Bi-directional relationships between body mass index and height from three to seven years of age: an analysis of children in the United Kingdom Millennium Cohort Study

Supplementary material

The multivariate piecewise linear growth model for ZHeight and zBMI can be expressed as:

$$zHeight_{ij} = b^h_{0j} + b^h_{1j} t_{ij1} + b^h_{2j} t_{ij2} + \Sigma b^h_{3kj} x_{kij} + e^h_{ij}$$

$$zBMI_{ij} = b^w_{0j} + b^w_{1j} t_{ij1} + b^w_{2j} t_{ij2} + b^w_{3kj} x_{kij} + e^w_{ij}$$

where $zHeight_{ij}$ and $zBMI_{ij}$ are the observed values of the repeated measures of zHeight and zBMI for individual i at time j, b^h_{0j} and b^w_{0j} are the latent intercept factors, and t_{ij1} and t_{ij2} are the latent slope factors (for before and after the knot at 5 years, respectively) representing a linear change in zHeight or zBMI when b^h_{1j} and b^w_{1j} (pre-knot) and b^h_{2j} and b^w_{2j} (post-knot) change by one unit. The time-varying covariates are represented by x_{kij} with coefficients b^h_{3kj} and b^w_{3kj}. The individual and time specific measurement error is represented by e^h_{ij} and e^w_{ij}, assumed to be normally distributed with variance σ^h_e and σ^w_e. The measurement error terms e^h_{ij} and e^w_{ij} are assumed to be independent given the covariance between the level-2 error terms u^h_j and u^w_j, defined below.

The intercept and slopes are treated as random variables, which can be expressed as:

$$b^h_{0j} = b^h_0 + \Sigma b^h_{0k} z_{kj} + u^h_{0j}$$

$$b^h_{1j} = b^h_1 + \Sigma b^h_{1k} z_{kj} + u^h_{1j}$$

$$b^h_{2j} = b^h_2 + \Sigma b^h_{2k} z_{kj} + u^h_{3j}$$

$$b^w_{0j} = b^w_0 + \Sigma b^w_{0k} z_{kj} + u^w_{0j}$$

$$b^w_{1j} = b^w_1 + \Sigma b^w_{1k} z_{kj} + u^w_{1j}$$

$$b^w_{2j} = b^w_2 + \Sigma b^w_{2k} z_{kj} + u^w_{3j}$$

$$u^h_j \sim N(0, \sigma^h_u{}^2); \ e^h_j \sim N(0, \sigma^h_e{}^2); \ u^w_j \sim N(0, \sigma^w_u{}^1); \ e^w_j \sim N(0, \sigma^w_e{}^2)$$

The intercepts b^h_{0j} and b^w_{0j} have fixed components b^h_0 and b^w_0, respectively, adjusted for time-invariant covariates z_{kj} with coefficients b^h_{2k} and b^w_{2k}, and individual (random) components u^h_{0j} and u^w_{0j}.

Similarly, the slopes b^h_{1j}, b^h_{2j} b^w_{1j} and b^w_{2j} have fixed components b^h_1, b^h_2, b^w_1 and b^w_2, respectively, adjusted for time-invariant covariates z_{kj} with coefficients b^h_{1k}, b^h_{2k}, b^w_{1k} and b^w_{2k}, and individual (random) components u^h_{1j}, u^h_{2j}, uw_{1j}, and u^w_{2j}. The random components are not estimated directly. Instead they are assumed to be normally distributed with variance σ^h_u and σ^w_u and allowed to covary.

Table S1. Estimates from the joint trajectory model of zHeight and zBMI for 5717 boys in the MCS

		Coefficient	S.E.	P
Regressions				
zBMI intercept on	age	0.121	0.075	0.104
	Indian	-0.526	0.132	< 0.0005
	Pakistani	-0.527	0.102	< 0.0005
	Bangladeshi	-0.38	0.205	0.063
	Caribbean	0.145	0.137	0.289
	African	0.034	0.152	0.822
	Other	-0.344	0.139	0.013
	birth weight	0.334	0.035	< 0.0005
zHeight intercept on	age	-0.14	0.085	0.101
	Indian	0.426	0.128	< 0.0005
	Pakistani	0.283	0.089	< 0.0005
	Bangladeshi	-0.083	0.188	0.659
	Caribbean	0.349	0.11	< 0.0005
	African	0.716	0.097	< 0.0005
	Other	-0.152	0.113	0.181
	birth weight	0.49	0.026	< 0.0005
zBMI slope 3-5 on	Indian	0.07	0.043	0.106
	Pakistani	0.008	0.042	0.847
	Bangladeshi	0.103	0.092	0.263
	Caribbean	0.023	0.06	0.697
	African	-0.015	0.05	0.77
	Other	0.022	0.051	0.658
	birth weight	0.009	0.016	0.585
zBMI slope 5-7 on	Indian	0.145	0.044	< 0.0005
	Pakistani	0.112	0.06	0.062
	Bangladeshi	0.018	0.067	0.787
	Caribbean	0.007	0.055	0.898
	African	0.121	0.048	0.011
	Other	0.024	0.041	0.561
	birth weight	-0.015	0.012	0.195
zHeight slope 3-5 on	Indian	0.011	0.027	0.675
	Pakistani	0.031	0.02	0.125
	Bangladeshi	0.087	0.058	0.13
	Caribbean	0.038	0.034	0.271
	African	0.012	0.032	0.699
	Other	0.051	0.032	0.109
	birth weight	-0.007	0.008	0.346
zHeight slope 5-7 on	Indian	0	0.023	0.994
	Pakistani	-0.035	0.021	0.095
	Bangladeshi	-0.06	0.035	0.082
	Caribbean	0.017	0.021	0.41
	African	-0.046	0.029	0.112
	Other	0.021	0.021	0.305
	birth weight	-0.007	0.005	0.17

zHeight 3 on	HH income3	-0.014	0.011	0.205
zBMI 3 on	HH income3	-0.019	0.019	0.311
zHeight 5 on	HH income5	0.022	0.011	0.047
zBMI 5 on	HH income5	-0.043	0.02	0.033
zHeight 7 on	HH income7	0.042	0.011	< 0.0005
zBMI 7 on	HH income7	-0.084	0.021	< 0.0005
Covariances				
zBMI intercept with	zBMI slope 3-5	-0.087	0.058	0.138
	zBMI slope 5-7	-0.026	0.01	0.011
	zHeight intercept	-0.001	0.025	0.964
zHeight intercept with	zHeight slope 3-5	-0.01	0.016	0.521
	zHeight slope 5-7	-0.009	0.004	0.011
zBMI slope 3-5 with	zBMI slope 5-7	-0.012	0.02	0.531
	zHeight slope 3-5	-0.037	0.005	< 0.0005
	zHeight intercept	0.069	0.011	< 0.0005
zBMI slope 5-7 with	zHeight slope 5-7	-0.019	0.004	< 0.0005
	zHeight intercept	0.016	0.007	< 0.0005
	zHeight slope 3-5	0.024	0.004	0.027
zHeight slope 3-5 with	zHeight slope 5-7	-0.006	0.005	0.222
	zBMI intercept	0.065	0.008	< 0.0005
zHeight slope 5-7 with	zBMI inercept	-0.01	0.005	0.043
	zBMI slope 3-5	0.024	0.003	< 0.0005
Intercepts				
HH income3		-0.005	0.008	0.548
HH income5		-0.005	0.007	0.422
HH income7		-0.002	0.007	0.716
zBMI 3		0.593	0.024	< 0.0005
zHeight 3		-0.006	0.021	0.778
zBMI 3-5		-0.032	0.01	< 0.0005
zBMI 5-7		-0.062	0.007	< 0.0005
zHeight 3-5		0.005	0.006	0.428
zHeight 5-7		0.063	0.004	< 0.0005
Variances				
zHeight 3		0.165	0.03	< 0.0005
zHeight 5-7		0.035	0.015	0.017
zHeight 7		0.028	0.012	0.021
zBMI 3		0.426	0.086	< 0.0005
zBMI 5-7		0.171	0.07	0.015
zBMI 7		0.222	0.072	< 0.0005
zBMI intercept		0.93	0.121	< 0.0005
zHeight intercept		0.832	0.041	< 0.0005
zBMI slope 3-5		0.104	0.032	< 0.0005
zBMI slope 5-7		0.061	0.034	0.067
zHeight slope 3-5		0.029	0.008	< 0.0005
zHeight slope 5-7		0.029	0.007	< 0.0005

Table S2. Estimates from the joint trajectory model of zHeight and zBMI for 5640 girls in the MCS

		Coefficient	S.E.	P
	Regressions			
zBMI intercept on	Age	0.05	0.082	0.547
	Indian	-0.461	0.105	< 0.0005
	Pakistani	-0.196	0.097	0.044
	Bangladeshi	-0.097	0.318	0.759
	Caribbean	0.25	0.14	0.075
	African	0.285	0.157	0.069
	Other	-0.006	0.113	0.957
	birth weight	0.399	0.032	< 0.0005
zHeight intercept on	Age	0.006	0.069	0.931
	Indian	0.361	0.134	0.007
	Pakistani	0.293	0.092	< 0.0005
	Bangladeshi	0.305	0.13	0.019
	Caribbean	0.233	0.126	0.064
	African	0.968	0.106	< 0.0005
	Other	0.141	0.11	0.198
	birth weight	0.508	0.029	< 0.0005
zBMI slope 3-5 on	Indian	0.071	0.039	0.07
	Pakistani	0.049	0.04	0.221
	Bangladeshi	0.029	0.136	0.83
	Caribbean	-0.013	0.048	0.781
	African	0.051	0.054	0.348
	Other	-0.043	0.034	0.197
	birth weight	-0.027	0.012	0.028
zBMI slope 5-7 on	Indian	0.129	0.042	< 0.0005
	Pakistani	-0.092	0.056	0.099
	Bangladeshi	-0.01	0.06	0.87
	Caribbean	0.076	0.033	0.023
	African	0.076	0.052	0.142
	Other	-0.038	0.037	0.313
	birth weight	-0.019	0.01	0.055
zHeight slope 3-5 on	Indian	-0.022	0.031	0.482
	Pakistani	-0.04	0.02	0.046
	Bangladeshi	-0.048	0.057	0.405
	Caribbean	0.059	0.033	0.075
	African	0.002	0.031	0.939
	Other	-0.022	0.027	0.411
	birth weight	-0.015	0.007	0.047
zHeight slope 5-7 on	Indian	-0.036	0.02	0.065
	Pakistani	-0.052	0.013	< 0.0005
	Bangladeshi	-0.077	0.023	< 0.0005
	Caribbean	-0.018	0.019	0.341
	African	-0.034	0.043	0.428
	Other	-0.042	0.018	0.017
	birth weight	-0.02	0.006	< 0.0005
zHeight 3 on	HH income3	-0.011	0.011	0.3
zBMI 3 on	HH income3	0.011	0.02	0.592

		Coefficient	S.E.	P
zHeight 5 on	HH income5	0.024	0.009	0.008
zBMI 5 on	HH income5	-0.038	0.014	0.006
zHeight 7 on	HH income7	0.019	0.01	0.044
zBMI 7 on	HH income7	-0.044	0.013	< 0.0005
Covariances				
zBMI intercept with	zBMI slope 3-5	-0.072	0.048	0.138
	zBMI slope 5-7	-0.005	0.007	0.451
	zHeight intercept	0.053	0.02	0.007
zHeight intercept with	zHeight slope 3-5	0.009	0.014	0.523
	zHeight slope 5-7	-0.016	0.004	< 0.0005
zBMI slope 3-5 wirh	zBMI slope 5-7	-0.005	0.01	0.624
	zHeight slope 3-5	-0.024	0.003	< 0.0005
	zHeight intercept	0.045	0.008	< 0.0005
zBMI slope 5-7 with	zHeight slope 5-7	-0.006	0.002	< 0.0005
	zHeight intercept	0.022	0.006	< 0.0005
	zHeight slope 3-5	0.013	0.002	< 0.0005
zHeight slope 3-5 with	zHeight slope 5-7	-0.005	0.003	0.122
	zBMI intercept	0.053	0.006	< 0.0005
zHeight slope 5-7 with	zBMI inercept	-0.01	0.003	< 0.0005
	zBMI slope 3-5	0.018	0.002	< 0.0005
Intercepts				
HH income3		-0.004	0.007	0.63
HH income5		-0.003	0.006	0.595
HH income7		-0.002	0.007	0.729
zBMI 3		0.483	0.021	< 0.0005
zHeight 3		-0.138	0.018	< 0.0005
zBMI 3-5		-0.036	0.008	< 0.0005
zBMI 5-7		-0.049	0.006	< 0.0005
zHeight 3-5		0.03	0.005	< 0.0005
zHeight 5-7		0.067	0.004	< 0.0005
Variances				
zHeight 3		0.173	0.028	< 0.0005
zHeight 5-7		0.018	0.011	0.11
zHeight 7		0.087	0.019	< 0.0005
zBMI 3		0.321	0.065	< 0.0005
zBMI 5-7		0.09	0.05	0.072
zBMI 7		0.282	0.085	< 0.0005
zBMI intercept		0.846	0.1	< 0.0005
zHeight intercept		0.809	0.037	< 0.0005
zBMI slope 3-5		0.07	0.024	< 0.0005
zBMI slope 5-7		0.021	0.03	0.494
zHeight slope 3-5		0.021	0.007	0.005
zHeight slope 5-7		0.012	0.006	0.057

Table S3. Correlations (standard errors) between baseline zHeight and zWaist[1] and changes over time for 5725 boys in the MCS

	zWaist 5	zWaist 5-7	zHeight 3	zHeight 3-5	zHeight 5-7
zWaist 5	1.00	-0.22 (0.56)	0.42 (0.08)***	0.27 (0.11)**	0.03 (0.04)
zWaist 5-7		1.00	-0.05 (0.03)	0.16 (0.11)	0.22 (0.12)[!]

[!] $P < 0.10$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

[1] zHeight and zWaist expressed in standard deviate scores, derived using LMS standardization [1]

Table S4. Correlations (standard errors) between baseline zHeight and zWaist[1] and changes over time for 5616 girls in the MCS

	zWaist 5	zWaist 5-7	zHeight 3	zHeight 3-5	zHeight 5-7
zWaist 5	1.00	0.18 (1.12)	0.46 (0.13)***	0.26 (0.15)[!]	0.03 (0.05)
zWaist 5-7		1.00	-0.02 (0.04)	0.37 (0.32)	0.55 (0.50)

[!] $P < 0.10$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

[1] zHeight and zWaist expressed in standard deviate scores, derived using LMS standardization [1]

Table S5. Correlations (standard errors) between % Fat at age seven and zHeight[1] trajectories for 5803 boys in the MCS

	%Fat 7	zHeight 3	zHeight 3-5	zHeight 5-7
%Fat 7	1.00	0.13 (0.02)***	0.28 (0.10)**	0.05 (0.03)[!]

[!] $P < 0.10$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

[1] zHeight expressed in standard deviate scores, derived using LMS standardization [1]

Table S6. Correlations (standard errors) between % Fat at age seven and zHeight[1] trajectories for 5700 girls in the MCS

	%Fat 7	zHeight 3	zHeight 3-5	zHeight 5-7
%Fat 7	1.00	0.18 (0.02)***	0.35 (0.17)*	0.17 (0.12)

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

[1] zHeight expressed in standard deviate scores, derived using LMS standardization [1]

Reference

1. Cole TJ. The LMS method for constructing normalized growth standards. Eur. J. Clin. Nutr. 1990;**44**:45-60