Body Mass Index and Cognitive Ability of Young Children

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Keywords

BMI · Overweight · Children · Cognition · K-ABC

Summary

Objective: This study prospectively assessed the association between body mass index (BMI) and cognitive ability of young children, while accounting for confounding factors. **Methods:** The study included 236 children born between 1990 and 1994 participating in a Dutch birth cohort study. Anthropometric data of the children at birth, 4, and 7 years of age were collected from growth records or measured at the Academic Hospital of Maastricht. The Kaufman Assessment Battery for Children (K-ABC) was used to assess cognitive ability at 7 years of age. The association between BMI and cognitive ability was investigated using univariate and multivariate linear regression analyses, including various covariates. **Results:** Although the results suggest that cognitive ability at 7 years of age decreased with increasing BMI at 4 years and 7 years of age, this association was not significant in any performed analysis. Multivariate analyses showed that maternal intelligence was strongly associated with all scales of the K-ABC as a significant covariate. Adjusting analyses for physical fitness of the child, maternal education, maternal pre-pregnancy BMI, maternal smoking during pregnancy, and birth weight did not change the results. **Conclusion:** This study found no evidence for an association between BMI and cognitive ability of school-aged children.

Introduction

Overweight and extreme overweight (obesity) during childhood is likely to persist through adulthood, and is associated with a wide range of physical and psychological problems [1–3]. Impairment of cognitive ability is one of the psychological consequences that could have a substantial impact on the future of overweight children, since declined cognitive ability may lead to worsened school performance, which in turn could contribute to the lower socio-economic status observed when overweight children reach adulthood [4]. There are different mechanisms put forward in the literature that might explain the association between overweight and cognitive ability. First, there might be physiological changes in brain tissue due to overweight, which impair cognitive ability [5, 6]. Second, lower levels of cognitive ability might cause poor control over neurological centres associated with impulsivity or addiction which in turn could lead to impaired control over food intake [7–10]. Third, different physical consequences of being overweight such as diabetes type II and sleep apnoea might cause lower levels of cognitive ability among children [11–13]. Finally, there are some indications for genetic and environmental factors that might play a role in this association.

Previous research concerning the association between overweight and cognitive ability mainly focussed on adolescents [14–19]. Although nowadays overweight is already highly prevalent at a young age [20, 21], studies examining the association between overweight and cognitive ability among young children in primary school are limited [10, 15, 22–26]. The majority of these studies reported lower levels of cognitive ability among overweight children. However, in most cases the results are based on cross-sectional data [10, 15, 22, 24, 25]. More importantly, while almost all of these studies hypothesise on the importance of potential confounding fac-

tors, such as maternal education or intelligence and the child's birth weight and physical fitness, only 1 cross-sectional [10] and 1 longitudinal study [26] actually adjusted their analyses for a considerable number of these factors. Therefore, the current study aimed to prospectively investigate the association between body mass index (BMI) and cognitive ability of young children in primary school, adjusted for relevant confounding factors.

Participants and Methods

Study Design and Participants

Respondents were recruited from a Dutch birth cohort study of 750 children born between December 1990 and January 1994 [27], originally designed to investigate the relation between essential fatty acid status at birth and physical, cognitive, visual, and motor function at a later age. Data were collected when pregnant women enrolled (at less than 16 weeks gestation), during their pregnancy (at around 22 and 32 weeks of gestation), when the children were born, and then yearly until the children were approximately 4 years of age. At the age of 7, children and their parents were invited to the paediatric outpatient clinic of the Maastricht University Hospital for follow-up measurements. For different reasons (deceased, emigrated, untraceable), 691 of the 750 families received this invitation. Of all invited families, 327 participated in the follow-up wave. During the study, 21 families dropped out. Since children with missing values of their BMI at 7 years of age were excluded, the current study population consisted of 297 children. This study was conducted according to the Declaration of Helsinki, and all procedures involving human subjects/patients were approved by the Ethics Committee of the University Hospital Maastricht. Written informed consent was obtained from all parents.

Measurements of Cognitive Ability

The Kaufman Assessment Battery for Children (K-ABC) was used to assess cognitive ability at 7 years of age [28, 29]. This battery is a standardized measure which consists of 2 scales, the Sequential Processing Scale and the Simultaneous Processing Scale, each measuring a different type of information processing. Together, these scales form the Mental Processing Composite which reflects a total score for cognitive ability [29] and is the main outcome of this study. Raw scores were standardized with a mean score of 100 and a standard deviation (SD) of 15. Scores were standardized by means of the United States' norms, as no Dutch standardization norm for the K-ABC was available.

Assessment of Anthropometric Data

Data on weight and height of children at 4 years of age were collected from official growth records of the health centres. At 7 years of age, children were weighed and measured by a physician in the hospital of Maastricht. Weight was assessed to the nearest 100 g using a SECA electronic digital scale, while the children only wore light underwear [30]. Children's height was measured to the nearest millimetre using a wall mounted stadiometer (Holtain LTD, Crymych, UK) [30]. All anthropometric data of the children were measured while the children only wore light underwear. BMI was calculated and overweight was defined using gender- and age-specific cut-off points [31].

Covariates

This study included different sets of covariates that are divided over 3 concepts; children's physical factors, pregnancy-related factors, and socio-economic-related factors. First, among the children's physical factors were birth weight [32, 33], gender, and physical fitness of the children

[34, 35]. Data on birth weight and gender were collected from medical records of the local hospitals where the children were born. Physical fitness data were collected during follow-up using a motor-driven treadmill test. Total workload (KJ) [16] was selected as a measure of VO_2^{max} , which provides a reliable estimate of the child's physical fitness [30, 36]. Second, pre-pregnancy BMI [37], smoking and drinking habits during pregnancy [38–40], being born prematurely [41], maternal age at birth [42], and breast feeding duration [43, 44] were considered among the pregnancy-related factors. Data concerning pre-pregnancy weight and height, smoking and drinking habits during pregnancy, pregnancy duration, and maternal age at child birth were collected from hospital charts when the mothers enrolled in the study, during their pregnancy, and after delivery. Children were considered to be born prematurely if the child was born after less than 259 days. Breastfeeding duration and maternal education (at the time of birth) were reported by the mothers at follow-up measurements when their child was 7 years of age. Finally, to measure socio-economic factors, maternal education, maternal intelligence, and family income were included [33, 45]. Maternal education was classified into 3 categories: high, intermediate, and low [46]. The Raven's Standard Progressive Matrices were used to test maternal intelligence during follow-up [47]. The mother could score a maximum of 60 points. Household income was estimated based on the postal code of the parents during pregnancy (Geomarktprofiel; Wegener DM, Nieuwegein, The Netherlands) and was divided into 3 categories: high (> modal), intermediate (modal), and low (< modal).

Statistical Analyses

Data were analysed using SAS version 9.1 (SAS Institute, Cary, NC). The association between BMI at 4 years of age and cognitive ability at the age of 7 as well as the association between BMI at 7 years of age and cognitive ability at the age of 7 was analysed using univariate and multivariate linear regression analyses. Variables that were associated with cognitive ability were included as covariates in the multivariate analyses (i.e., physical fitness of the child, maternal education, maternal intelligence, maternal pre-pregnancy BMI, maternal smoking during pregnancy, maternal age at child birth, birth weight, breastfeeding duration, and premature birth). Moreover, it was determined which covariates were significantly associated with both cognitive ability and BMI. These factors were considered as confounders of the investigated associations. Physical fitness of the child and birth weight confounded the association between BMI at 4 years of age and cognitive ability at the age of 7, while physical fitness of the child, maternal education, maternal pre-pregnancy BMI, maternal smoking during pregnancy, and birth weight confounded the analyses on the association between BMI at 7 years of age and cognitive ability at the age of 7.

Moreover, since children were only approximately 4 and 7 years of age when BMI was measured and the interpretation of BMI during childhood is highly age-specific, z-scores of BMI at 4 and 7 years of age were calculated by means of reference growth curves of the Dutch Fourth Nationwide Growth Study [48]. All regression analyses were also performed using the BMI z-scores. Results were considered significant when $p < 0.05$.

Results

The mean age of children at follow-up was 7.3 years, and 44.8% were female. The mean BMI at 4 years of age was 15.6 kg/m^2 , and 7.6% of the children were overweight. During follow-up, the mean BMI remained 15.6 kg/m^2 , however, due to age-based cut-off points, 10.6% of the children were overweight. The mean score of total intellectual ability, the

Table 1. Descriptive statistics of the study population

Variable	Total n	Mean	SD
Age at 4 years, years	236	4.1	0.1
BMI at 4 years, kg/m ²	236	15.6	1.3
BMI z-score at 4 years, kg/m ²	236	-0.1	0.8
Age at 7 years, years	297	7.3	0.3
BMI at 7 years, kg/m ²	297	15.6	1.8
BMI z-score at 7 years, kg/m ²	297	-0.2	1.0
Cognitive ability at 7 years (Kaufman ABC)	233		
Mental processing composite		107.2	11.9
Sequential processing		101.8	12.5
Simultaneous processing		109.8	11.8
Physical fitness at 7 years (total workload), KJ	286	24.6	6.4
Maternal age at child birth, years	296	29.9	4.2
Maternal pre-pregnancy BMI, kg/m ²	274	23.6	4.0
Maternal intelligence (correct answers out of 60)	279	45.6	7.7
Breastfeeding duration, months	294	2.1	3.3
Birth weight, kg	296	3.3	0.5
	Total n	Total %	
Gender, % girls	297	44.8	
Overweight at 4 years	236	7.6	
Overweight at 7 years	297	10.4	
Maternal education	266		
High		21.4	
Mid		56.8	
Low		21.8	
Household income	265		
High		34.3	
Mid		49.8	
Low		15.9	
Smoking during pregnancy	269	30.1	
Alcohol use during pregnancy	293	23.2	
Premature birth	296	6.4	

Mental Processing Composite, was 107.2, which lies within 1 standard deviation (SD) of the reference mean. Table 1 shows further descriptive statistics of the study population.

Although the results suggest that cognitive ability at 7 years of age decreased with increasing BMI at 4 years and 7 years of age, this association was not significant in any performed analysis (tables 2 and 3). Univariate analyses indicated that a large range of covariates were associated with cognitive ability, whereas multivariate analyses showed that only a higher maternal intelligence resulted in higher scores on all outcomes of cognitive ability (tables 2 and 3). Using the BMI z-scores (results not shown) and adjusting for the confounding factors did not change these findings.

Discussion

This study found no significant association between BMI and cognitive ability of young children. Although this is in line

with previous performed cross-sectional studies [10, 15, 25], 2 longitudinal studies did find a significant association between elevated BMI (overweight) and cognition in children [23, 26]. This discrepancy might be caused by the fact that these authors did not adjust their analyses for important confounding factors like children's physical fitness and maternal intelligence. In addition, Li [24] reported that severe obesity was associated with declined intelligence quotient (IQ) in children. As the association between BMI and cognitive outcomes might only be apparent at the extreme end of the BMI distribution, it is highly likely to find an association when comparing severely obese children to a normal-weight control population. This may also explain the absence of an association within our study and previous performed studies [10, 15, 25]. The results of our prospective analyses indicated that the time lag between becoming overweight and developing declined cognitive ability is larger than 3 years. Together, the current results imply that the proposed mechanisms explaining a possible association between overweight and cognitive

Table 2. Association between BMI at 4 years of age, covariates, and cognitive ability at 7 years of age

	Cognitive ability (Kaufman ABC)					
	mental processing composite		sequential processing scale		simultaneous processing scale	
	beta	95% CI	beta	95% CI	beta	95% CI
<i>Crude analysis</i>						
BMI at 4 years of age, kg/m ²	-0.37	-1.59; 0.85	-0.52	-1.80; 0.75	-0.12	-1.31; 1.07
Physical fitness (total workload), KJ	0.32 ^b	0.08; 0.56	0.42 ^c	0.16; 0.67	0.20	-0.03; 0.44
Birth weight, g	5.39 ^d	2.41; 8.37	4.89 ^c	1.75; 8.02	4.73 ^c	1.81; 7.66
<i>Adjusted analyses^a</i>						
BMI at 4 years of age, kg/m ²	-0.89	-2.10; 0.32	-1.15	-2.42; 0.13	-0.50	-1.69; 0.69
Maternal intelligence (correct answers out of 60)	<i>0.40^d</i>	<i>0.20; 0.61</i>	<i>0.33^c</i>	<i>0.12; 0.55</i>	<i>0.38^d</i>	<i>0.18; 0.57</i>
Maternal education (low vs. high)	6.19 ^c	2.45; 9.93	5.19 ^b	1.21; 9.16	5.55 ^c	1.93; 9.17
Maternal age at child birth, years	0.56 ^c	0.15; 0.97	0.46 ^b	0.03; 0.90	0.52 ^a	0.11; 0.92
Maternal pre-pregnancy BMI, kg/m ²	-0.62 ^c	-1.03; -0.21	-0.61 ^c	-1.04; -0.17	-0.52 ^c	-0.92; -0.13
Breastfeeding duration, months	0.93 ^d	0.41; 1.45	0.64 ^b	0.09; 1.20	0.93 ^d	0.42; 1.43
Smoking during pregnancy	-4.30 ^b	-7.77; -0.83	-5.10 ^c	-8.73; -1.47	-3.15	-6.55; 0.26
Premature birth	-6.83	-14.34; 0.67	-10.98 ^c	-18.75; -3.21	-2.73	-10.12; 4.67

^aAdjusted for physical fitness of the child and birth weight. *Italic figures indicate significant (p < 0.05) associations within multivariate regression analysis (adjusted for all covariates and confounding factors).*

^bp < 0.05.

^cp < 0.01.

^dp < 0.001.

95% CI = 95% confidence interval.

Table 3. Association between BMI at 7 years of age, covariates, and cognitive ability at 7 years of age

	Cognitive ability (Kaufman ABC)					
	mental processing composite		sequential processing scale		simultaneous processing scale	
	beta	95% CI	beta	95% CI	beta	95% CI
<i>Crude analysis</i>						
BMI at 7 years of age, kg/m ²	-0.19	-1.08; 0.70	-0.54	-1.47; 0.39	0.13	-0.74; 1.00
Physical fitness (total workload), KJ	0.32 ^b	0.08; 0.56	0.42 ^c	0.16; 0.67	0.20	-0.03; 0.44
Maternal education (low vs. high)	12.09 ^d	7.37; 16.82	10.80 ^d	5.69; 15.92	10.73 ^d	6.16; 15.30
Maternal pre-pregnancy BMI, kg/m ²	-0.66 ^c	-1.08; -0.25	-0.66 ^c	-1.11; -0.22	-0.55 ^c	-0.95; -0.14
Smoking during pregnancy	-4.79 ^c	-8.24; -1.35	-6.12 ^d	-9.69; -2.54	-3.20	-6.58; 0.20
Birth weight, g	5.39 ^d	2.41; 8.37	4.89 ^c	1.75; 8.02	4.73 ^c	1.81; 7.66
<i>Adjusted analyses^a</i>						
BMI at 7 years of age, kg/m ²	-0.30	-1.16; 0.57	-0.83	-1.75; 0.09	0.15	-0.69; 1.00
Maternal intelligence (correct answers out of 60)	<i>0.44^d</i>	<i>0.26; 0.62</i>	<i>0.34^d</i>	<i>0.14; 0.53</i>	<i>0.41^d</i>	<i>0.25; 0.59</i>
Maternal age at child birth, years	<i>0.46^b</i>	<i>0.10; 0.81</i>	0.25	-0.14; 0.63	<i>0.49^c</i>	<i>0.15; 0.84</i>
Breastfeeding duration, months	0.51 ^b	0.08; 0.94	0.32	-0.14; 0.78	0.52 ^b	0.11; 0.94
Premature birth	-3.87	-10.60; 2.86	-5.95	-13.10; 1.20	-1.81	-8.36; 4.74

^aAdjusted for physical fitness of the child, maternal education, maternal pre-pregnancy BMI, maternal smoking during pregnancy and birth weight. *Italic figures indicate significant (p < 0.05) associations within multivariate regression analysis (adjusted for all covariates and confounding factors).*

^bp < 0.05.

^cp < 0.01.

^dp < 0.001.

95% CI = 95% confidence interval.

ability are not applicable to young children. This might be due to the time needed for these alterations to take form; after becoming overweight it probably takes several years before serious physiological changes in the brain tissue develop. On the other hand, the small number of obese children in this study population may have contributed to this conclusion. Future longitudinal research with a wide time span is needed to investigate how much time it takes before overweight starts to influence cognitive ability.

Strengths and Limitations

The prospective design of this study is a major strength since this eliminates potential recall bias of the included variables. In contrast to other studies, the current study was able to investigate the association using both cross-sectional and prospective data, and included a large range of possible confounders such as maternal education, intelligence, and physical fitness [15, 24, 25]. Moreover, since children's weight and height were measured by a physician, the BMI estimates were less susceptible for underestimation and thereby more accurate compared to self-reported measures of weight and height [49–51]. Subsequently, additional analyses were performed to confirm the accuracy of the current study outcomes. Within these analyses, underweight children were excluded to eliminate the effect of a possible association between underweight and cognitive ability. This did not change current study outcomes (results not shown).

Some limitations must be noted. The sample size was small, resulting in a small number of obese children. As stated above, this might explain the absence of the association within the current study. However, despite the small sample size other covariates did show significant effects as expected [52, 53], which makes current findings concerning the lack of an association between BMI and cognitive ability plausible. Furthermore, a high number of children ($n = 444$) were lost to follow-up. However, previous research on this cohort states that there is no significant difference between the initial and follow-up cohort with respect to demographic, anthropometric, and maternal variables [28]. This study used the K-ABC

as the sole measure of cognitive ability. The different subscales of this measure are difficult to interpret which lowers the validity of both subscales [54, 55]. However, since the total score for cognitive ability (Mental Processing Composite) was the main outcome of this study, the interpretation of the subscales might be less important. Still, future research should use the K-ABC II when measuring cognition as this test clarified the subscales in greater detail [55]. Finally, US reference data were used to calculate standardized scores of the different scales of the K-ABC. Although these scores were validated within a representative study population of the USA and could therefore cause slight mis-categorization of some children in the current study, we do not think this influenced the study outcomes. A Dutch validation study of these standardization norms showed significant associations between K-ABC scores and maternal education, maternal intelligence, and birth weight, which are all known to relate to children's cognitive ability [28].

Conclusion and Implications for Future Research

This study showed no evidence for an association between BMI and cognitive ability in young children. Although no effect of BMI on cognitive ability was found, a high BMI could affect school performance in young children through increased school absenteeism and psychological factors such as bullying. Future studies need to reveal whether children with a high BMI fall short in school due to other factors than their cognitive ability.

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Disclosure Statement

There were no conflicts of interest to declare.

References

- 1 Lee YS: Consequences of childhood obesity. *Ann Acad Med Singapore* 2009;38:75–7.
- 2 Must A, Strauss RS: Risks and consequences of childhood and adolescent obesity. *Int J Obes Relat Metab Disord* 1999;23(suppl 2):S2–11.
- 3 Wabitsch M: Overweight and obesity in European children: definition and diagnostic procedures, risk factors and consequences for later health outcome. *Eur J Pediatr* 2000;159(suppl 1):S8–13.
- 4 Gortmaker SL, Must A, Perrin JM, Sobol AM, Dietz WH: Social and economic consequences of overweight in adolescence and young adulthood. *N Engl J Med* 1993;329:1008–12.
- 5 Gustafson D, Lissner L, Bengtsson C, Bjorkelund C, Skoog I: A 24-year follow-up of body mass index and cerebral atrophy. *Neurology* 2004;63:1876–81.
- 6 Gustafson DR, Steen B, Skoog I: Body mass index and white matter lesions in elderly women. An 18-year longitudinal study. *Int Psychogeriatr* 2004;16:327–36.
- 7 Chang HJ: Scientists probe brain's role in obesity. *JAMA* 2010;303:19.
- 8 Wang GJ, Volkow ND, Logan J, Pappas NR, Wong CT, Zhu W, Netusil N, Fowler JS: Brain dopamine and obesity. *Lancet* 2001;357:354–7.
- 9 Volkow ND, Wise RA: How can drug addiction help us understand obesity? *Nat Neurosci* 2005;8:555–60.
- 10 Guxens M, Mendez MA, Julvez J, Plana E, Forns J, Basagana X, Torrent M, Sunyer J: Cognitive function and overweight in preschool children. *Am J Epidemiol* 2009;170:438–46.
- 11 Taras H, Potts-Datema W: Sleep and student performance at school. *J Sch Health* 2005;75:248–54.
- 12 Taras H, Potts-Datema W: Chronic health conditions and student performance at school. *J Sch Health* 2005;75:255–66.
- 13 Rhodes SK, Shimoda KC, Waid LR, O'Neil PM, Oexmann MJ, Collop NA, Willi SM: Neurocognitive deficits in morbidly obese children with obstructive sleep apnea. *J Pediatr* 1995;127:741–4.

- 14 Cserjesi R, Molnar D, Luminet O, Lenard L: Is there any relationship between obesity and mental flexibility in children? *Appetite* 2007;49:675–8.
- 15 Halkjaer J, Spitznagel MB, Paul RH, Cohen RA, Kohn M, Luyster FS, Clark R, Williams LM, Gordon E: Body mass index and neuropsychological function in healthy children and adolescents. *Appetite* 2008;50:246–51.
- 16 Halkjaer J, Holst C, Sorensen TI: Intelligence test score and educational level in relation to BMI changes and obesity. *Obes Res* 2003;11:1238–45.
- 17 Huang TT, Goran MI, Spruijt-Metz D: Associations of adiposity with measured and self-reported academic performance in early adolescence. *Obes Res* 2006;14:1839–45.
- 18 Li Y, Dai Q, Jackson JC, Zhang J: Overweight is associated with decreased cognitive functioning among school-age children and adolescents. *Obesity* (Silver Spring) 2008;16:1809–15.
- 19 Sorensen TI, Sonne-Holm S, Christensen U, Kreiner S: Reduced intellectual performance in extreme overweight. *Hum Biol* 1982;54:765–75.
- 20 Ogden CL, Carroll MD, Curtin LR, Lamb MM, Flegal KM: Prevalence of high body mass index in US children and adolescents, 2007–2008. *JAMA* 2010;303:242–9.
- 21 Popkin BM: Recent dynamics suggest selected countries catching up to US obesity. *Am J Clin Nutr* 2010;91:284S–288S.
- 22 Azurmendi A, Braza F, Sorozabal A, Garcia A, Braza P, Carreras MR, Munoz JM, Cardas J, Sanchez-Martin JR: Cognitive abilities, androgen levels, and body mass index in 5-year-old children. *Horm Behav* 2005;48:187–95.
- 23 Heinonen K, Raikonen K, Pesonen AK, Kajantie E, Andersson S, Eriksson JG, Niemela A, Varti T, Peltola J, Lano A: Prenatal and postnatal growth and cognitive abilities at 56 months of age: a longitudinal study of infants born at term. *Pediatrics* 2008;121: e1325–33.
- 24 Li X: A study of intelligence and personality in children with simple obesity. *Int J Obes Relat Metab Disord* 1995;19:355–7.
- 25 Mond JM, Stich H, Hay PJ, Kraemer A, Baune BT: Associations between obesity and developmental functioning in pre-school children: a population-based study. *Int J Obes (Lond)* 2007;31:1068–73.
- 26 Silva A, Metha Z, O'Callaghan JF: The relative effect of size at birth, postnatal growth and social factors on cognitive function in late childhood. *Ann Epidemiol* 2006;16:469–76.
- 27 Al MD, van Houwelingen AC, Badart-Smook A, Hasaart TH, Roumen FJ, Hornstra G: The essential fatty acid status of mother and child in pregnancy-induced hypertension: a prospective longitudinal study. *Am J Obstet Gynecol* 1995;172:1605–14.
- 28 Bakker EC, Ghys AJA, Kester ADM, Vles JSH, Cubas JS, Blanco CE, Hornstra G: Long-chain polyunsaturated fatty acids at birth and cognitive function at 7 years of age. *Eur J Clin Nutr* 2003;57:89–95.
- 29 Kaufman AS, Kaufman NL: Kaufman Assessment Battery for Children. Circle Pines, MN, American Guidance Service, 1983.
- 30 Rump P, Verstappen F, Gerver WJ, Hornstra G: Body composition and cardiorespiratory fitness indicators in prepubescent boys and girls. *Int J Sports Med* 2002;23:50–4.
- 31 Cole TJ, Bellizzi MC, Flegal KM, Dietz WH: Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* 2000;320:1240–3.
- 32 Rodrigues MC, Mello RR, Fonseca SC: Learning difficulties in schoolchildren born with very low birth weight. *J Pediatr (Rio J)* 2006;82:6–14.
- 33 Huijbregts SCJ, Se'guin JR, Zelazo PD, Parent S, Japel C, Tremblay RE: Interrelations between maternal smoking during pregnancy, birth weight and sociodemographic factors in the prediction of early cognitive abilities. *Infant Child Dev* 2006;15:593–607.
- 34 Taras H: Physical activity and student performance at school. *J Sch Health* 2005;75:214–8.
- 35 Hillman CH, Erickson KI, Kramer AF: Be smart, exercise your heart: exercise effects on brain and cognition. *Nat Rev Neurosci* 2008;9:58–65.
- 36 Yamaji K: Measurement of maximum oxygen uptake – indirect method; in Yamaji K (ed): *Science of Maximum Oxygen Uptake*. Tokyo, Kyoinsinshoin Co., 1994.
- 37 Brion MJ, Zeegers M, Jaddoe V, Verhulst F, Tie-meier H, Lawlor DA, Smith GD: Intrauterine effects of maternal prepregnancy overweight on child cognition and behavior in 2 cohorts. *Pediatrics* 2011;127:e202–11.
- 38 Larsson M, Montgomery SM: Maternal smoking during pregnancy and physical control and coordination among offspring. *J Epidemiol Community Health* 2010; doi: 10.1136/jech.2008.085241.
- 39 Julvez J, Ribas-Fito N, Torrent M, Forns M, Garcia-Esteban R, Sunyer J: Maternal smoking habits and cognitive development of children at age 4 years in a population-based birth cohort. *Int J Epidemiol* 2007;36:825–32.
- 40 (No authors listed): Prenatal exposure to alcohol. *Alcohol Res Health* 2000;24:32–41.
- 41 Milligan DW: Outcomes of children born very pre-term in Europe. *Arch Dis Child Fetal Neonatal Ed* 2010;95:F234–40.
- 42 Fergusson DM, Woodward LJ: Maternal age and educational and psychosocial outcomes in early adulthood. *J Child Psychol Psychiatry* 1999;40:479–89.
- 43 Kramer MS, Aboud F, Mironova E, Vanilovich I, Platt RW, Matush L, Igumnov S, Fombonne E, Bogdanovich N, Ducruet T, Collet JP, Chalmers B, Hodnett E, Davidovsky S, Skugarevsky O, Trofimovich O, Kozlova L, Shapiro S: Breastfeeding and child cognitive development: new evidence from a large randomized trial. *Arch Gen Psychiatry* 2008;65:578–84.
- 44 Jain A, Concato J, Leventhal JM: How good is the evidence linking breastfeeding and intelligence? *Pediatrics* 2002;109:1044–53.
- 45 Tong S, Baghurst P, Vimpani G, McMichael A: Socioeconomic position, maternal IQ, home environment, and cognitive development. *J Pediatr* 2007; 151:284–8, 288 e1.
- 46 Herngreen WP, Reerink JD, van Noord-Zaadstra BM, Verloove-Vanhorick SP, Ruys JP: Connections between socio-economic status and differences in care during pregnancy, delivery and lying-in period (in Dutch). *Ned Tijdschr Geneesk* 1993; 137:1007–1012.
- 47 Raven J, Court J, Raven J: *Standard Progressive Matrices*. Oxford, Oxford Psychologists Press, 1996.
- 48 Fredriks AM, van Buuren S, Burgmeijer RJ, Meulmeester JF, Beuker RJ, Brugman E, Roede MJ, Verloove-Vanhorick SP, Wit JM: Continuing positive secular growth change in The Netherlands 1955–1997. *Pediatr Res* 2000;47:316–23.
- 49 Scholtens S, Brunekreef B, Visscher TL, Smit HA, Kerkhof M, de Jongste JC, Gerritsen J, Wijga AH: Reported versus measured body weight and height of 4-year-old children and the prevalence of overweight. *Eur J Public Health* 2007;17:369–74.
- 50 Tokmakidis SP, Christodoulos AD, Mantzouranis NI: Validity of self-reported anthropometric values used to assess body mass index and estimate obesity in Greek school children. *J Adolesc Health* 2007;40:305–10.
- 51 Huybrechts I, de Bacquer D, van Trimont I, de Backer G, de Henauw S: Validity of parentally reported weight and height for preschool-aged children in Belgium and its impact on classification into body mass index categories. *Pediatrics* 2006;118: 2109–18.
- 52 Drane DL, Logemann JA: A critical evaluation of the evidence on the association between type of infant feeding and cognitive development. *Paediatr Perinat Epidemiol* 2000;14:349–56.
- 53 Silva A, Mehta Z, O'Callaghan FJ: Duration of breast feeding and cognitive function: population based cohort study. *Eur J Epidemiol* 2006;21:435–41.
- 54 Kline RB, Snyder J, Castellanos M: Lessons from the Kaufman Assessment Battery for Children (K-ABC): toward a new cognitive assessment model. *Psychol Assessment* 1996;8:7–17.
- 55 Reynolds MR, Keith TZ, Fine JG, Fisher ME, Low JA: Confirmatory factor structure of the Kaufman Assessment Battery for Children – second edition: consistency with Cattell-Horn-Carroll theory. *Sch Psychol Quarterly* 2007;22:511–539.