The CODAtwins project: the cohort description of COllaborative project of Development of Anthropometrical measures in Twins to study macro-environmental variation in genetic and environmental effects on anthropometric traits

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Abstract

For over one hundred years, the genetics of human anthropometric traits has attracted scientific interest. In particular, height and body mass index (BMI, calculated as kg/m^2) have been under intensive genetic research. However, it is still largely unknown whether and how heritability estimates vary between human populations. Opportunities to address this question have increased recently because of the establishment of many new twin cohorts and the increasing accumulation of data in established twin cohorts. We started a new research project to analyze systematically 1) the variation of heritability estimates of height, BMI and their trajectories over the life course between birth cohorts, ethnicities and countries, and 2) to study the effects of birth related factors, education and smoking on these anthropometric traits and whether these effects vary between twin cohorts. We identified 67 twin projects including both monozygotic and dizygotic twins using various sources. We asked for individual level data on height and weight including repeated measurements, birth related traits, background variables, education and smoking. By the end of 2014, 48 projects participated. Together, we have 893,458 height and weight measures (52% females) from 434,723 twin individuals, including 201,192 complete twin pairs (40% monozygotic, 40% same-sex dizygotic and 20% opposite-sex dizygotic) representing 22 countries. This project demonstrates that large-scale international twin studies are feasible and can promote the use of existing data for novel research purposes.

Introduction

The genetics of human anthropometric traits has long attracted scientific interest. Height is a prototypical anthropometric phenotype because it is approximately normally distributed and does not change in adulthood except slight shrinking in old age. By the late 19th century, Galton (1886) analyzed height of parents and offspring and inferred that 'when dealing with the transmission of stature from parents to children, the average height of the two parents is all we need care to know about them'. Later, Pearson and Lee (1903) presented correlations of height between relatives also suggesting genetic influence. The first heritability estimate of height was calculated by Fisher (1918) in his seminal paper presenting the statistical principles of quantitative genetics. Interest in the genetic influences on height was renewed when genetic linkage studies enabled research into genetic effects over the whole genome on quantitative traits (Perola et al. 2007). Later genome wide association (GWA) studies allowed for the genome-wide identification of candidate genes. In 2010 a large scale GWA study identified 180 loci associated for height (Lango Allen et al. 2010), and since then several large GWA studies have been published focusing on height on populations of European (Weedon et al. 2008), Asian (Cho et al. 2009, Okada et al. 2010, Hao et al. 2013) and African ancestry (N'Diaye et al. 2011). The latest GWA study for height published in 2014 found 697 genetic polymorphisms associated with height in populations of European ancestry (Wood et al. 2014). As a polygenic and normally distributed trait, height serves also to explore new methodological approaches to human genetics such as assumption free estimation of heritability from genome-wide identity-by-descent sharing between full siblings (Visscher et al. 2006, Hemani et al. 2013).

Genetic studies of obesity and body mass index (BMI, calculated as kg/m^2) also have a long history. In an article published in 1923, Davenport showed that the tendency for obesity varies between families, and he interpreted this finding to suggest genetic effects on obesity (Davenport 1923). After this initial paper, the evidence on the genetic effects on obesity accumulated, and in 1966 a review paper on previous family studies concluded that genetic factors played an important role in obesity (Seltzer and Mayer 1966). After this review, interest in the genetics of BMI has rapidly increased because of the health consequences and related impact on public health of increased mean BMI over the world. The studies by Stunkard and co-workers demonstrating the importance of genetic factors underlying variation in BMI in studies based on twin (Stunkard et al. 1986) and adoption data (Stunkard et al. 1986, Stunkard et al. 1990) were a major achievement in this area. These findings corroborated earlier

results reported on Finnish twins reared-apart (Langinvainio et al. 1984). In 2007 the FTO gene was found to be associated with obesity in a case-control study of type 2 diabetes (Frayling et al. 2007), and it is now recognized to be the most promising candidate gene of obesity. The latest GWA study on BMI identified 97 loci explaining 2.7% of the variation of BMI while all measurable variants accounted for around 20% of the variance (Locke et al. 2015).

After over a hundred years of research, we might assume that the heritability of height and BMI is already well known. However, surprisingly little research is available on the variation of heritability estimates of height and BMI between populations. Changes in mean height (Eveleth and Tanner 2003) and BMI (Finucane et al. 2011) over time and changes in BMI across the human life span (Dahl et al. 2014) have been reported. According to basic principles of quantitative genetics, heritability estimates are not constant but rather are statistics describing the magnitude of genetic variation in a particular population and dependent on the underlying genetic make-up of the population under study and the environmental variation at play. Accordingly, these estimates may change over the life course and vary between study populations. A meta-analysis of nine twin studies found that the heritability of BMI increased over childhood and the effect of common environmental factors disappeared after mid-childhood (Silventoinen et al. 2010). Increasing heritability of height and BMI after early childhood was also found in a study of four twin cohorts (Dubois et al. 2012). However these two studies did not reveal systematic variation in the heritability estimates between populations. A meta-analysis based on 88 independent heritability estimates of BMI reported inter-study variation in the heritability estimates, but meta-regression did not reveal any systematic patterns behind these differences (Elks et al. 2012). It is possible that this negative result was due to methodological limitations since many of the heritability estimates were based on data covering large age ranges, birth cohorts and social classes, and the authors did not have access to the original data. Twin studies for adult height (Silventoinen et al. 2003) and BMI (Schousboe et al. 2003) in seven European populations and Australia also found some variation in heritability estimates but were not able to find systematic patterns in these estimates. A study based on eight populations of adolescent twins found higher genetic variance of height and weight in Caucasian as compared to East-Asian populations; however, because total variance for height and BMI was also higher in Caucasian populations, the heritability estimates were approximately equivalent (Hur et al. 2008). Thus, the previous meta-analyses have demonstrated the variation in the

genetic components of height and BMI but have largely failed to identify factors behind the variation between populations.

The scant evidence on the variation of genetic and environmental contributions on height and BMI between populations may, however, reflect methodological limitations of previous studies rather than the lack of this type of variation. Previous studies conducted in Denmark (Rokholm et al. 2011a) and Sweden (Rokholm et al. 2011b) have demonstrated that genetic variation of BMI has increased over time in birth cohorts as the mean BMI increased; however heritability estimates did not change. A Finnish study reported that environmental variation of height decreased especially in women from cohorts born at the beginning of the 20th century compared to those born after the Second World War leading to higher heritability estimates of height (Silventoinen et al. 2000). There is also evidence that parental social position may modify the genetic architecture of BMI in childhood (Lajunen et al. 2012). International comparisons addressing the methodological limitations of previous studies may be able to demonstrate comparable variation in genetic and environmental effects between populations.

During the recent decade, possibilities for international comparisons in twin studies have improved because of the establishment of new twin cohorts and the increasing accumulation of data in established twin cohorts. Thus the number of twins available internationally for research has greatly increased expanding the ability to examine ethnic, economic and cultural variation between twin cohorts. These new opportunities to answer research questions not possibly to address before led to the start of a new international research project: COllaborative project of Development of Anthropometrical measures in Twins (CODATwins). The aims of this project are to analyze systematically 1) the variation of heritability estimates of height, BMI and their trajectories over the life course between birth cohorts, ethnicities and countries and 2) to study the effects of birth related factors, education and smoking on these anthropometric traits and whether these effects vary between twin cohorts. Additionally, this project aims to gain practical knowledge on the feasibility and opportunities offered by pooling a large number of twin cohorts as suggested by the International Network of Twin Registries (INTR) consortium (Buchwald et al. 2014).

Collection of a collaborative database

We started the CODATwins project in May 2013 by identifying all twin projects in the world. The only criterion was the availability of data from both monozygotic (MZ) and dizygotic (DZ) twin pairs. The main sources used to identify the projects were a special issue of Twin Research and Human Genetics (Hur and Craig 2013) and the participants of the INTR consortium (Buchwald et al. 2014, van Dongen et al. 2012); these sources were complemented by personal communications. Together we identified 67 eligible twin projects. We sent e-mail invitations to principle investigators of all these projects in September 2013 along with the study protocol. We asked the investigators to send us individual level data on height and weight including repeated measurements, birth related traits (birth weight, birth length, birth order and gestational age), background variables (twin identifier, sex, zygosity, ethnicity, birth year and age at the time of measurements), education (own education for adults and mother's and father's education for children) and smoking for adults to the CODATwins data management center at the University of Helsinki. To those who did not respond, we sent reminders in October 2013, January 2014 and September 2014; with the final reminder, we sent the first year progress report including the list of all twin projects already collaborating with this project.

We did not receive a response from eight projects; internet searches (PubMed and Google) indicated that these projects had not been active in recent years and some of them may not even have ever been established. Eight projects declined: two because of lack of height and weight data, one because of lack of information on zygosity and four because the delivery of the data was not possible to organize due to local regulations. One project informed that they are currently publishing their own results, but the data may become available later when the original articles have been published. Three projects that initially accepted the invitation have not sent data. Based on the correspondence, the main reason was the lack of resources to prepare the data file. By the end of 2014, 47 projects had sent data to the data management center. Additionally, one cohort is available through the remote access system but is not part of the pooled database. Figure 1 describes the accumulation of the CODATwins database.

Structure of database

Table 1 presents the twin cohorts participating in the CODATwins project. Because one twin project can include several cohorts, there are 54 twin cohorts available representing 22 countries. From these cohorts, 35 are longitudinal. Figure 2 presents the number of height and weight measures by sex and

age. Together there are 893,458 measures. Children are well represented, and 41% of the measures were conducted at 18 years of age or younger. Overall about half of the measures are for females (52%); however the cohorts vary considerably regarding the proportion of their samples that are females and some cohorts include only males while others mainly include females (Supplementary Table 1). Most of the height and weight measures were self-reported (63%) or parentally reported (21%) and only minority were based on measured values (16%). The reason is that data in the largest cohorts were collected by questionnaires, and the collection of clinical measures was generally conducted in cohorts smaller in size. In 27 cohorts we had additional information on birth weight and in most of these cohorts also had data on birth length (Supplementary Table 1). Together, we have 122,321 birth weight measures in the database; 77% of these measures were parentally reported, 17% self-reported and 6% clinically measured.

In total, data are available for 434,723 twin individuals having at least one height and weight measure. Most of the twins are from Europe (60%) and North-America (30%) followed by Australia (6%), East-Asia (3%), South-Asia and Middle-East (1%) and Africa (less than 0.1%); no twin cohort is available from Latin-America. Figure 3 presents the number of complete twin pairs by birth year and zygosity. Together there are 201,192 complete twin pairs. Among these pairs, 40% are MZ twins, 40% same-sex DZ twins and 20% opposite-sex DZ twins. A quarter of the twin pairs (25%) were born in the 1980s and 1990s. The numbers of twin individuals and complete twin pairs by cohorts are presented in Supplementary Table 1.

Discussion

We have successfully launched large international twin collaboration, and our database now includes slightly over 200,000 complete twin pairs with height and weight measures from 22 countries. The vast majority of established twin cohorts responded positively to our request for individual level data. For some of the cohorts who did not participate, the reason was the lack of suitable data or that the cohort was no longer active. The value of pooling either summary data in GWA studies for height (Wood et al. 2014) and BMI (Speliotes et al. 2015) or pooling individual data for psychiatric conditions (Schizophrenia Working Group of the Psychiatric Genomics Consortium 2014) is well recognized. This project demonstrates that the same strategy can be used in classical twin research as well.

However this project also revealed certain limitations with respect to available twin data. While European countries, especially in the northern and western parts of Europe, North-America and Australia are well represented, there is much less data on twins from other parts of the world. Our final database is heavily weighted toward European-origin populations following the Westernized lifestyle. The exception is East-Asia with several twin cohorts available from China, Japan and South-Korea and one from Mongolia. Even though many of these non-western cohorts are not very large, these cohorts do provide an invaluable resource for studying the potential genetic variations in anthropometric phenotypes. It was unfortunate that there are few twin cohorts from Southern Asia, Africa and all of South America. As pointed out earlier, there is a real need and value to the creation of new twin cohorts in the developing world (Sung et al. 2006). Increasing collaboration between established twin projects can be helpful to stimulate new research activity and starting new twin projects (Buchwald et al. 2014).

In addition to the lack of representation of specific ethnic groups among the registry populations included, another limitation is that the populations represented are relatively affluent populations. Of the four countries officially classified as non-industrialized countries represented in this project, only Guinea-Bissau can be regarded as a real developing country. In contrast, China and Sri-Lanka are moderately affluent societies and enjoy life-expectancy nearly comparable to the USA whereas Mongolia can be regarded as a middle income country with life expectancy at the level of East-European countries (Wang et al. 2012). Anthropometric data from twin pairs in diverse populations going through the demographic transition would be invaluable in understanding the influence of broad societal change on many phenotypes. However, it is noteworthy that we have substantial variation in birth cohorts; the oldest twins were born at the end of 19th century and around one-fifth of them before 1940. Major changes in the prevalence of obesity and standard of living during the 20th century allow for the testing of different hypotheses as demonstrated before for BMI in Denmark (Rokholm et al. 2011a) and Sweden (Rokholm et al. 2011b) and height in Finland (Silventoinen et al. 2003).

When considering further collaborative twin research projects, it is noteworthy that only 16% of the height and weight measures were based on clinical measure whereas the majority was obtained by self- or parental report. Height and weight are some of few anthropometric traits possible to measure relatively reliably based on self-report. Data on even the most basic metabolic traits such as blood

glucose, blood pressure, and blood lipids would require clinical assessments which are currently lacking in many twin samples. This shows that even when there are many large twin cohorts available, more data collection using clinical measures is still needed. Height and weight are widely available in twin cohorts, and there is also much less variation in the measurement protocols of these traits compared to other anthropometric traits, such as waist circumference, making harmonization straightforward; the biggest difference we found was the measurement units used for height (cm vs. foot and inch) and weight (kg and g vs. pound and ounce). However, it is noteworthy that even for height and weight there can be differences in the precision of equipment used for measuring weight (scale) and height (tape, anthropometer or stadiometer). When examining other traits, availability of the data and differences in measurement protocols will increase challenges to data harmonization.

In addition to the anthropometric traits, we collected information on own education, parental education and smoking. After reporting the main results for the anthropometric indicators, we will move to study how they are modified by education and smoking. Working with these variables is much more challenging compared to the anthropometric traits because of different classifications, varying educational systems and large differences in mean levels of education between countries and birth cohorts. However, this variation also presents an opportunity because it allows for the study of these associations in very different environments and, for example, to study the relevance of absolute and relative education. In these future analyses, we can rely on work done to harmonize these variables in other contexts such as the OECD classification of educational level (oecd.org) and the P3G consortium (p3g.org). This effort also demonstrates the potential of international collaborations of twin projects beyond calculating heritability estimates. For example, there are 10,410 adult MZ twin pairs discordant for BMI (more than 3 kg/m^2) at least at one time point when measured at the same age in the database. Previous studies have demonstrated the high value of BMI discordant pairs for epigenetic research (Pietiläinen et al. 2008).

In conclusion, the CODATwins project demonstrates that large-scale international studies obtaining individual-level data from twin cohorts are feasible. Using the data from these twin cohorts creates novel opportunities for examining how genetic and environmental influences may vary across countries and regions. Future efforts in the CODATwins project will continue to extract from the substantial data already collected in the various twin projects in order to contribute to this objective.

Conflict of interest

None

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Table 1. Number of height and weight measures in the twin cohorts participating in the CODATwins project.

Cohort name	Main reference	Region	Number of height and weight measures	Number of longitudinal surveys
Africa				
Guinea-Bissau Twin Study	(Bjerregaard-Andersen et al. 2013)	Guinea-Bissau	1,042	7
Australia				
Australian Twin Registry	(Hopper et al. 2013)	Australia	2,536	1
Peri/Postnatal Epigenetic Twins Study (PETS)	(Loke et al. 2013)	Australia, Melbourne	571	2
Queensland Twin Register	(Liu et al. 2010)	Australia, Queensland province	55,479	> 10
East-Asia				
Guangzhou Twin Eye Study	(Zheng et al. 2013)	China, Guangzhou province	1,122	1
Japanese Twin Cohort	(Ooki 2013)	Japan	34,405	>10
Korean Twin-Family Register	(Gombojav et al. 2013b)	South Korea	2,702	4
Mongolian Twin Registry	(Gombojav et al. 2013a)	Mongolia	166	1
Osaka University Aged Twin Registry	(Hayakawa et al. 2013)	Japan	1,289	4
South Korea Twin Registry	(Hur et al. 2013)	South Korea	2,278	1
Qingdao Twin Registry (adults)	(Duan et al. 2013)	China, Shandong province	986	1
Qingdao Twin Registry (children)	(Duan et al. 2013)	China, Shandong province	1,175	1
West Japan Twins and Higher Order Multiple Births Registry	(Yokoyama 2013)	Japan	7,617	>10
Europe				

Adult Netherlands Twin Registry	(Willemsen et al. 2013)	Netherlands	37,638	>10
Berlin Twin Register	(Busjahn 2013)	German, Berlin city	722	5
Bielefeld Longitudinal Study of Adult Twins	(Kandler et al. 2013)	German	2,366	1
Danish Twin Cohort	(Skytthe et al. 2013)	Denmark	34,665	1
East Flanders Prospective Twin Survey	(Derom et al. 2013)	Belgium, East Flanders Province	803	1
Finnish Older Twin Cohort	(Kaprio 2013)	Finland	68,683	4
FinnTwin12	(Kaprio 2013)	Finland	16,211	4
FinnTwin16	(Kaprio 2013)	Finland	24,438	5
Gemini Study	(van Jaarsveld 2010)	UK	19,639	>10
Genesis 12-19 Study	(McAdams et al. 2013)	UK	2,131	3
Hungarian Twin Registry	(Littvay et al. 2013)	Hungary	825	1
Italian Twin Registry	(Brescianini et al. 2013)	Italy	18,834	5
Murcia Twin Registry	(Ordoñana et al. 2013)	Spain, Region of Murcia	4,392	3
Norwegian Twin Registry	(Nilsen et al. 2013)	Norway	20,188	2
Portugal Twin Cohort	(Maia et al. 2013)	Portugal, North of mainland, Azores, and Madeira Islands	1,789	1
Swedish Twin Cohorts	(Magnusson et al. 2013)	Sweden	110,117	3
Swedish Young Male Twins Study (adults)	(Rasmussen et al. 2006)	Sweden	5,702	3
Swedish Young Male Twins Study (children)	(Rasmussen et al. 2006)	Sweden	10,440	> 10
TCHAD-study	(Lichtenstein et al. 2007)	Sweden	7,521	4

Twins Early Development Study (TEDS)	(Haworth et al. 2013)	UK	59,108	7
TwinsUK	(Moayyeri et al. 2013)	UK	31,321	7
Young Netherlands Twin Registry	(van Beijsterveldt et al. 2013)	Netherlands	119,649	10
South-Asia and Middle-East				
Longitudinal Israeli Study of Twins	(Avinun and Knafo 2013)	Israel	1,228	2
Sri Lanka Twin Registry	(Sumathipala et al. 2013)	Sri Lanka	2,485	1
Turkish Twin Study	(Öncel and Aliev 2013)	Turkey	584	1
North-America				
Boston University Twin Project	(Saudino and Asherson 2013)	USA, Massachusetts	1,228	2
California Twin Program	(Cozen et al. 2013)	USA, California	27,237	1
Carolina African American Twin Study of Aging	(Whitfield 2013)	USA, North Carolina	532	1
Colorado Twin Registry	(Rhea et al. 2013)	USA, Colorado	8,671	5
Michigan State University Twin Registry	(Burt and Klump 2013)	USA, Michigan	22,172	2
Mid Atlantic Twin Registry	(Lilley and Silberg 2013)	USA, Virginia, North Carolina, South Carolina	11,801	1
Minnesota Twin Family Study	(Iacono and McGue 2002)	USA, Minnesota	3,269	3
Minnesota Twin Registry	(Krueger and Johnson 2002)	USA, Minnesota	10,122	1
NAS-NRC Twin Registry	(Gatz et al. 2014)	USA, WWII veterans	54,904	4
Quebec Newborn Twin Study	(Boivin et al. 2013)	Canada, Greater Montreal area	5,991	9
SRI-international	(Krasnow et al. 2013)	USA, California	1,092	1
Texas Twin Project	(Harden et al. 2013)	USA, Texas	565	1

University of British Columbia Twin Project	(Jang 2013)	Canada, Greater Vancouver area	1,450	1
University of Southern California Twin Study	(Baker et al. 2013)	USA, Greater Los Angeles area	3,622	5
University of Washington Twin Registry	(Strachan et al. 2013)	USA, Washington State	27,452	3
Vietnam Era Twin Study of Aging	(Kremen et al. 2013)	USA, Vietnam era veterans	2,245	2

Figure 1. Accumulation of the CODATwins database.

Figure 2. Number of height and weight measures by sex and age.

Figure 3. Number of complete twin pairs by birth year and zygosity.

Supplementary Table 1. Basic characteristics of the twin cohorts participating in the CODATwins project.											
Cohort name	Number of twin individuals	% of females	Number of complete twin pairs	% of MZ pairs	% of OSDZ pairs	Age range	Birth cohorts	Identification of twin pairs	Zygosity measure	Height and weight measures	Birth anthropometric measures
Africa											
Guinea-Bissau Twin Study	253	53	108	15	58	0-3	2009-2013	Hospitals, demographic surveillance sites	Q	Measured	Measured length and weight
Australia											
Australian Twin Registry	2,536	78	1,210	72	9	18-97	1916-1996	Media, Australian Multiple Birth Association, hospitals	DNA and Q	Self-reported	Self-reported weight
Peri/Postnatal Epigenetic Twins Study (PETS)	443	53	221	41	26	1-7	2007-2009	Twin pregnancies in three hospitals	DNA	Measured	Measured lengths and weight
Queensland Twin Register	23,456	59	10,685	44	24	6- 95	1900-2002	Birth records	DNA and Q	Measured and self-reported	NA
East-Asia											
Guangzhou Twin Eye Study	1,122	52	561	63	19	6-19	1990-2002	Population registry	DNA and Q	Measured	NA
Japanese Twin Cohort	4,341	51	2,169	62	15	1-12	1950-2003	High school applicants	Q	Parentally reported	Parentally reported length and weight
Korean Twin-Family Register	1,353	62	672	82	0	20-79	1934-1990	Population registry	DNA and Q	Measured	NA

Mongolian Twin Registry	166	49	83	43	22	0- 65	1948-2012	Birth records	Q	Self-reported	Self-reported length and weight
Osaka University Aged Twin Registry	689	60	288	61	5	20- 98	1915-1993	School records	DNA and Q	Self-reported	NA
South Korea Twin Registry	2,278	54	1,139	59	20	7-26	1983-2003	Schools, hospitals, media and childcare agencies	Q	Self-reported	NA
Qingdao Twin Registry (adults)	986	51	493	61	20	23-81	1925-1984	Medical records, schools and media	DNA and blood type	Measured	NA
Qingdao Twin Registry (children)	1,175	52	587	53	20	8-17	1989-1998	Medical records, schools and media	DNA and blood type	Measured	Parentally reported length and weight
West Japan Twins and Higher Order Multiple Births Registry	1,552	53	767	53	25	0-45	1964-2013	Contacting public health centers	Q	Parentally reported	Parentally reported length and weight
Europe											
Adult Netherlands Twin Registry	9,645	64	4,786	50	22	18-91	1918-1994	City council registers, media, websites and social media	DNA and Q	Measured and self-reported	Self-report birth weight
Berlin Twin Register	614	58	307	66	12	10-78	1925-1990	Media	DNA and Q	Self-reported	NA

Bielefeld Longitudinal Study of Adult Twins	2,366	75	1,088	66	10	14-80	1914-1980	Registration offices, media, twin clubs	Q	Self-reported	NA
Danish Twin Cohort	34,665	54	11,667	29	31	30-100	1895-1982	Birth registers, population registers and medical birth registers	Q	DNA and Q	NA
East Flanders Prospective Twin Survey	803	52	379	64	11	18-34	1964-1982	Birth records	Chorionicity,blood and DNA	Measured	Measured weight
Finnish Older Twin Cohort	29,568	51	13,422	28	11	18-101	1880-1957	Birth records	Q	Self-reported	NA
FinnTwin12	4,954	50	2,467	34	33	10-27	1983-1987	Birth records	Q	Self-reported	Parentally reported length and weight
FinnTwin16	5,701	52	2,846	32	35	16-37	1974-1979	Birth records	Q	Self-reported	Parentally reported length and weight
Gemini Study	3,495	51	1,737	33	33	0-5	2007	Birth records	DNA and Q	Measured	Parentally reported length and weight
Genesis 12-19 study	1,662	55	747	36	33	13-28	1985-1988	Birth records	DNA and Q	Self-reported	NA
Hungarian Twin Registry	825	65	389	59	13	2-82	1927-2012	Twin festivals, media	DNA and Q	Measured	Self-reported weight
Italian Twin Registry	17,361	56	7,432	44	25	1-90	1917-2007	Municipality records, disease registries and hospitals	DNA and Q	Measured and self-reported	Parentally reported length and weight

Murcia Twin Registry	2,258	57	999	35	27	41-71	1939-1966	Health records	DNA and Q	Measured and self-reported	Self-reported weight
Norwegian Twin Registry	13,941	53	5,254	46	0	20-75	1915-1960	Birth records	Q	Self-reported	Self-reported weight
Portugal Twin Cohort	1,789	50	803	42	23	3-20	1982-2004	Schools, media, city halls, twin meetings	DNA and Q	Measured	NA
Swedish twin cohorts	65,995	53	29,820	31	19	14- 99	1886-1958	Birth records	Q	Self-reported	NA
Swedish Young Male Twins Study (adults)	2,151	0	1,074	57	0	17-29	1973-1979	Birth records	Q	Self-reported	Measured length and weight
Swedish Young Male Twins Study (children)	898	0	352	63	0	0- 23	1973-1979	Birth records	Q	Measured	Measured length and weight
TCHAD-study	2,570	52	1,265	40	30	7- 21	1976-1978	Birth records	Q	Parentally and self-reported	NA
Twins Early Development Study	18,354	51	9,065	34	33	2- 17	1994-1996	Birth records	DNA and Q	Parentally and self-reported	Parentally reported length and weight
TwinsUK	9,034	88	4,316	51	1	18-88	1917-1990	media, websites and social media	DNA and Q	Measured and self-reported	NA

Young Netherlands Twin Registry	34,524	50	17,237	33	33	1-20	1986-2005	Association of parents of multiples, commercial organizations websites and social media	DNA and Q	Parental and self-reported	Parentally reported length and weight as assessed by obstetrician/mid wife
South-Asia and Middle-East											
Longitudinal Israeli Study of Twins	995	49	489	23	36	3-10	2003-2007	Birth records	DNA and Q	Measured	NA
Sri Lanka Twin Registry	2,485	56	933	45	27	20-88	1925-1993	Door-to-door visit survey, newsletters, cultural activities, media, birth records	DNA and Q	Self-reported	NA
Turkish Twin Study	584	46	288	37	27	14- 69	1942-1996	Birth records	Q	Self-reported	NA
North-America											
Boston University Twin Project	627	47	313	46	0	2-3	2001-2004	Birth records	DNA	Measured	Parentally reported length and weight
California Twin Program	27,237	58	13,384	39	26	17-91	1908-1982	Birth records	Q	Self-reported	NA
Carolina African American Twin Study of Aging	532	59	249	35	27	22-88	1910-1979	Birth records	DNA and Q	Measured	Self-reported weight
Colorado Twin Registry	2,861	48	1,421	48	19	11-29	1979-1991	Birth records	DNA and Q	Measured	Measured weight
Michigan State University Twin	22,172	49	10,253	30	34	2-51	1961-2010	Birth records	DNA and Q	Parentally and self-	Parentally and self-reported

Registry										reported; Measured	weight
Mid Atlantic Twin Registry	11,801	65	5,743	46	23	16-93	1894-1987	Birth records, schools, hospitals and events	DNA and Q	Self-reported	NA
Minnesota Twin Family Study	1,511	50	755	64	0	10-19	1972-1984	Birth records	DNA	Measured	Parentally reported weight
Minnesota Twin Registry	10,122	55	3,998	40	23	26-63	1923-1958	Birth records	Q	Self-reported	Weight based on birth certificate
NAS-NRC Twin Registry	27,093	0	13,540	44	0	15-82	1917-1927	Birth records	Q and DNA	Measured and self-reported	NA
Quebec Newborn Twin Study	1,342	50	668	38	30	0-14	1997-1997	Birth records	DNA and Q	Measured and parentally reported	Measured length and weight
SRI-international	1,092	70	539	75	8	17-83	1921-1997	Community based advertising	Q	Measured and self-reported	NA
Texas Twin Project	565	51	282	35	30	8-20	1991-2003	Schools	Q	Self-reported	NA
University of British Columbia Twin Project	1,450	67	719	53	13	15-86	1905-1976	Media	Q	Self-reported	NA
University of Southern California Twin Study	1,541	50	770	44	26	9-22	1990-1995	Schools, birth and voter records	DNA and Q	Measured	Parentally reported length and weight
University of Washington Twin Registry	15,940	61	7,921	53	22	18-97	1914-1995	The Washington State Department	DNA and Q	Self-reported	NA

								of Licensing application system			
Vietnam Era Twin Study of Aging	1,237	0	614	57	0	51-67	1943-1955	Department of Defense and Department of Veteran Affairs databases	DNA and Q	Measured	NA

Q=questionnaire; MZ=monozygotic; OSDZ=opposite-sex dizygotic