.030	4,163	165.5	<.001	6.64	.242
	DZ	7,199	177.1		7.44		6,218	166.3		6.46	
Age 18	MZ	7,578	175.4	<.001	7.61	.663	3,747	166.1	.003	6.80	.326
	DZ	9,831	176.3		7.63		5,041	166.6		6.71	
Age 19	MZ	4,538	176.6	<.001	7.83	.614	4,142	165.7	<.001	6.87	.008
	DZ	6,685	177.9		7.70		5,336	166.9		6.61	
Age 20–29	MZ	21,958	177.3	<.001	7.55	.003	24,132	165.1	<.001	6.69	.856
	DZ	32,777	178.0		7.43		29,812	165.9		6.69	
Age 30–39	MZ	14,350	178.0	<.001	7.11	.206	22,196	164.5	<.001	6.73	.019
	DZ	24,698	178.7		7.02		30,720	165.2		6.64	
Age 40–49	MZ	17,490	176.9	<.001	6.94	.707	17,612	163.6	<.001	6.61	.010
	DZ	29,653	177.7		6.97		28,839	164.3		6.46	
Age 50–59	MZ	11,886	176.1	<.001	6.88	.842	14,924	162.7	<.001	6.41	.011
	DZ	24,718	176.7		6.91		27,520	163.5		6.23	
Age 60–69	MZ	9,778	175.3	<.001	6.76	.446	9,731	161.6	<.001	6.25	.326
	DZ	17,609	175.7		6.80		17,565	162.4		6.23	
Age 70–79	MZ	5,362	174.1	<.001	6.84	.988	4,355	160.7	.093	6.50	.132
	DZ	8,453	174.4		6.90		7,535	161.2		6.34	
Age ≥80	MZ	970	172.3	.399	7.18	.575	1,265	159.6	.006	6.45	.709
	DZ	1,621	172.2		7.15		2,299	160.3		6.48	

Note: [a] *p*-value for equality of mean values.
[b] *p*-value for equality of variances; *SD*: standard deviation.

BMI in the majority of populations (Schousboe et al., 2003; Silventoinen et al., 2003).

Our results from this very large international database confirmed previous findings of a greater mean height and BMI in DZ than in MZ twins, and in addition showed that these differences (lower than 2% in all age groups) decrease with age. The small but significant zygosity differences observed in this study demonstrate the importance of large sample sizes to detect such differences; for example, to detect a difference of 1 cm in mean adult height (equal variances by zygosity) at a significance level of 0.05 and a power of 90%, we would need about 1,000 twins in each zygosity, age, and sex group. Thus, the non-significant findings reported in many earlier studies, based on smaller samples, would be primarily due to the lack of statistical power to detect such small differences.

The reasons for zygosity differences in height and BMI are not clear. It is possible that vascular and placental circumstances characterizing monochorionic pregnancies might be important; an indicator of the more adverse

TABLE 2

Number of Twin Individuals, Mean, and *SD* of BMI (kg/m^2) by Zygosity, Age, and Sex

		Males					Females				
		N	Mean	*p*-value[a]	*SD*	*p*-value[b]	*N*	Mean	*p*-value[a]	*SD*	*p*-value[b]
Age 1	MZ	5,791	17.15	.789	1.41	.210	6,104	16.75	.730	1.40	.002
	DZ	10,128	17.12		1.37		9,685	16.72		1.35	
Age 2	MZ	4,682	16.52	.503	1.38	.963	4,748	16.08	.495	1.37	.950
	DZ	8,350	16.45		1.39		7,751	16.10		1.37	
Age 3	MZ	5,908	15.94	.672	1.39	<.001	6,572	15.62	.328	1.47	.043
	DZ	11,426	15.92		1.50		11,030	15.67		1.54	
Age 4	MZ	3,421	15.85	.911	1.78	.063	3,436	15.63	.389	1.96	.148
	DZ	6,697	15.87		1.84		6,406	15.69		1.87	
Age 5	MZ	2,816	15.26	.798	1.52	.202	2,934	15.06	.181	1.61	.161
	DZ	5,439	15.28		1.59		5,050	15.17		1.68	
Age 6	MZ	1,365	15.49	.267	1.78	.049	1,154	15.19	.216	1.66	<.001
	DZ	1,957	15.55		1.92		1,698	15.49		2.06	
Age 7	MZ	4,996	15.38	.212	1.73	.001	5,396	15.40	.130	1.94	.013
	DZ	8,771	15.44		1.87		8,547	15.52		2.05	
Age 8	MZ	2,519	15.67	.173	1.76	<.001	2,526	15.66	.059	1.97	<.001
	DZ	3,983	15.81		2.07		3,634	15.95		2.26	
Age 9	MZ	2,805	16.42	.349	2.27	<.001	2,734	16.40	.130	2.44	<.001
	DZ	4,261	16.60		2.52		4,012	16.72		2.73	
Age 10	MZ	4,364	16.67	.716	2.33	.127	4,575	16.68	.020	2.49	.001
	DZ	7,167	16.68		2.41		6,870	16.92		2.63	
Age 11	MZ	3,566	17.25	.001	2.54	<.001	3,742	17.42	.014	2.82	<.001
	DZ	5,583	17.54		2.79		5,220	17.76		3.03	
Age 12	MZ	4,860	17.87	.013	2.75	<.001	5,039	17.98	.006	2.85	<.001
	DZ	7,280	18.02		2.99		7,243	18.20		3.06	
Age 13	MZ	1,967	18.59	.598	2.95	.105	1,862	18.94	.623	3.19	.248
	DZ	3,141	18.69		3.12		2,999	18.93		3.14	
Age 14	MZ	3,572	19.33	<.001	2.88	.001	3,976	19.71	.047	3.14	.897
	DZ	6,115	19.60		3.17		6,245	19.83		3.17	
Age 15	MZ	2,263	19.95	.045	3.23	.473	2,300	20.18	.272	3.23	.721
	DZ	3,641	20.05		3.15		3,520	20.33		3.32	
Age 16	MZ	3,118	20.70	.075	3.01	.613	3,785	20.57	.002	2.94	.092
	DZ	5,627	20.82		3.02		5,826	20.84		3.15	
Age 17	MZ	4,447	21.08	<.001	2.68	.002	4,163	20.71	.002	2.97	.358
	DZ	7,199	21.36		2.83		6,218	20.91		2.92	
Age 18	MZ	7,578	21.53	<.001	2.54	.005	3,747	21.19	.044	3.24	.054
	DZ	9,831	21.80		2.74		5,041	21.24		3.10	
Age 19	MZ	4,538	21.97	.118	2.71	.904	4,142	21.34	<.001	3.16	.432
	DZ	6,685	22.01		2.73		5,336	21.52		3.27	
Age 20–29	MZ	21,958	22.97	<.001	3.04	.781	24,132	21.93	<.001	3.74	.432
	DZ	32,777	23.14		3.06		29,812	22.06		3.75	
Age 30–39	MZ	14,350	24.62	<.001	3.31	.384	22,196	23.05	<.001	4.20	.195
	DZ	24,698	24.76		3.36		30,720	23.25		4.27	
Age 40–49	MZ	17,490	25.33	.087	3.23	.001	17,612	24.20	.001	4.45	.028
	DZ	29,653	25.43		3.33		28,839	24.28		4.33	
Age 50–59	MZ	11,886	25.99	.613	3.59	.009	14,924	24.98	.002	4.39	.001
	DZ	24,718	25.97		3.45		27,520	25.07		4.20	
Age 60–69	MZ	9,778	26.00	.821	3.57	.407	9,731	25.43	.536	4.36	.489
	DZ	17,609	26.06		3.54		17,565	25.51		4.31	
Age 70–79	MZ	5,362	25.66	.323	3.35	.037	4,355	24.92	.224	4.23	.208
	DZ	8,453	25.68		3.43		7,535	25.04		4.16	
Age ≥80	MZ	970	24.65	.673	3.30	.266	1,265	23.66	.770	3.91	.827
	DZ	1,621	24.65		3.39		2,299	23.67		4.03	

Note: [a] *p*-value for equality of mean values.
[b] *p*-value for equality of variances; *SD:* standard deviation.

intrauterine environment of monochorionic MZ twins is their significantly lower birth weight compared with dichorionic MZ and DZ twins (Dube et al., 2002; Loos et al., 2001). Low birth weight predicts lower adult height and BMI in twins (Johansson & Rasmussen, 2001; Pietiläinen et al., 2001); however, the difference in body size between monochorionic and dichorionic twins has been observed to diminish during childhood (Falkner & Matheny, 1995). The decreasing mean differences between MZ and DZ twins observed with age in our study, which were more evident for height, could be explained by the rapid catch-up growth that occurs in MZ twins, especially during the first years of life. Accordingly, a study on zygosity and chorion type showed that the prenatal disparities between monochorionic and dichorionic MZ twins did not result in larger intra-pair differences in adult height and BMI in monochorionic twins, as would be predicted from the prenatal programming hypothesis (Loos et al., 2001).

According to the 'natural selection' hypothesis, women who are predisposed to having twins are more likely to

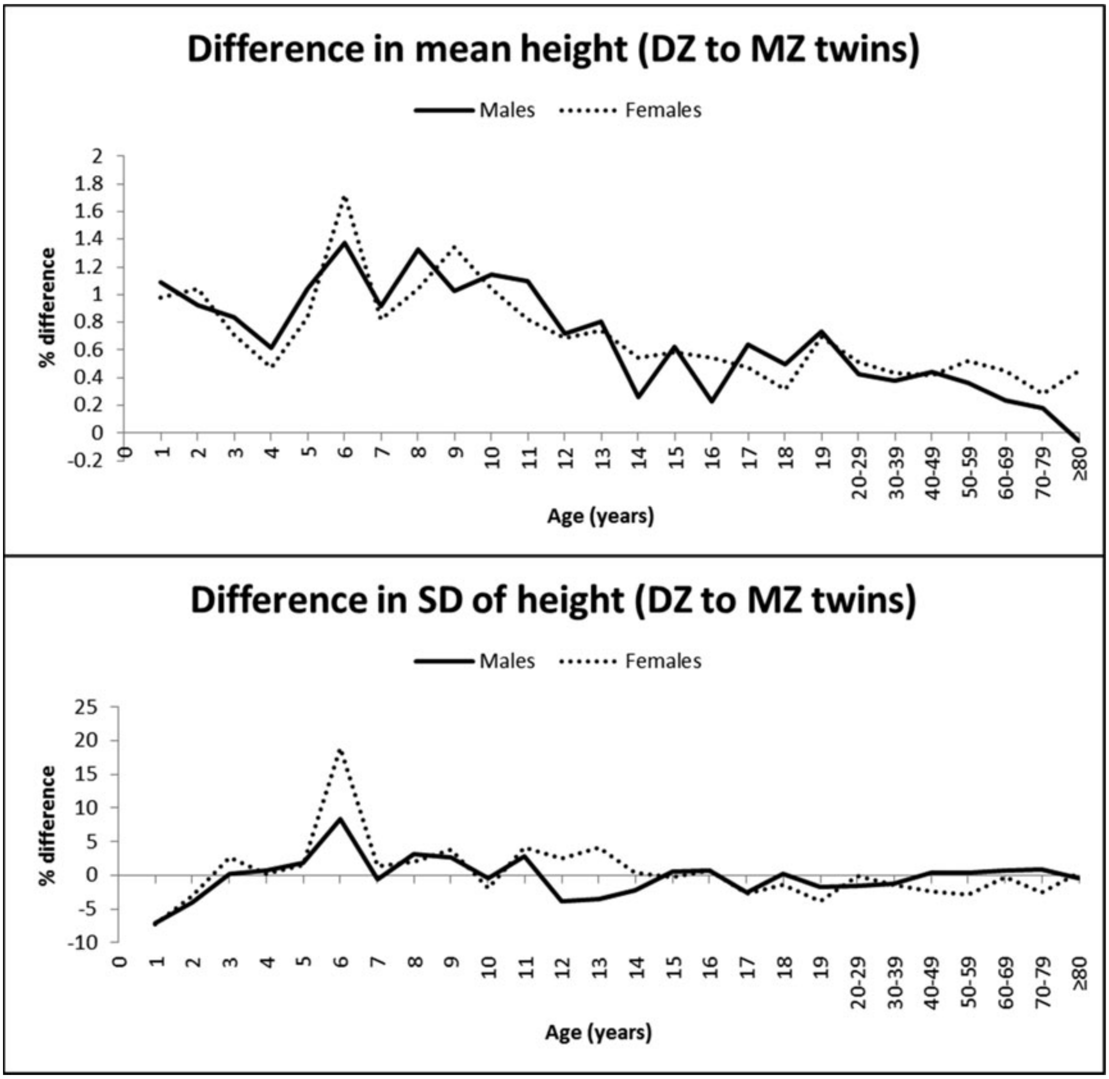

FIGURE 1

Mean and *SD* differences (%) in height between DZ and MZ twins across ages.

produce them in a healthy reproductive environment (Helle et al., 2004; Lummaa et al., 1998). Since variation in twinning is mostly due to differences in DZ twinning rates, and favorable reproductive conditions would be expected to result in more robust phenotypes in offspring, our findings of a greater height and BMI in DZ twins are in line with this hypothesis. Since height and BMI are highly heritable traits, the evidence that mothers of DZ twins are taller and heavier than mothers of MZ twins (Corney et al., 1979; Hoekstra et al., 2010; Nylander, 1981; Reddy et al., 2005) offers a further possible explanation. Basso et al. (2004) observed that the association of maternal height and BMI with the odds of twinning was slightly stronger when singleton mothers were compared with opposite-sex twin mothers (i.e., DZ twin mothers) than with all twin mothers. Although information on the zygosity of the same-sex twin pairs was not available in that study, it may reflect that DZ twin mothers not only differ from MZ twin mothers but also from non-twin mothers. Therefore, DZ twin parents might represent a group from the population with enrichment for a particular set of genes, and the greater height and BMI in DZ twins would be a reflection of this inheritance. However, our finding of decreasing zygosity differences with age suggests that genetics is not the only reason for the observed differences.

Another explanation for the observed zygosity differences might be fertility treatments, which generally produce DZ twins. It has been reported that parents of twins conceived via fertility treatments are better educated and are better off financially than those of naturally conceived twins (Burt & Klump, 2012; Davies et al., 2012). Due to the expenses of fertility treatments in many countries, these treatments would be more accessible to parents of a better socio-economic status (SES), which is in turn associated

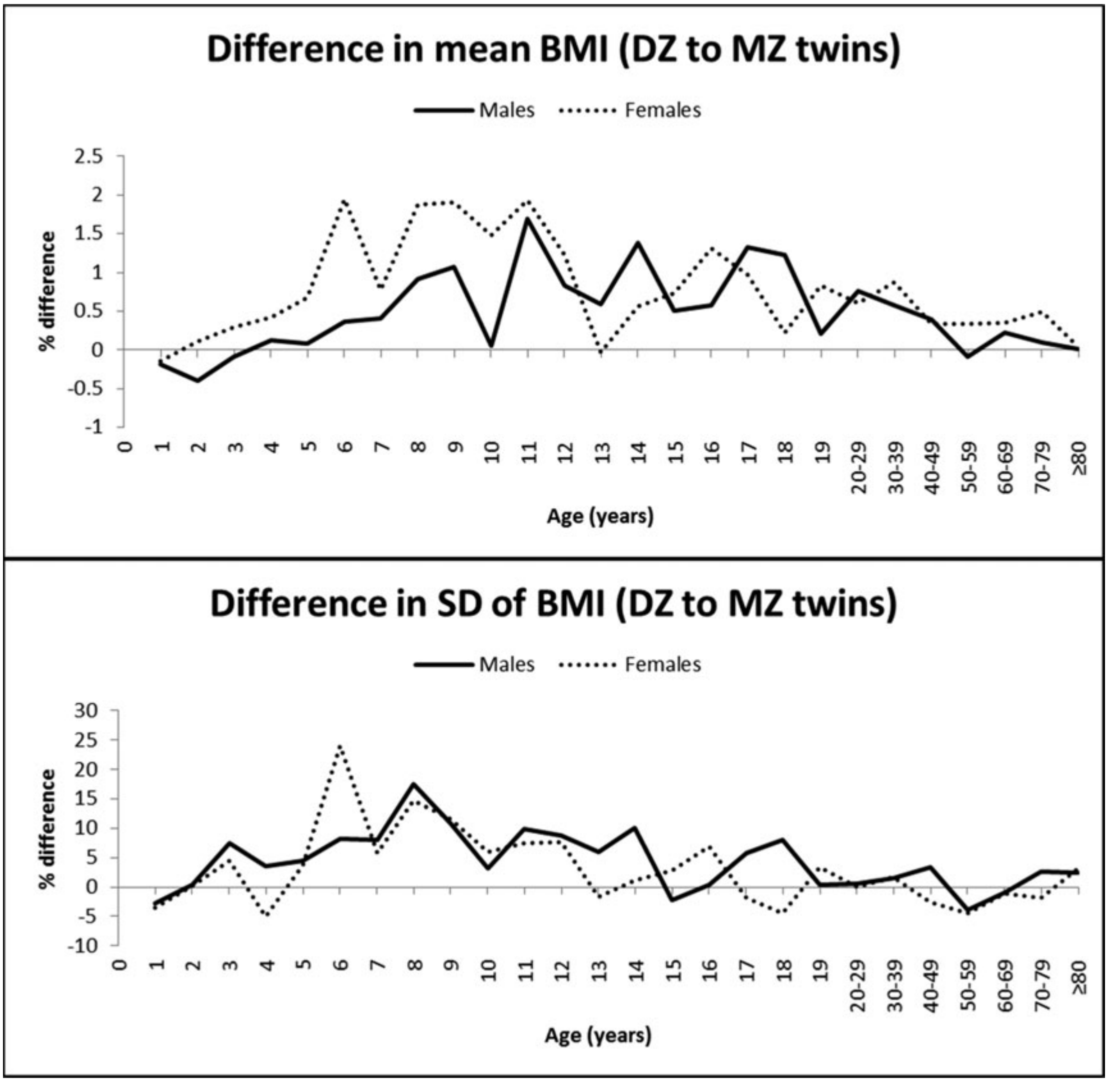

FIGURE 2

Mean and *SD* differences (%) in BMI between DZ and MZ twins across ages.

with taller height (Bogin, 2001). The association of SES with BMI is more complex and depends on the country's social and economic prosperity, and is generally inverse in developed countries (McLaren, 2007). However, because obesity has been associated with a higher risk of infertility (Lash & Armstrong, 2009; Ramlau-Hansen et al., 2007), an increased use of fertility treatments among overweight and obese women could also account for higher BMI in DZ compared with MZ twins. Since the larger increase in DZ twinning rates started in the late 1980s (Blickstein et al., 2005), it can be assumed that virtually no twins born before 1980 are the result of fertility treatments. Additional analyses of the data reported herein revealed that zygosity differences were also present in cohorts born before 1980 (results not shown), thus suggesting that differences between MZ and DZ twins are not related to fertility treatments.

The variance of height was overall similar in MZ and DZ twins, except at the age of 1 and 2 years. Similarly, other studies have reported no zygosity difference in height variance, and small differences between MZ and DZ twins did not show any consistent pattern (Antoniades et al., 2003; Boomsma et al., 2005; Hur et al., 2008; Jelenkovic et al., 2011; Silventoinen et al., 2003, 2007a, 2008b). It should be noted that the zygosity difference in the variance of both height and BMI observed in females at age 6 was considerably greater than for the rest of age and sex groups, and thus its significance should be interpreted with caution.

In contrast to the observations for height, we found significant differences in the variance of BMI between MZ and DZ twins in middle and late childhood. Our findings are in agreement with the slightly greater variance in MZ twins until the age of 4 years but greater in DZ twins from the age of 5 years in Swedish males (Silventoinen et al., 2007b).

Other studies have also shown a trend toward a slightly greater variance of BMI for DZ twins in adolescence and adulthood (Antoniades et al., 2003; Lajunen et al., 2009; Schousboe et al., 2003). A possible explanation is social interaction, which causes variance of a phenotype to depend on the degree of relationship of social actors (Rietveld et al., 2003). Social interactions can have important implications for quantitative genetic models because they produce systematic differences in twin variances; cooperation results in greater total phenotypic variance in MZ than in DZ twins, whereas competition results in greater total phenotypic variance in DZ twins. Competition or contrast effects, in which a high trait value in one sibling tends to act in the opposite direction in the other, might be expected to be especially marked in environments in which there is competition for limited resources (Rietveld et al., 2003). The greatest zygosity differences in the variance of BMI observed during childhood in our study might be indicating competition for nutritional resources in a period highly sensitive to environmental influences, when the individualized parental care provided during the first years of life becomes less important.

The main strength of the present study is the large sample size of our international database of twin cohorts, with height and weight measures covering the whole lifespan. In contrast to earlier meta-analyses of twin data on height and BMI, our analysis is based on individual (although anonymized) data. However, a limitation is that countries or regions are not equally represented, and the database is heavily weighted toward Caucasian populations following westernized lifestyles. Another limitation of the data is that overall unadjusted descriptive statistics reflect not only within population differences but also differences in the distribution within each age group of different cohorts. Multiple testing may have resulted in false-positive differences between MZ and DZ twins; however, mean values and variances showed a quite consistent pattern across age and sex groups, which provides considerable robustness to the results. Moreover, information on chorionicity is crucial to determine whether the observed zygosity differences in height and BMI are explained, at least in part, by differences in monochorionic and dichorionic MZ twins. Finally, another important issue is whether twins differ from singletons in their height and BMI. Some studies reported that the differences in body size between twins and singletons disappear in childhood, while others showed these differences to remain until adulthood (Buckler & Green, 2004; Eriksen et al., 2013; Estourgie-van Burk et al., 2006, 2010; Pietiläinen et al., 1999; Silventoinen et al., 2008a). In the present study, we do not have comparable sampling schemes for singletons; however, differences between twins and singletons would not invalidate the twin method, but depending on the cause of these differences offer an interesting opportunity for further research. Further research in twins and their sibling first needs to determine whether early life differences in body size between twins and the general population disappear in childhood or remain until adulthood. Mechanistic searches for possible causes for complete or incomplete catch-up growth in twins may focus on whether these causes differ for DZ and MZ twins, and maybe even shed light on the genes that are associated with twinning itself.

We observed that DZ twins were generally taller and had greater BMI than MZ twins. However, these zygosity differences were modest and decreased with age in both sexes, but still may be associated with genes that also influence DZ twinning itself. Alternatively, social explanations may be of importance, where, for example, the greater variance observed in DZ twins for BMI in childhood might indicate competition for nutritional resources. These findings have theoretical significance and might help to shed light on the underlying mechanisms linking zygosity status and body size in future research.

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