Gemini: A UK Twin Birth Cohort With a Focus on Early Childhood Weight Trajectories, Appetite and the Family Environment

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Gemini is a cohort study of young twins in the United Kingdom designed to assess genetic and environmental influences on early childhood weight trajectories with a focus on infant appetite and the family environment. A total of 2402 families with twins born in England and Wales between March and December 2007 agreed to participate and returned completed baseline questionnaires. The sample includes 1586 same-sex and 816 opposite-sex twins. The study is currently funded for 5 years of follow-up, but is planned to continue into early adolescence and beyond, pending funding. With current funding of the study, families will be followed up when twins are: 8 months old (baseline), and then at 15, 20, 24, 36 and 48 months of age. Gemini is in its early stages, with baseline and first follow-up data collection completed. This is the first twin cohort to focus on childhood weight gain with detailed and repeated measures of children's appetite, food preferences, activity behavior and parental feeding styles, alongside detailed and repeated collection of anthropometrics. This article reviews the rationale for the Gemini study, its representativeness and the main measures.

Keywords: twins, birth cohort, obesity, appetite, physical activity

The spotlight in obesity research is turning on childhood. This is partly in recognition of the impact of childhood obesity on concurrent health and wellbeing, but it also responds to growing concern that longer-term obesity risk could be programmed by features of prenatal, postnatal and early childhood environment (Bouret, 2009; Oken & Gillman, 2003; Ong, 2006; Reilly et al., 2005; Stettler et al., 2005; Wu & Suzuki, 2006).

Multiple interacting genetic and environmental pathways are likely to be involved in the intergenerational transmission of weight status: parents pass on genes to their children, the mother provides the intrauterine environment, they feed their children, they control much of the rearing environment, and they transmit norms for attitudes and behaviors. Each of these pathways could modify weight trajectories in childhood or adult life; and each factor could modify the expression of the others.

Existing research on the determinants of childhood obesity has focused on the effect of childhood diet and physical activity without definitive findings (Procter, 2007; Rennie et al., 2005). A crucial modifier of the effects of environmental exposures (specifically diet and activity) on weight gain is appetite. It is important to distinguish diet (i.e., which foods are consumed) from appetite (i.e., factors that determine initiation and cessation of episodes of eating). Factors such as responsiveness to internal cues of satiety, eating pace, responsiveness to external food cues or fussiness can all influence intake (Carnell & Wardle, 2007). A child exposed to what might be called an 'obesogenic' diet (e.g., energy-dense, low-fibre, high-fat foods) may never gain excess weight if they are highly responsive to their internal cues of satiety. Equally, variation in physical activity may not affect weight if they cause compensatory changes in appetite. Characterizing appetitive traits could make an important contribution to explaining variation in children's weight.

The evidence is clear that there is a strong heritable genetic component to variation in weight and overweight in children (Haworth et al., 2008; Wardle et al., 2008). Genetic effects on weight gain must result from interactions with an environment that facilitates weight gain to make sense of the dramatic increase in weight seen in recent years. This suggests that 'obesogenic' aspects of the environment may have a stronger effect among those who are more genetically susceptible (Wardle & Boniface, 2008).

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Gemini is a cohort study of young twins established within the Department of Epidemiology and Public Health at University College London. It was set up by Professor Jane Wardle to assess genetic and environmental influences on early childhood weight trajectories with a focus on infant appetite, activity preference and the family food and activity environments. The study is funded by Cancer Research UK and is being carried out at the Health Behavior Research Centre (University College London) in collaboration with Professor Robert Plomin at the Institute of Psychiatry (Kings College London), Professor Tim Cole at the Institute of Child Health (University College London) and Professor Stephen O'Rahilly at the University of Cambridge.

Aims

The purpose of the Gemini study is (i) to advance understanding of the genetic and environmental influences on weight gain, (ii) to identify modifiable determinants of excessive weight gain in early childhood and (iii) to create a rich resource of data on early childhood exposures that can be used to assess the determinants of long-term health.

Gemini has a unique focus on behavioral mechanisms in weight gain. By collecting data on the child's appetitive traits, the parents' feeding style, and the home environment, we will be able to characterize the extent to which appetitive traits are expressed in different rearing environments and discover how these factors influence weight gain from birth.

Methods

Sample

All families with twins born in England and Wales between March and December 2007 were approached by the Office for National Statistics using birth registration data (N = 6754) in January 2008. A total of 3435 families (51%) were willing to be contacted by the research team. Baseline questionnaires and consent forms were sent out between February and April 2008, and 2402 families agreed to participate and returned completed baseline questionnaires (36% of the target population; 70% of those willing to be approached; see Figure 1). The response rate of 36% was considered reasonable given that families were approached when twins had been born less than 9 months earlier and mothers were asked to complete two long booklets of questions about the twins and the rest of the family. Participating families live across the whole of England and Wales, and the distribution mirrors the population density (Figure 2).

Data Collection

The study is currently funded for 5 years of follow-up, but is planned to continue into early adolescence and beyond, pending funding. With current funding of the study, families will be followed up when twins are: 8 months old (baseline), and then at 15, 20, 24, 36 and 48 months of age.

The main measures include: anthropometrics from birth, appetite, food preferences, activity behavior and parental feeding style. These will be measured at multiple time points. An overview of these and other measures in Gemini is presented in Table 1. The majority of data are collected using questionnaires that can be completed on paper or online via the internet (9.7% of families completed the baseline questionnaire online). Infant weight and height data is reported from the *Red Book* (a health professional record held by the mother) by sending copies of relevant pages. Electronic weighing scales and height charts were provided to all families when twins were 2 years old for collecting self-reported weight and height at 3-month intervals. Other measures include a diet diary for both twins at age 20 months, and objectively measured activity levels using actigraphs around 4 years of age (pending funding). DNA was collected from the twins when they were around 2 years old using cheek swabs.

Gemini is in its early stages, and the first analyses of baseline data will focus on mapping early growth in relation to feeding practices, infant appetite and parental feeding styles.

Results

Response Rates

The target population was all families with twins born in England and Wales in a 9-month period. Gemini enrolled 2402 families (36% of the total target population) with complete baseline questionnaires. Nonresponse analyses were performed using three variables (month of twins' birth, mother's age at twins' birth and region of residence) as this information was available from the Office of National Statistics on the target population (see Table 2). Response rates ranged from 32% to 42% by month of twins' birth (χ^2 = 21.187 (9df), p = .0118) with somewhat higher response rates among more recent births and lower response rates for births earlier in the year (March and April). As all families were first contacted by the Office of National Statistics in November 2007–January 2008, twins born in March or April were older at initial contact which might relate to the lower response rates among these families. There is also a higher likelihood of families having moved from the address that was recorded in birth registration data. Response rates ranged from 23% to 45% by mother's age at twins' birth, χ^2 = 151.447 (5df), p < .001, with higher response rate in 30–34 year olds and lower response rates in younger (20–24 years) and older (over 40 years) age groups. Response rates ranged from 19% to 45% by region of residence, χ^2 = 241.261 (9df), p < .001, with higher response rates in South East, East of England, East Midlands and South West and the lowest response rate in London (see Table 2).

Baseline data collection started in February 2008 and was completed in July 2008. The first follow-up

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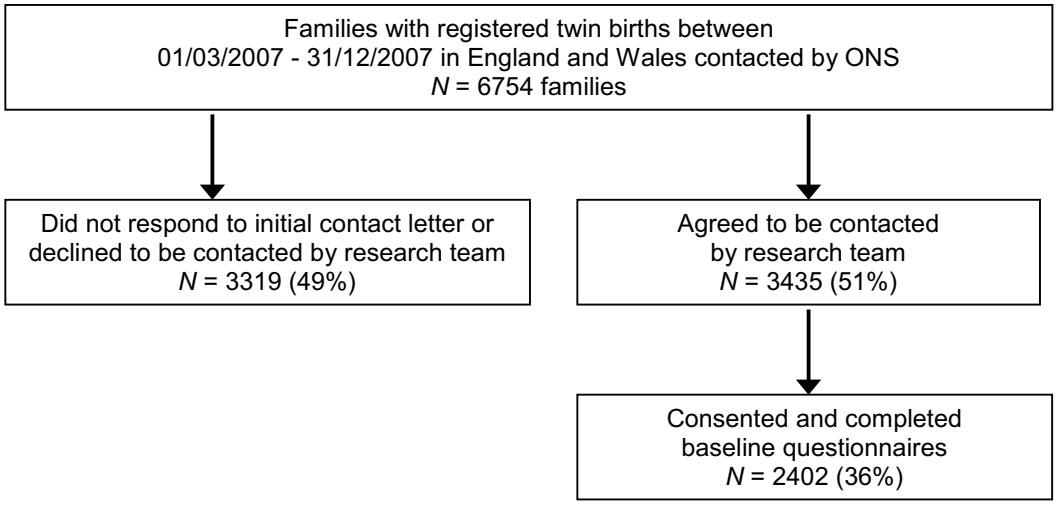

Figure 1

Flow diagram of recruitment of Gemini families.

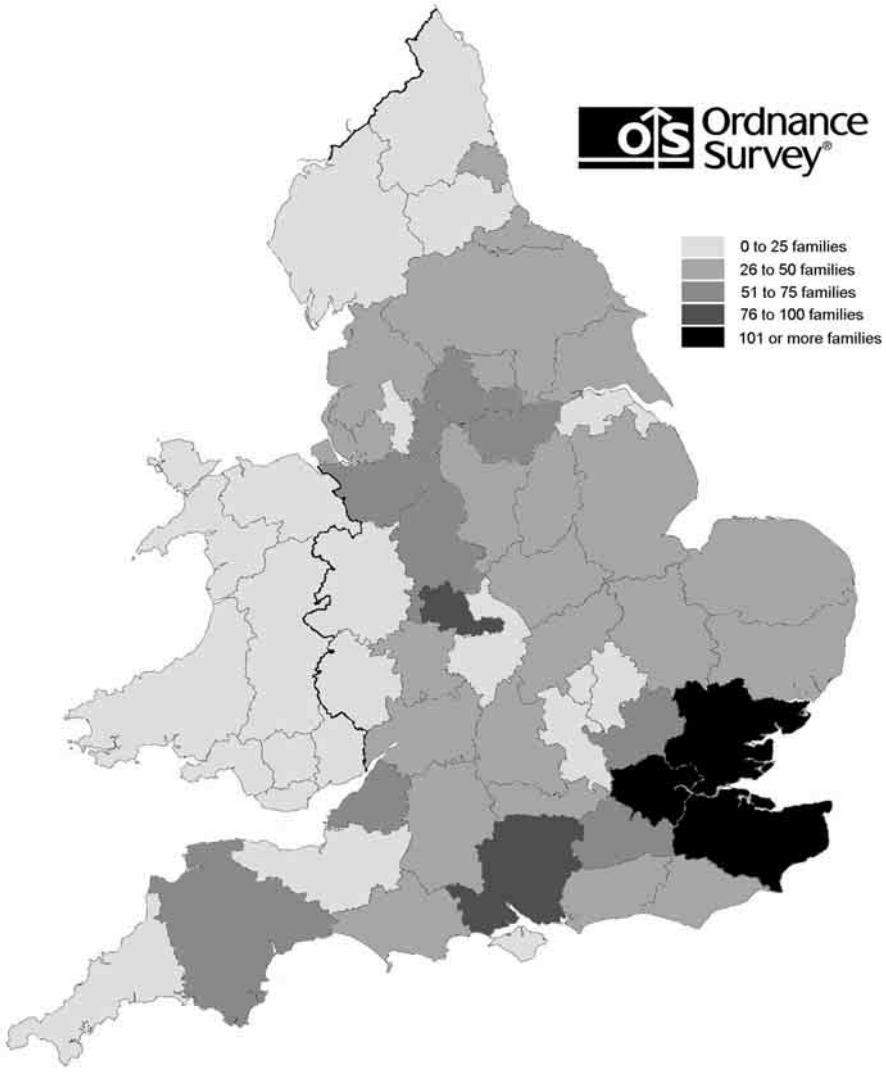

Figure 2

Map of England and Wales showing the distribution of families participating in Gemini.

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Table 1

Schematic Overview of the Measures and Assessment Points in Gemini

	Age of twins (months)					
	8	15	20	24	36[a]	48[a]
Child variables						
Anthropometrics[b]	X	X		X	X	X
Eating behavior / appetite — CEBQ (Wardle et al., 2001)	X	X				X
Food preferences[c]		X				X
Activity behavior — IBQ, ECBQ, CBQ (Gartstein & Rothbart, 2003; Putnam et al., 2006; Rothbart et al., 2001)	X	X				X
TV watching (Anderson et al., 1985) and sleeping behavior (Iglowstein et al., 2003)		X				X
Birth complications, early life illnesses, infant feeding practices[c]	X					
Introduction of solid foods[c]	X	X				
Three-day diet diary for twins food and drink intake[c]			X			
Temperament — CBQ (Putnam et al., 2006)						X
DNA collection using cheek swab				X		
Parental variables						
Parental feeding style — PFSQ (Wardle et al., 2002), CFQ (Birch et al., 2001), PFQ (Baughcum et al., 2001)	X	X				X
Demographics, anthropometrics, health behaviors of both parents	X			X		
Parental eating behavior — DEBQ (Van Strien et al., 1986)				X		
Parental activity behavior — IPAQ (Craig et al., 2003)				X		
Home environment						
Options for physical activity e.g. garden / park nearby[c]					*X*	
Food availability[c]					*X*	

Note: [a] Measures included after 24 months are subject to change.

[b] Anthropometrics include weight, length and head circumference as recorded by health professional in red book from birth. Electronic weighing scales and height charts with detailed instructions are sent at age 2 years for parents to measure their twins' growth in 3-month intervals.

[c] Measures that are modified for use in infants or newly designed for Gemini. These are all intensively piloted in parents of young children (both singletons and twins). All other measures are based on validated questionnaires.

started in June 2008 and will finish in March 2009. Response rate for the first follow-up is 85%. Well-designed paper-based and online questionnaires, reminders sent twice following the questionnaire, a website for participating families with study updates and information (www.geministudy.co.uk), personalized birthday cards for twins, and annual newsletters, are all used to promote engagement with the study and maximize retention.

Representativeness of the Gemini Cohort

The representativeness of the Gemini cohort is studied in three ways: first, by the non-response analyses (discussed above, Table 2); second, by examining the distribution of Gemini families across the country (also discussed above, Figure 2); and third, by comparing baseline characteristics of the Gemini participants with national statistics (Tables 3 and 4). These comparisons do not highlight major concerns about the ability of the Gemini cohort to represent the target population, although slight differences are observed. In summary, the Gemini study includes twins that are comparable in sex, zygosity, gestational age, and birthweight to national averages of twins (Table 3). However, mothers are somewhat older, and both parents are on average slightly healthier than the national population (lower BMI, lower smoking rates and higher consumption of fruit and vegetables). As in many cohort studies, there is an over-representation of White–British in Gemini. Married couples are also over-represented, although this is not surprising given that the target sample is young parents, whereas national statistics refer to all adults aged 16 and over (Table 4).

Discussion

The strengths of Gemini include the fact that it is a large population-based cohort that enrolled 36% of target families. The two key elements of the Gemini study are that it involves twins and that it is a longitudinal study from birth. The twin design permits estimations of genetic and environmental contributions to appetite, food and activity preferences and weight gain. The longitudinal design from birth permits assessment of very early influences and provides information about causal processes behind excessive early weight gain.

This is the first twin cohort to focus on childhood weight gain with detailed and repeated measures of children's appetite, food preferences, activity behavior and parental feeding styles. Appetite has never before been characterized from such an early age. Previous studies of older children have shown that appetite and

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Table 2

Non-Response Analyses Comparing Families Participating in Gemini Cohort With the Target Population

	Target population $N = 6754$ [a]	Gemini cohort $N = 2402$	Response %
Month of twins' birth (all in 2007)			
March	766	245	0.32 [b]
April	720	238	0.33 [b]
May	776	277	0.36
June	773	282	0.36
July	861	296	0.34
August	677	244	0.36
September	718	252	0.35
October	729	261	0.36
November	616	261	0.42 [c]
December	118	46	0.39
Mother's age at twins' birth			
Under 20 years	82	25	0.30
20–24 years	594	160	0.27 [b]
25–29 years	1345	446	0.33
30–34 years	1993	900	0.45 [c]
35–39 years	1995	714	0.36
Over 40 years	667	151	0.23 [b]
Not known	78	6	—
Region of residence			
London	1209	231	0.19 [b]
South East	1057	468	0.44 [c]
North West	824	275	0.33
West midlands	712	228	0.32
East of England	699	317	0.45 [c]
Yorkshire and the Humber	634	222	0.35
East Midlands	468	194	0.41 [c]
South West	567	255	0.45 [c]
Wales	320	117	0.37
North East	262	94	0.36
Not Known	2	1	—
Total	6754	2402	0.36

Note: [a] The target population consisted of 6754 families with registered twin births in England or Wales between March and December 2007 which were contacted by Office of National Statistics.
[b] Groups with much lower response rates compared to overall mean of 36%.
[c] Groups with much higher response rates compared to overall mean of 36%.

Table 3

Characteristics of Twins Participating in Gemini Compared to National Statistics for Twins

	Gemini cohort ($N = 2402$)			National twin statistics [a]
Sex of twin pair	*N*	*(%)*		*%*
Males	785	(32.7)		32.1
Female	801	(33.3)		32.8
Male–female	816	(34.0)		35.1
Zygosity [b]				
Dizygotic — opposite sex	816	(34.0)		
Dizygotic — females	389	(16.2)		
Dizygotic — males	400	(16.6)		
Monozygotic — females	384	(16.0)		
Monozygotic — males	345	(14.4)		
Not known	68	(2.8)		
Pre-term (< 37 weeks)	1045	(43.5)		40
	Mean	(*SD*)	Range	Mean
Weight at birth in grams	2464	(541)	540–4220	2500
Length at birth in cms	47.4	(4.5)	22–60	
Head circumference at birth in cms	33.0	(2.0)	21–46	
Gestational age at birth in weeks	36.2	(2.5)	25–42	37

Note: [a] Office for National Statistics (2006). Birth statistics Series FM1 no.35. Review of the Registrar General on births and patterns of family building in England and Wales. Newport. (Numbers are for twin births in 2006).
[b] Zygosity based on questionnaire data. (Goldsmith, 1991). These numbers correspond to national statistics indicating that one-third of twins are monozygotic (identical) and two-thirds are dizygotic (nonidentical), and that opposite sex twins are most common and monozygotic males twin pairs are the least common.

body size are linked, however the causal direction of this association has not been established. Assessing appetite and growth from birth will contribute to understanding the causal relationship.

In addition to the main part of the study involving psychometric data collected using questionnaires, Gemini also aims to collect information from other sources: e.g. diet diaries, DNA and actigraph data. Three-day diet diaries are being sent when twins are 20 months old to collect comprehensive data on all foods and drinks consumed by the twins in a three day period. DNA was collected when twins were about two years old, to verify phenotypically assigned zygosity and conduct genetic analyses on the association between appetite and activity behavior and weight-related SNPs that have been identified in other studies. Gemini also plans to collect objective data on activity around age of 4 years with actigraphs (pending funding). A clinic visit including all twins is also planned when the twins are aged 5 years to obtain accurate data on body composition as well as other biological markers of health to assess current and future disease risk.

Data are stored confidentially and anonymously according to the UK Data Protection Act. The data are currently not freely available as it is a study in progress, but specific proposals for collaboration are welcomed. For further information contact the principal investigator; Professor Jane Wardle at j.wardle@ucl.ac.uk.

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References

Anderson, D. R., Field, D. E., Collins, P. A., Lorch, E. P., & Nathan, J. G. (1985). Estimates of young children's

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Table 4

Baseline Characteristics of Parents Participating in Gemini Compared to National Statistics

	Gemini cohort ($N = 2402$)			National statistics
Age at twins' birth in years	Mean	(*SD*)	Range	Mean
Mother	33.6	(5.2)	15–56	29.5 [a]
Father	36.4	(6.2)	19–71	—
BMI [d] in kg/m^2				
Mother	25.1	(4.8)	14–60	26.8 [b]
Father	26.4	(3.9)	15–50	27.1 [b]
At least 5 portions of fruit/ vegetables a day	*N*	*(%)*		*%*
Mother	790	(32.9)		31.0 [b]
Father	663	(27.6)		27.0 [b]
Current smoker				
Mother	306	(12.7)		21.0 [b]
Father	466	(19.4)		24.0 [b]
Mother's ethnicity				
White–British	2089	(87.0)		78.1 [a]
Non White–British	311	(12.9)		21.9
Not known	2	(0.1)		
Father's ethnicity				
White–British	1988	(87.8)		72.6 [a]
Non White–British	275	(11.4)		27.4
Not known	139	(5.8)		
Marital status				
Married or cohabiting	2276	(94.8)		60.0 [c]
Divorced or separated	31	(1.3)		20
Single	93	(3.9)		21
Not known	2	(0.1)		—

Note: [a] Office for National Statistics (2006). ONS Population report for England and Wales. Statistics correspond to parents with life births in 2006
[b] Health Survey for England 2007 Volume 1. Health lifestyles: knowledge, attitudes and behavior. Ed R. Craig & N. Shelton. The health and social care Information Centre, 2008.
[c] General Household Survey 2006, data for Great Britain in persons 16 and over.
[d] BMI calculated from self-reported height and weight.

time with television: A methodological comparison of parent reports with time-lapse video home observation. *Child Development, 56,* 1345–1357.

Baughcum, A. E., Powers, S. W., Johnson, S. B., Chamberlin, L. A., Deeks, C. M., Jain, A., & Whittaker, R. C. (2001). Maternal feeding practices and beliefs and their relationships to overweight in early childhood. *Journal of Developmental and Behavioral Pediatrics, 22,* 391–408.

Birch, L. L., Fisher, J. O., Grimm-Thomas, K., Markey, C. N., Sawyer, R., & Johnson, S. L. (2001). Confirmatory factor analysis of the Child Feeding Questionnaire: A measure of parental attitudes, beliefs and practices about child feeding and obesity proneness. *Appetite, 36,* 201–210.

Bouret, S. G. (2009). Early life origins of obesity: role of hypothalamic programming. *Journal of Pediatric Gastroenterology and Nutrition, 48 Suppl 1,* S31–38.

Carnell, S. & Wardle, J. (2007). Measuring behavioral susceptibility to obesity: Validation of the child eating behavior questionnaire. *Appetite, 48,* 104–113.

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F, & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise, 35,* 1381–1395.

Gartstein, M. & Rothbart, M. (2003). Studying infant temperament via a revision of the Infant Behavior Questionnaire. *Infant Behavior and Development, 26,* 64–86.

Goldsmith, H. H. (1991). A zygosity questionnaire for young twins: A research note. *Behavior Genetics, 21,* 257–269.

Haworth, C. M., Plomin, R., Carnell, S., & Wardle, J. (2008). Childhood obesity: Genetic and environmental overlap with normal-range BMI. *Obesity (Silver. Spring), 16,* 1585–1590.

Iglowstein, I., Jenni, O. G., Molinari, L., & Largo, R. H. (2003). Sleep duration from infancy to adolescence: reference values and generational trends. *Pediatrics, 111,* 302–307.

Oken, E. & Gillman, M. W. (2003). Fetal origins of obesity. *Obesity Research, 11,* 496–506.

Ong, K. K. (2006). Size at birth, postnatal growth and risk of obesity. *Hormone Research, 65, 3*(Suppl.), 65–69.

Procter, K. L. (2007). The aetiology of childhood obesity: A review. *Nutrition Research Reviews, 20,* 29–45.

Putnam, S. P., Gartstein, M. A., & Rothbart, M. K. (2006). Measurement of fine-grained aspects of toddler temperament: The early childhood behavior questionnaire. *Infant Behavior and Development, 29,* 386–401.

Reilly, J. J., Armstrong, J., Dorosty, A. R., Emmett, P. M., Ness, A., Rogers, I., Steer, C., Sherriff, A., and Avon Longitudinal Study of Parents and Children Study Team. (2005). Early life risk factors for obesity in childhood: Cohort study. *British Medical Journal, 330,* 1357.

Rennie, K. L., Johnson, L., & Jebb, S. A. (2005). Behavioral determinants of obesity. *Best Practice and Research. Clinical Endocrinology and Metabolism, 19,* 343–358.

Rothbart, M. K., Ahadi, S. A., Hershey, K. L., & Fisher, P. (2001). Investigations of temperament at three to seven years: the Children's Behavior Questionnaire. *Child Development, 72,* 1394–1408.

Stettler, N., Stallings, V. A., Troxel, A. B., Zhao, J., Schinnar, R., Nelson, S. E., Ziegler, E. E., & Strom, B. L. (2005). Weight gain in the first week of life and overweight in adulthood: A cohort study of European American subjects fed infant formula. *Circulation, 111,* 1897–1903.

Van Strien, T., Frijters, J. E. R., Bergers, G. P. A., & Defares, P. B. (1986). The Dutch Eating Behavior

https://doi.org/10.1375/twin.13.1.72 Published online by Cambridge University Press

Questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior. *International Journal of Eating Disorders, 5*, 295–315.

Wardle, J., & Boniface, D. (2008). Changes in the distributions of body mass index and waist circumference in English adults, 1993/1994 to 2002/2003. *Internation Journal of Obesity (London), 32*, 527–532.

Wardle, J., Carnell, S., Haworth, C. M., & Plomin, R. (2008). Evidence for a strong genetic influence on childhood adiposity despite the force of the obesogenic environment. *American Journal of Clinical Nutrition, 87*, 398–404.

Wardle, J., Guthrie, C. A., Sanderson, S., & Rapoport, L. (2001). Development of the Children's Eating Behavior Questionnaire. *Journal of Child Psychology and Psychiatry, 42*, 963–970.

Wardle, J., Sanderson, S., Guthrie, C. A., Rapoport, L., & Plomin, R. (2002). Parental feeding style and the intergenerational transmission of obesity risk. *Obesity Research, 10*, 453–462.

Wu, Q. & Suzuki, M. (2006). Parental obesity and overweight affect the body-fat accumulation in the offspring: the possible effect of a high-fat diet through epigenetic inheritance. *Obesity Reviews, 7*, 201–208.

https://doi.org/10.1375/twin.13.1.72 Published online by Cambridge University Press