

## Other Reviews

# Intelligence in relation to obesity: a systematic review and meta-analysis

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*Received 15 May 2009; revised 5 August 2009; accepted 6 August 2009*

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## Summary

We performed a systematic review describing obesity/intelligent quotient (IQ) association, particularly childhood IQ in relation to adulthood obesity. After screening 883 citations from five electronic databases, we included 26 studies, most of medium quality. The weighted mean difference (WMD) of the full IQ (FIQ)/obesity association in the pre-school children was  $-15.1$  ( $P > 0.05$ ). Compared with controls, the WMD of FIQ and performance IQ of obese children were  $-2.8$  and  $-10.0$ , respectively ( $P < 0.05$ ), and the WMD of verbal IQ was  $-7.01$  ( $P > 0.05$ ). With increasing obesity, the FIQ in pre-school children declined, with a significant difference for severely obese children and FIQ. In pubertal children, a slightly different effect of FIQ and obesity emerged. Two studies reported an inverse FIQ/obesity association in adults, but it was non-significant after adjusting for educational attainment. Four papers found that childhood FIQ was inversely associated with adult body mass index, but after adjusting for education, became null. Overall there was an inverse FIQ/obesity association, except in pre-school children. However, after adjusting for educational attainment, FIQ/obesity association was not significantly different. A lower FIQ in childhood was associated with obesity in later adulthood perhaps with educational level mediating the persistence of obesity in later life.

**Keywords:** Intelligence quotient, meta-analysis, obesity, systematic review.

**obesity reviews** (2009)

## Introduction

Obesity is a serious public health problem that currently affects a large part of the world population, including many developing nations. In China, the prevalence of obesity is 7.2% in 2006, which is 3.6 times higher than that in 1996 (1). Of concern, these prevalence estimates are higher in developed nations. In Europe, the prevalence of obesity in men range from 4.0% to 28.3% and in women from 6.2% to 36.5% (2).

Obesity has been associated with many adult diseases, such as hypertension (3), coronary heart disease and stroke (4,5), and diabetes mellitus (6). In addition, obesity has also been associated with poor cognitive function and decreases in brain volume (7,8) and is related to some diseases that

manifest a progressive decline in cognitive function, such as dementia and Alzheimer's disease (9,10). These findings suggest that such brain volume decreases in the obese population could possibly cause reduced intelligence quotients (IQ). Whether obesity causes reduced IQ requires further study, but some believe that IQ could be used as a predictor of obesity. Findings from a series of case-control studies indicate that childhood IQ is inversely associated with childhood obesity (11,12). Some studies have explored the relationship of childhood IQ with adult obesity (13,14), although there is still no consensus regarding their association. While various studies indicate a decreased IQ with higher body mass index (BMI) compared with those in the normal range (15,16), this decrease in risk varies widely across publications, and the effect of childhood IQ on later

adult obesity is less clear. The aim of this article was to assess and quantify published evidence on the mutual relationship between obesity and IQ, and investigate whether childhood intelligence score affects later adult obesity.

## Methods

This systematic review followed the Cochrane methodology and the recommendations for reporting proposed by the Meta-analysis of Observational Studies in Epidemiology (MOOSE) group (17).

### Selection criteria for studies

#### *Types of studies*

Observational studies (cohort, case-control and cross-sectional) that report on the association between IQ and obesity were considered for inclusion in this systematic review.

#### *Participants*

Subjects referred to studies for obesity were eligible for inclusion. We accepted participants of any parity, education, socioeconomic status, race or ethnic group fulfilling the previous criteria. Subjects with congenital abnormalities associated with mental retardation were excluded.

#### *Types of exposures and outcomes*

The BMI is calculated by dividing the body weight (kg) by the square of height ( $m^2$ ). The body-weight categories evaluated in this review include the normal weight and obese state. The National Center for Health Care Statistics and the Centers for Disease Control have published BMI reference standards for children and adolescents, and obesity was defined as a BMI of  $\geq 95$ th percentile (18). For adults, the World Health Organization defined obesity as having a BMI  $> 30.0 \text{ kg m}^{-2}$  (19). For children and adolescents, the studies that classify obesity by deviation from ideal weight were also included and calculated by using the ratio of weight (W) to ideal weight (IW), and obesity was defined as  $W/IW > 1.2$  (22). Obesity is divided into three subcategories by W/IW, namely mild obesity ( $W/IW = 1.2-1.3$ ), moderate obesity ( $W/IW = 1.3-1.5$ ) and severe obesity ( $W/IW > 1.5$ ) (20). In this review, we included studies that defined the categories of body weight according to the BMI and W/IW criteria (21). The standardized intelligence (or equivalent) tests were used to measure IQ, and test results were provided by the authors.

### Search strategy for identification of studies

The search strategy used the following terms, adapted for each database searched: 'overweight' or 'obesity' or 'body

mass index' or 'BMI' or 'weight gain' or 'obesity related diseases' and 'intelligence' or 'intelligent quotient' or 'IQ' or 'cognitive ability' or 'neuropsychology'. (Appendix S1). Five electronic bibliographic databases, China Journal Full Text Database of the China National Knowledge Infrastructure (CNKI), Wanfang DATA databases, MEDLINE, EMBASE, CINAHL, were searched systematically from January 1970 to January 2009. There were no language or country restrictions. Searching of grey literature and hand searching was not done. When data in the original publication did not contain sufficient details, the authors were contacted for additional information.

### Screening and data-extraction form

All citations identified by electronic databases were organized, duplicates deleted, and each citation was assigned a unique identification number. Initially, two investigators (Z. B. Yu and X. G. Cao) independently screened the results of the electronic searches to select potentially relevant citations based on title and abstracts. Discrepancies were resolved through consensus. When the citation was relevant or when the title/abstract was not sufficient for deciding on inclusion/exclusion, the full texts were retrieved and evaluated. All articles selected at first screening were read and abstracted independently by the two reviewers (Z. B. Yu and X. G. Cao). Differences between the two reviewers were resolved by consensus or referred to a third reviewer (S. P. Han) if necessary. Information extracted from each article included: (i) general characteristics of the study, such as design, population, setting, source of data and (ii) information on BMI and IQ assessment.

### Quality assessment of the studies

To assess the quality of included studies, we created a specific checklist (Appendix S2), based on the criteria proposed by the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (22) and Tooth *et al.* (23) for the assessment of observational studies. Briefly, we assessed the quality of all included studies in accordance with the following items: type of study, loss of follow-up, sample size, participant selection, comparability of groups, statistical method, diagnostic criteria for obesity and measurement of IQ. According to the score achieved (from 0 to 18), studies were classified as high ( $>14$ ), medium (11–14) or low ( $<11$ ) quality.

### Statistical analysis

The Review Manager 4.2.2 program was used for the analysis of the data from the selected studies. If results from

the studies could be quantitatively combined, a statistical meta-analysis of the data was undertaken to determine the typical effect size of the IQ and obesity. A weighted mean difference (WMD) was calculated for continuous data or a summary odds ratio (OR) for dichotomous data. The chi-squared test was used to test for heterogeneity across the studies. The significance value was set at 0.05. A random effects model was used to handle possible heterogeneity between studies, as such a model defaults to the fixed effects model approach if there was no heterogeneity (24). Heterogeneity was assessed by the  $I^2$  statistic and publication bias by use of a funnel plot and the Begg's test, and the statistical analyses were conducted using Stata v.10 (College Station, TX, USA). In case of significant heterogeneity, attempts were made to explain this by stratification according to specific subgroups examined.

## Results

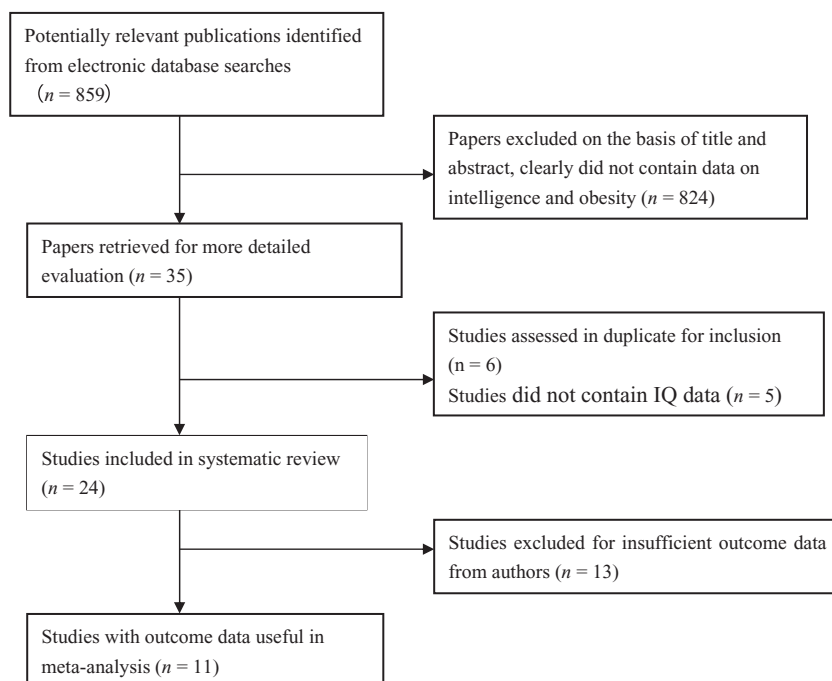
### Included studies

A search of the five electronic databases identified 883 papers, of which 843 were excluded as ineligible based on the title or abstract content. Figure 1 shows the flow chart for the systematic review. Studies were excluded from the review for a variety of reasons: based on the same study sample (13,25–28) that only be used as a study; did not contain IQ data (29–32) ( $n = 4$ ); were assessed in duplicate

for inclusion (33–38) ( $n = 6$ ). Twenty-six articles were included in the systematic review (11–16,39–58). The descriptive information of each included study is presented in Table 1. There were 11 case-control and 15 cohort studies. Most of the studies (61.5%) were of medium quality (Appendix S3). A total of eight studies were from developed and 18 from developing countries, 17 (65.4%) of which were from China. A total of 17 studies reported diagnostic criterion for obesity according to the W/IW, and nine studies defined obesity using the BMI. Some of the studies (34.6%) used the Wechsler Intelligence Scale for Children as the measurement of IQ and 65.4% offered other measurement methods (Table 1). Because we were unable to obtain sufficient data on IQ from these papers (13,14,46–58) ( $n = 15$ ), 11 studies were included in the meta-analysis (11,12,15,16,41–45). Tables S1–S3 show the fact IQ data from these studies in the children and adolescents; among them were six studies that did not offer clear means and standard deviations (SD) of IQ and therefore which could not be pooled by meta-analysis and systematically reviewed (46–51).

### The intelligence score and obesity in pre-school children

Three papers (39,40,49) evaluated IQ/obesity association in pre-school children. Li *et al.* (49) reported the intelligence score that included full IQ (FIQ), verbal IQ (VIQ)



**Figure 1** Flow chart of article screening and selection process.

**Table 1** Characteristics of 26 observational studies examining the relationship between IQ and obesity

Paper	Setting	Enrolment dates/recruitment procedure	Baseline age, sex	Control group (n)	Obesity group (n)	Diagnostic criteria for obesity	Measurement of IQ	Outcome
The intelligence score and obesity in the pre-school children								
Wang (1992) (39)	China	September 1990 Case-control study Children enrolled in two kindergartens of Suzhou City in Jiangsu Province n = 710	3–7 years of age, Both	19	19	W/IW	PPVT	FIQ
Li <i>et al.</i> (1998) (49)	China	Enrolment dates not stated Case-control study Children enrolled in three kindergartens of Guiyang City in Guizhou Province n = 1 360	3–7 years of age, Both	40 boys and 25 girls	40 boys and 25 girls (40 mild obesity, 21 moderate obesity, four severe obesity)	W/IW	WPPSI	FIQ, VIQ, PIQ
Lin (2001) (40)	China	Enrolment dates not stated Case-control study Children enrolled in five kindergartens of Hangzhou City in Zhejiang Province n = 811	4–6 years of age, Enrolment sex not stated	128	128	W/IW	MSCA	FIQ
The intelligence score and obesity in the school-age children								
Qian <i>et al.</i> (1994) (11)	China	Enrolment dates not stated Case-control study Children enrolled in a primary school of Tianjin City Enrolment number of students not stated	7–13 years of age, Both	114	73 boys and 41 girls (57 mild obesity, 35 moderate obesity, 22 severe obesity)	BMI	CRT	FIQ
Xiao (1995) (46)	China	Enrolment dates not stated Case-control study Children enrolled in 18 primary schools of Nanjing City in Jiangsu Province Enrolment number of students not stated	6–13 years of age, Both	65 boys and 37 girls	65 boys and 37 girls (six mild obesity, 65 moderate obesity, 31 severe obesity)	W/IW	WISC	FIQ, VIQ, PIQ
Lv <i>et al.</i> (1996) (47)	China	Enrolment dates not stated Case-control study Children enrolled in six primary schools of Changchun City in Jilin Province and Tongliao City in Inner Mongolia Autonomous Region Enrolment number of students not stated	7–12 years of age, Both	200	112 boys and 86 girls (88 mild obesity, 91 moderate obesity, 16 severe obesity)	W/IW	WISC	FIQ
Zhang and Li (1996) (12)	China	Enrolment dates not stated Case-control study Children enrolled in eight primary or high schools of Jinan City in Shandong Province n = 6 224	7–15 years of age, Both	150	82 boys and 68 girls	W/IW	WISC	FIQ, VIQ, PIQ
Jiang and Li (1997) (15)	China	Enrolment dates not stated Case-control study Children enrolled in six primary schools of Haiyang City in Shandong Province Enrolment number of students not stated	8–11 years of age, Enrolment sex not stated	50	50	W/IW	WISC	FIQ, VIQ, PIQ
Wang (1997) (48)	China	March 1996 Case-control study Children enrolled in primary schools of Nanning City in Guangxi Province n = 2 232	10–12 years of age, Both	32 boys and 18 girls	32 boys and 18 girls	W/IW	CRT	FIQ

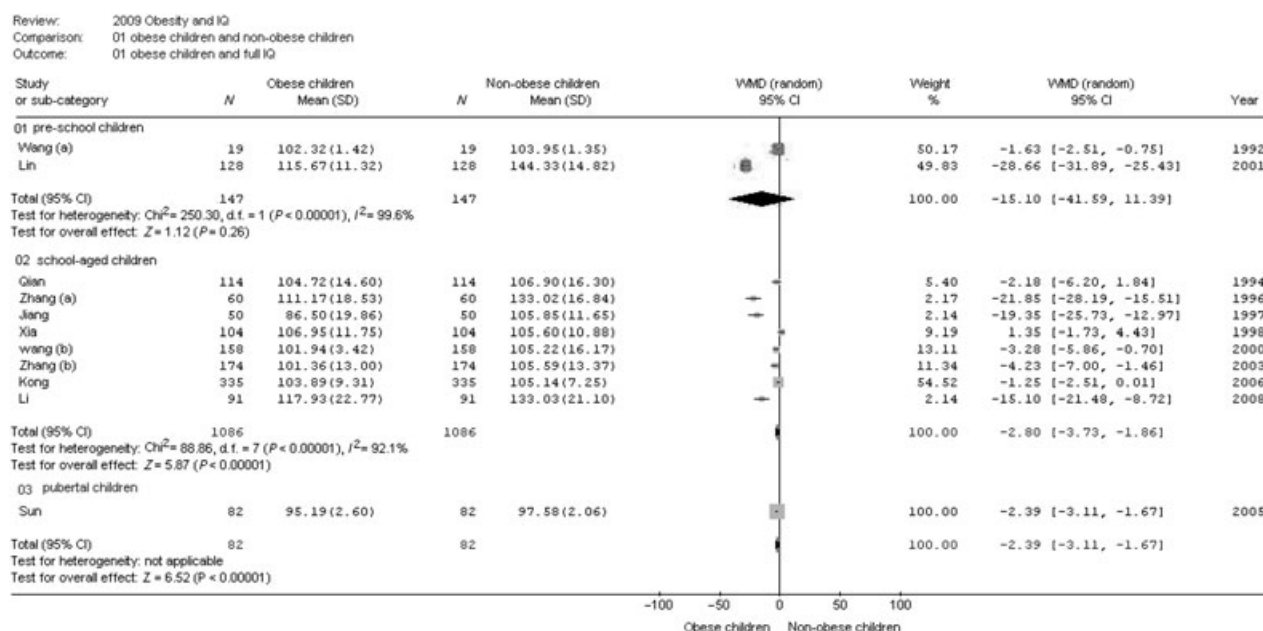
Table 1 Continued

Paper	Setting	Enrolment dates/recruitment procedure	Baseline age, sex	Control group (n)	Obesity group (n)	Diagnostic criteria for obesity	Measurement of IQ	Outcome
Xia <i>et al.</i> (1998) (16)	China	Enrolment dates not stated Case-control study Children enrolled in two primary schools of Shanghai City Enrolment number of students not stated	10–12 years of age, Both	104	73 boys and 31 girls	W/IW	CRT	FIQ
Guo <i>et al.</i> (1999) (50)	China	March to April 1998 Case-control study Children enrolled in six primary schools of Yinchuan City in Ningxia Hui Autonomous Region Enrolment number of students not stated	7–12 years of age, Both	100	100 (nine mild obesity, 59 moderate obesity, 32 severe obesity)	W/IW	WISC	FIQ, VIQ, PIQ
Wang and Wang (2000) (41)	China	Enrolment dates not stated Case-control study Children enrolled in six primary schools of Changchun City in Jilin Province Enrolment number of students not stated	7–12 years of age, Both	158	92 boys and 66 girls (86 mild obesity, 60 moderate obesity, 12 severe obesity)	W/IW	WISC	FIQ
Dong <i>et al.</i> (2002) (51)	China	Enrolment dates not stated Case-control study Children enrolled in primary schools of Luoyang City in Henan Province n = 800	7–13 years of age, Both	68 boys and 32 girls	68 boys and 32 girls (57 mild obesity, 32 moderate obesity, 11 severe obesity)	W/IW	CRT	FIQ
Zhang <i>et al.</i> (2003) (42)	China	Enrolment dates not stated Case-control study Children enrolled in five primary or high schools of Weifang and Dongying City in Jilin Province Enrolment number of students not stated	9–14 years of age, Both	174	114 boys and 60 girls	W/IW	CRT	FIQ
Kong (2006) (43)	China	March to June 2003 Case-control study Children enrolled in primary schools of Qufu City in Shandong Province n = 7 120	6–11 years of age, Both	187 boys and 148 girls	187 boys and 148 girls (169 mild obesity, 153 moderate obesity, 51 severe obesity)	W/IW	WISC	FIQ, VIQ, PIQ
Li <i>et al.</i> (2008) (44)	China	Enrolment dates not stated Case-control study Children enrolled in the third primary school of Baotou City in Inner Mongolia Autonomous Region Enrolment number of students not stated	7–12 years of age, Both	58 boys and 33 girls	58 boys and 33 girls (40 mild obesity, 41 moderate obesity, 10 severe obesity)	W/IW	WISC	FIQ, VIQ, PIQ
The intelligence score and obesity in the pubertal children								
Sun and Tao (2005) (45)	China	Enrolment dates not stated Case-control study Children enrolled in High schools of Hefei City in Anhui Province n = 120	12–18 years of age, Both	82	62 boys and 20 girls	W/IW	WISC	FIQ
The intelligence score and obesity in the adulthood								
Kreze <i>et al.</i> (1974) (52)	Czechoslovakia	Enrolment dates not stated cohort study Employees of various plant in the town of Liptovský Mikuláš	18–58 years of age, Both	334 men and 220 women		W/IW	AR-B Intelligence test	FIQ
Sorensen <i>et al.</i> (1982) (28)	Denmark	During the period 1956–1977 and 1964–1977 Danish Military Draft Study n = 311 689	at 18 years, men	1 806	2719	BMI	Børge Priens Prøve	FIQ (MedianObesity/MedianControl)

Table 1 Continued

Paper	Setting	Enrolment dates/recruitment procedure	Baseline age, sex	Control group (n)	Obesity group (n)	Diagnostic criteria for obesity	Measurement of IQ	Outcome
Teasdale <i>et al.</i> (1992) (53)	Denmark	Danish Military Draft Study During the period 1947–1958 Enrolment number of students not stated	at 18 years, men	26 274		BMI	Børge Priens Prøve	Standardized regression coefficient
Childhood intelligence score and later adult obesity								
Hart <i>et al.</i> (2004) (14)	UK	In the 1932 and followed up in the 1970s The Scottish Mental Survey <i>n</i> = 87 498	At 11 years and followed up at 36 years, Both	937		BMI	The Moray House test	Correlation coefficient
Lawlor <i>et al.</i> (2006) (54)	UK	Between 1950 and 1956 and follow-up survey in 2001 Cohort study in Aberdeen, Scotland <i>n</i> = 5 467	At 7 years and followed up at 48 years, Both	643 sibling pairs		BMI	Moray House Picture Intelligence test numbers 1 or 2	Mean difference (95%CI) in adult BMI ( $\text{kg m}^{-2}$ ) per one SD childhood intelligence
Chandola <i>et al.</i> (2006) (55)	UK	In the late 1950s and follow-up at 42 years of age. Cohort study in Great Britain National Child Development (1958) Study <i>n</i> = 17 414	At 11 years and followed up at 42 years, Both	17 414 at 11 years and 10 979 followed up at 42 years		BMI	A general ability test	OR (per SD decrease in IQ score)
Batty <i>et al.</i> (2007a) (56)	UK	The 1970 British Cohort Study The Data from 1980–1981 when study participants completed cognitive ability tests at the age of 10 years, followed up from 1999–2000 when, aged 30 years <i>n</i> = 17 198	At 10 years and followed up at 30 years, Both	3 948 men and 4 223 women at the age of 10 years; 7 861 followed up at 30 years		BMI	The Human Figure Drawing Test, a Copying Designs Test, the English Picture Vocabulary Test and the Profile Test	OR (95% confidence intervals) for the relation of a one SD increase in mental ability score
Batty <i>et al.</i> (2007b) (57)	UK	The Aberdeen Children of the 1950s Data from a school-based survey beginning in 1962 Followed up between 2000 and 2003 <i>n</i> = 12 150	At 11 years of age; followed up between approximately 44 and 52 years	12 015 took part in a school-based survey 7 183 followed up between approximately 44 and 52 years		BMI	Two tests of verbal reasoning (the Moray House verbal reasoning tests I and II)	OR (95% CIs) per one SD advantage in childhood IQ
Intelligence score in early adulthood and later adult obesity								
Halkjaer <i>et al.</i> (2003) (13) [based on the same study sample (so-called case-cohort sampling design) with the study of Sorensen <i>et al.</i> (1982) (28)]	Denmark	During the period 1956–1977 and 1982–1984 Danish Military Draft Study <i>n</i> = 362 200	At 18 years during the period 1956–1977 and followed up during the period 1982–1984, men	907 at 18 years, 883 followed up during the period 1982–1984		BMI	Børge Priens Prøve	Regression coefficient
Batty <i>et al.</i> (2008) (58)	UK	The Vietnam Experience Study, Data from entry to the service in early adulthood A telephone interview in 20 years later from 1985–1986; <i>n</i> = 18 313	At 20.4 years (range 16–30), followed up at mean age 38.3 years (range 31–46), men	4 411 at mean age 20.4 years, 4 157 followed up at mean age 38.3 years		BMI	The Army General Technical Test	OR (per SD increase in IQ score)

BMI, body mass index; CRT, Combined Ravens Test; FIQ, Full IQ; IQ, Intelligence Quotient; MSCA, McCarthy Scales of Children's Abilities; OR, odds ratio; PIQ, Performance IQ; PPVT, Peabody Picture Vocabulary Test; SD, standard deviation; VIQ, Verbal IQ; WISC, Wechsler Intelligence Scale for Children; W/IW, The ratio of weight (W) to ideal weight (IW); WPPSI, Wechsler Preschool and Primary Scale of Intelligence.



**Figure 2** Forest plot of the association between obese children or adolescents and FIQ.

and performance IQ (PIQ). No statistically significant effects emerged. However, as the obesity grades increased, the FIQ declined, and there was a significant difference between severely obese children and FIQ ( $P < 0.05$ ). The outcome between the FIQ and obesity in the pre-school children from both studies by Wang *et al.* and Lin *et al.* was pooled and showed a non-statistically significant difference between obese children and control children: WMD -15.1 (95% CI: -41.59, 11.39),  $P = 0.26$  ( $n = 147$ ) (39,40) (Fig. 2).

### The intelligence score and obesity in school-age children

Thirteen papers (11,12,15,16,41–44,46–48,50,51) evaluated IQ/obesity association in the school-age children. Five trials reported the outcomes using mean difference of IQ and could not be pooled by meta-analysis (46–48,50,51). These results of these studies were non-conforming. Xiao and Guo *et al.* (46,50) reported the intelligence score that included FIQ, VIQ and PIQ. Statistically significant effects on obesity emerged with FIQ and PIQ scores, but no such association was found with the VIQ. However, the report by Lv *et al.* showed no association between the FIQ and obesity in the school-age children (47).

With the increase in obesity grades, Guo *et al.* reported that the FIQ declined (50) with a significant difference between moderately and severely obese children and FIQ ( $P < 0.05$ ). However, Xiao showed that the association

between obese grades and full-scale intelligence scores were inconsistent (46).

The outcomes between the FIQ and obesity in the school-age children from eight trials were pooled and showed a statistically significant difference between obese children and control children: WMD -2.8 (95% CI: -3.73, -1.86),  $P < 0.01$  ( $n = 1086$ ) (11,12,15,16,41–44) (Fig. 2).

The outcomes between the VIQ and obesity in the school-age children from four trials were pooled and showed a non-statistically significant difference of PIQ between obese children and control children: WMD -7.01 (95% CI: -14.27, 0.25),  $P = 0.06$  ( $n = 536$ ) (12,15,43,44) (Fig. 3).

The outcomes between the PIQ and obesity in the school-age children from four trials were pooled and showed a slight difference between obese children and control children: WMD -10.0 (95% CI: -19.74, -0.26),  $P = 0.04$  ( $n = 536$ ) (12,15,43,44) (Fig. 4).

Zhang *et al.* evaluated the association between IQ and obese children categorized by different sexes, but no statistically significant effects emerged: WMD 2.10 (95% CI: -1.87, 6.07),  $P = 0.30$  ( $n = 174$ ) (42) (Figs 5 and 6). With the increase in obese grades, the FIQ declined, and there was a significant difference between severely obese children and FIQ: WMD -4.28 (95% CI: -7.25, -1.30) ( $P < 0.05$ ). Meanwhile, the FIQ between mildly and moderately obese children showed a non-statistically significant difference (WMD -0.88, 95% CI -2.30, 0.53 and WMD -1.11, 95% CI -2.99, 0.77 respectively) (13,42,43) (Fig. 7).



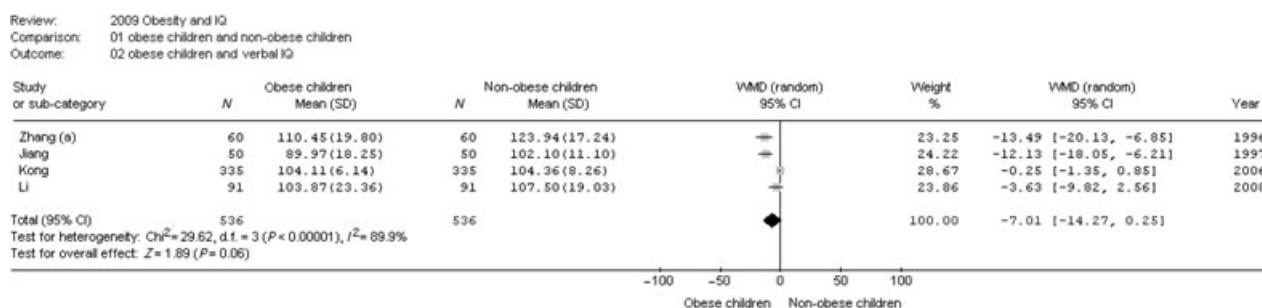


Figure 3 Forest plot of the association between obese children and VIQ.

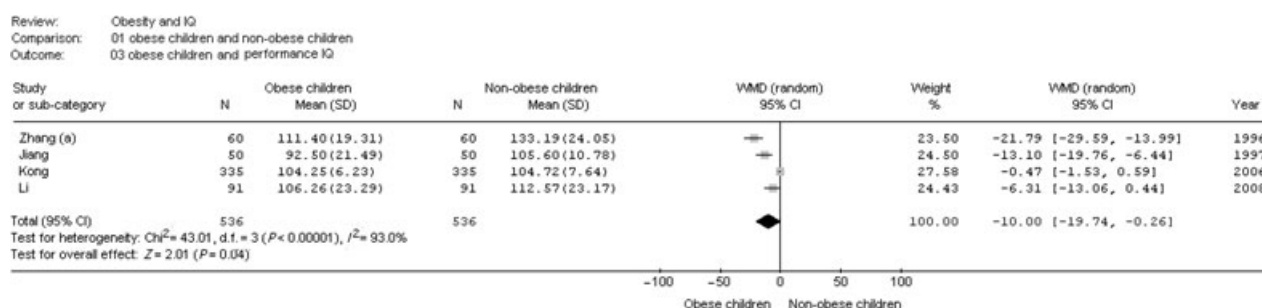


Figure 4 Forest plot of the association between obese children and PIQ.

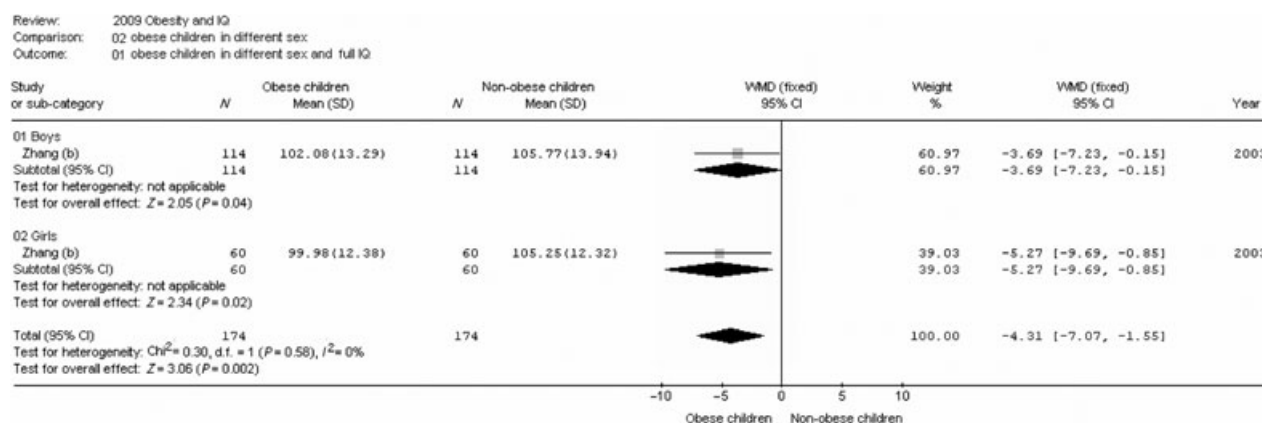


Figure 5 Forest plot of the association between obese children in different sex and FIQ.

### The intelligence score and obesity in pubertal children

Sun and Tao (45), in a case-control study, reported the association between IQ and obesity in the pubertal children and showed a slightly difference between obese and control children: WMD -2.39 (95% CI: -3.11, -1.67),  $P < 0.05$  ( $n = 82$ ) (Fig. 2).

### The intelligence score and obesity in adulthood

Kreze *et al.* administered an AR-B intelligence test to 220 women and 334 men and reported increased OR of low

IQ in both obese women and men (OR 3.53, 95% CI 1.81, 6.87 and OR 1.07, 95% CI 0.47, 2.45, respectively) (52).

Sorensen *et al.* performed a Danish Military Draft Study with 1806 obese adult men and 2719 non-obese controls and found that obesity is strongly associated with reduced intellectual performance (28). The test scores in the obese adult men were significantly lower than those in the control group, where 67% of the obese scored less than the median score of the controls. However, after adjusting for educational attainment, this association between the intelligence score and obesity was not significantly different (Standardized regression



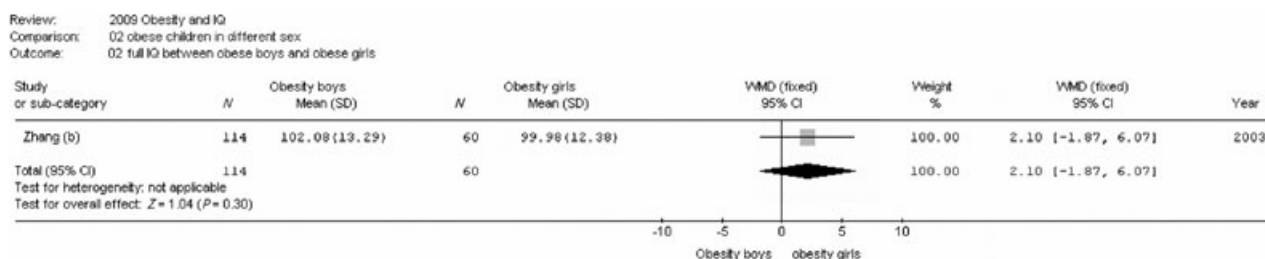


Figure 6 Forest plot of FIQ between obese boys and obese girls.

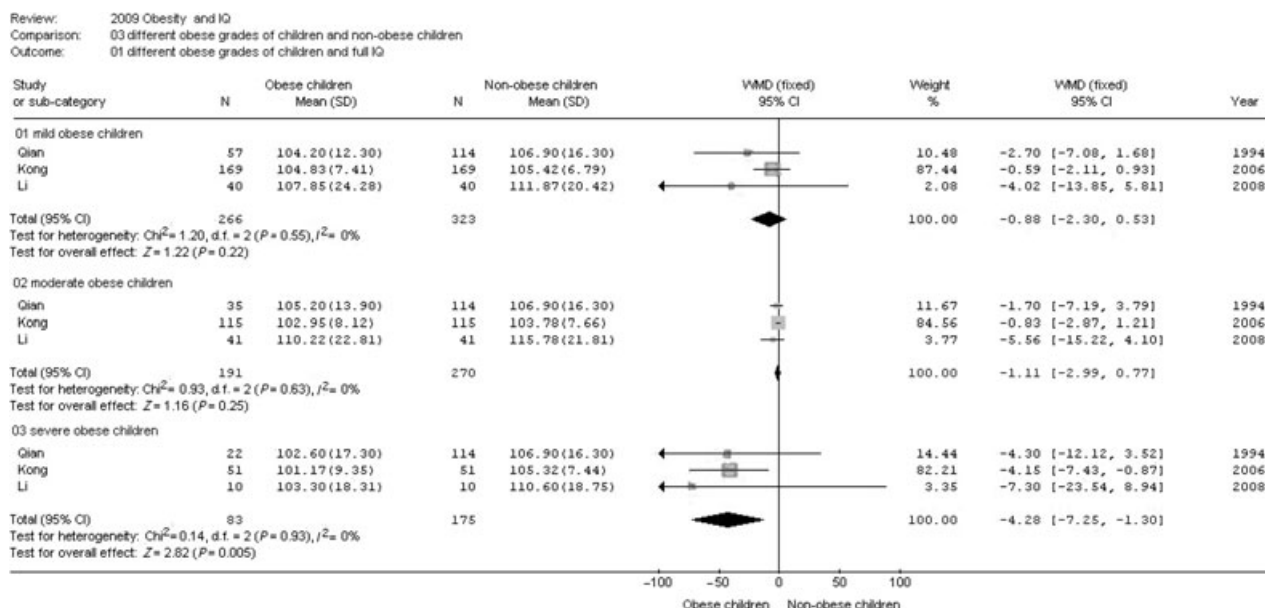


Figure 7 Forest plot of the association between different obese grades of children and FIQ.

coefficient:  $-0.096$ ). The study by Teasdale *et al.* is particularly important that it shows that there is an inverse J shaped relationship between IQ, education and degree of obesity (assessed by BMI), with a maximum of IQ and education below the median BMI, but then with lower IQ and education for BMI is lower than that maximum (53). For BMI is above the maximum, there is a steady linear decline in IQ and educational level the greater the BMI all the way up to the largest ones in this sample.

### Childhood intelligence score and later adult obesity

Five reports (14,54–57) evaluated the association between childhood intelligence score and later adult obesity. Lawlor *et al.* reported a prospective study in a birth cohort of 5467 individuals who were born in Aberdeen, Scotland between 1950 and 1956, and conducted a follow-up survey in 2001(54). Comparisons were performed of associations within sibling pairs of the same family to associations between different families in 643 sibling pairs (1286

individuals) who are participants in the main cohort. The study reported that childhood intelligence (age 7 years) was inversely associated with adult BMI (mean age 48 years): the sex- and age-adjusted mean change in adult BMI per SD of intelligence was  $-0.35 \text{ kg m}^{-2}$  (95% CI:  $-0.49$ ,  $-0.21 \text{ kg m}^{-2}$ ). On adjustment for education the association between childhood intelligence and adult BMI became null ( $-0.03 \text{ kg m}^{-2}$  [ $-0.19$ ,  $0.13 \text{ kg m}^{-2}$ ]).

Chandola *et al.* analysed data from the National Child Development Study (1958), a prospective cohort study of 17 414 births to parents residing in Great Britain in the late 1950s (55). Childhood IQ was measured at age 11 years and BMI was assessed at 42 years of age. The study found that lower childhood IQ scores were associated with an increased prevalence of adult obesity at age 42 years. This relationship was somewhat stronger in women (OR<sub>per SD decrease in IQ score</sub> [95% CI]: 1.38 [1.26, 1.50]) than men (1.26 [1.15, 1.38]). With adjustment for education the association between childhood intelligence and adult BMI became null (women: 1.11 [0.99, 1.25]; men: 1.10 [0.98, 1.23]).

However, there is still no consensus on the relationship between childhood IQ and adult obesity. Hart *et al.* investigated the influence of childhood IQ on the relationships between risk factors of cardiovascular disease, coronary heart disease and stroke in adulthood (14). Nine hundred and thirty-eight participants were successfully matched with their age 11, IQ data from the Scottish Mental Survey 1932; follow-up surveys of BMI were conducted at age 36. The correlation coefficient between childhood IQ and BMI (mid-span risk factors for cardiovascular disease) was  $-0.04$  ( $P > 0.05$ ).

Batty *et al.* performed in the 1970 British Cohort Study, an ongoing longitudinal study of 17 198 live births occurring to parents residing in Great Britain. The paper examined the relation of scores on tests of mental ability across childhood with established risk factors for premature mortality at the age of 30 years. At the same time, it also investigated the association of IQ and obesity. The result indicated that higher IQ score at age 10 years was associated with a reduced prevalence of obesity (0.84; 0.79, 0.92) (56).

Batty *et al.* also analysed data from the Aberdeen Children of the 1950s study which examined the association between childhood IQ and a range of established physiological and behavioural risk factors for premature mortality in adulthood. It also investigated the association of IQ and obesity. The result indicated in sex-adjusted analyses based on an analytical sample of 5340 (2687 women); higher childhood IQ scores were associated with a decreased prevalence of obesity (0.78: 0.72, 0.83) (57).

### Intelligence score in early adulthood and later adult obesity

Halkjaer *et al.* examined 907 men with juvenile-onset obesity and 883 non-obese men in 1956, and follow-up surveys were conducted between 1982 and 1984 (13), which were based on the same study samples (so-called case-cohort sampling design) as those in the study by Sorensen *et al.* (28). When the intelligence test score was used as a continuous variable, the regression coefficient for each five-point increase was  $-0.19$  (95% CI:  $-0.25, -0.13$ ), corresponding to a score difference of 26 points for one BMI unit ( $P < 0.0001$ ). With the increase in intelligence test score, later adult BMI gain declined for a given baseline BMI at the follow-up. Compared with the lowest test-score quintile, the highest intelligence test-score quintile had less increases in BMI ( $-1.59$ ; 95% CI:  $-2.06, -1.12$ ), and there was a clear and highly significant inverse trend. However, after adjusting for educational attainment, the inverse trend between intelligence test score and BMI changes lost significance and the regression coefficient for each five-point increase was  $-0.06$ ; 95% CI,  $-0.15$  to  $0.02$  ( $P > 0.05$ ).

Batty *et al.* analysed data from the Vietnam Experience Study, a large cohort of former US army personnel who had their IQ assessed at entry to the service in early adulthood and then took part in a telephone interview and medical examination some 20 years later (58). Such a study provided a novel opportunity to examine the IQ–metabolic syndrome relationship. The author also evaluated the association between childhood cognition and the risk of each of the five components of the metabolic syndrome. After full adjustment for all covariates, higher IQ scores were associated with a reduced prevalence of obesity ( $OR_{1\text{ SD increase in IQ}} 0.87$ , 95% CI  $0.77\text{--}0.98$ ) (58).

### Analysis of heterogeneity and publication bias

Heterogeneity ( $I^2 > 50\%$ ) was high for the pooled WMD of the case–control studies comparing obese children vs. normal weight children. The  $\chi^2$ -test for heterogeneity was significant for two studies of the intelligence score and obesity in the pre-school children ( $\chi^2 = 250.30$ ,  $P < 0.00001$ ) (35,36), probably due to the different IQ tests used to assess a single domain, resulting in a variety of  $d$  values. This was taken into account by analysing these data using a random model.

The  $\chi^2$ -test for heterogeneity was significant for the eight studies of the intelligence score and obesity in the school-age children ( $\chi^2 = 88.86$ ,  $P < 0.00001$ ), and this was taken into account by analysing the data using a random model. Sensitivity analyses were performed (Table S4), and subgroups were divided based on the difference of statistical method, study design, sample size, quality grade of study, diagnostic criteria for obesity and measurement of IQ. The results found that the difference of sample size, quality grade of study, diagnostic criteria for obesity and measurement of IQ made a strong impact on the association between IQ and obesity in the school-age children; these factors may partially explain the heterogeneity between the studies. No signs of publication bias could be detected in the funnel plot (see Appendix S4), and the statistical test for publication bias was non-significant ( $P = 0.065$ ).

## Discussion

### Summary of findings

The results of this study indicate that the FIQ and PIQ of obesity in school-age children were lower than normal weight children, while the VIQ was non-significantly different between those two groups. Cornette showed that obesity had a significant psycho-socio-emotional impact on children, such as depression, social isolation, discrimination, low self-esteem and self-image, and poor academic performance (59). At the same time, the changes of body shape in obese children led to inconvenient activities and

lower PIQ of obese children; furthermore, FIQ was also affected and lowered, although the VIQ was not influenced.

With the increase in obesity grades, the FIQ in the pre-school children declined; there was a significant difference between the FIQ of severely obese and normal children. Mildly and moderately obese children showed a non-statistically significant difference in FIQ. Therefore, in order to prevent a decline in childhood IQ, we should lower the occurrence of severely obese children. The study supported the notion that childhood intelligence is inversely associated with adult obesity. However, after adjustment for educational attainment the association between childhood intelligence and later adult obesity became null. This result suggests that a lower FIQ in childhood is associated with obesity in later adulthood and perhaps with educational level acting as a mediator of the persistence of obesity in later life (13).

### Strengths and weaknesses

A robust search strategy was developed for the review, and five electronic databases were included. Furthermore, we strived to obtain information following the MOOSE recommendations. The problem of childhood obesity is increasing in China, where an estimated 21.37 million Chinese children (13.43 million boys and 7.94 million girls) are overweight or obese (60). Acceptance of the problem and subsequent epidemiological studies had begun in China as indicated by the fact that most of the studies identified for this review were conducted in this country, most of which reported on the relationship between childhood IQ and obesity. This is a meaningful research topic that has aroused the attention of some Chinese scholars (11,12). When we searched the non-Chinese literature, there were no articles which researched the relationship between childhood IQ and obesity. The Chinese medical literature may be a rich source of evidence to inform clinical practice and other systematic reviews (61). However, evidence of the effectiveness of this treatment came from Chinese sources that are not routinely searched when systematic reviews are carried out in the West. Because of concerns about the poor quality of reporting in all trials and the possibility of publication bias, we attempted to detect publication bias by use of a funnel plot and the Begg's test. No signs of publication bias could be discovered in the funnel plot, and the statistical test for publication bias was non-significant.

At the same time, we assessed the quality of included Chinese studies, and the results found that most of the studies (58.3%) were of medium and not high quality. Therefore, an adequately powered, high quality, case-control study or cohort study is needed to investigate the relationship between childhood IQ and obesity.

Sources of bias in any meta-analysis are the selection and heterogeneity of the included studies. Regarding this point,

a specific limitation of our systematic review and meta-analysis is related to the difficulty of combining studies that used different methods to assess and classify the exposure (obesity) and outcome (IQ) of the participants. This is directly related to the lack of consensus about the categorization of obesity and the measurement methods for IQ. In order to evaluate the sources of bias of the review, we performed subgroup analyses (Table S4). The results found that the difference of sample size, quality grade of study, diagnostic criteria for obesity and measurement of IQ made a strong impact on the association between IQ and obesity in the school-age children, and the factors may partially explain the between-studies heterogeneity.

The other variables were not able to further explain the heterogeneity. Some studies did not contain IQ data with means and SD or reported the outcomes using mean difference of IQ that could not be pooled for the meta-analysis. The exclusion of these studies for these reasons may reduce the effectiveness of the test results in our meta-analysis.

Finally, various other factors may also have contributed to IQ/obesity association and childhood intelligence score in relation to later adult obesity, such as demographic, behavioural, dietary, social and economic factors. Therefore, further studies should adjust for these factors and analyse them at different levels.

### Mechanism of the IQ/obesity relationship

Obesity causes major changes in physiological and psychological function. For example, obesity has been found to be associated with brain volume decreases and poor cognitive function (7,8). Some recent population-based studies found that elevated BMI was associated with reduced global brain volume (62). More recently, a study revealed that the regional gray matter volume of obese individuals was significantly lower than in lean individuals (63). We hypothesize that such regional brain volume decreases of the obesity group could possibly cause lower cognitive function and reduce IQ in these subjects, although we cannot clarify the causal relationships among the BMI, gray matter volume and IQ. These findings invite further studies to investigate such anatomical differences between the obese and non-obese groups, possibly explain the IQ-obesity relationship.

Higher intelligence may reduce the risk of obesity by promoting more healthful behaviours. Individuals may be able to better prevent overweight and obesity when they are more informed about their own behavioural risk factors. For example, analyses of data from a cohort study showed children with higher mental ability scores reported significantly more frequent consumption of fruit, vegetables (cooked and raw), wholemeal bread, poultry, fish and foods fried in vegetable oil in adulthood. They were also

more likely to have a lower intake of chips (French fries), non-wholemeal bread, and cakes and biscuits (64). Correspondingly, higher scores for IQ in childhood are associated with an increased likelihood of being a vegetarian as an adult, a lower FIQ in childhood is likely associated with smoking (65), alcohol-induced hangovers (66) and bad eating habits (67) which lead to obesity in later adulthood.

Childhood IQ also influences physical well-being throughout life (68), as it has been associated with many adult diseases, such as hypertension (69), the metabolic syndrome (58), coronary heart disease and stroke (70), later cancer risk (71) and later mortality risk (72). In this study, a childhood intelligence score is related to later adult obesity. Our analysis points to the fact that higher childhood IQ test scores predict favourable socioeconomic positions in later life (as indexed by high educational attainment, elevated income and raised occupational social status) (73,74), and subsequent placement into a well-remunerated, high-status occupation in mid-life leads to a reduction in obesity in later life. There are other strong lines of evidence that show a gradient between educational attainment and obesity and/or overweight in men and women (75). Therefore, educational attainment is a possibly modifiable factor to reduce obesity.

### Implications for practice

The results of this review could be used for a better understanding of IQ/obesity association and childhood IQ in relation to later adult obesity. It could also be useful in counselling young children about their risk for obesity. Because obese people are often stigmatized, we do not wish to add the additional stigma of an association with lower IQ scores. We emphasize that while the current rise in the prevalence of obesity is accompanied by a fall in IQ levels during childhood, our significant findings suggest that rising levels of obesity are associated with falling levels of educational attainment. Among the risk factors for obesity, educational attainment is potentially modifiable. Therefore, a child should also be informed about his/her risks of obesity in adulthood and perhaps be able to reduce the risk by increasing educational levels.

### Implications for research

More epidemiological studies on obesity and IQ are needed to explore IQ/obesity associations and childhood intelligence scores in relation to later adult obesity. Obesity is affected by many factors, such as demographic, behavioural, dietary, social and economic factors. After adjusting for these factors, we would better understand the IQ/obesity association.

### Conclusion

There is still no consensus as to the association between IQ and obesity, and the findings are inconsistent among published studies. Our study and review of the literature overall suggests that there are inverse FIQ/obesity associations, except in pre-school children. However, after adjusting for educational attainment, this FIQ/obesity association became null. In the present study, a lower IQ score in childhood is associated with obesity in later adulthood; this relationship is perhaps mediated via educational attainment in later life. These results encourage further studies into the mechanism underlying the relationships between IQ, educational level and risk of obesity. Better understanding of these relationships may allow improved targeting and, thereby, more effective prevention and treatment of obesity. These findings also invite further trials – after adjusting the effect of other factors on IQ, such as demographic, social, economic factors – to re-evaluate the IQ/obesity association and childhood intelligence score in relation to later adult obesity.

### Conflict of Interest Statement

No conflict of interest was declared.

### Acknowledgements

This review was funded by the National Natural Science Foundation of China (Grant No. 30772364), the Foundation of Ministry of Education, China (Grant No 20070312001), the Natural Science Foundation of Jiangsu Province, China (Grant No BK2007230) and Nanjing Medical University (Grant No 07NMUZ024). We are grateful to Dr Q Tang (Southeast University librarian) for his help with the electronic search strategy and retrieval of articles and to R.Y. Zhang (Public Health, Nanjing Medical University) for her assistance with statistical data analysis. The review teams wish to thank Professor Thorkild I.A. Sørensen (Institute of Preventive Medicine, Copenhagen University Hospitals, Centre for Health and Society, Copenhagen DK1357K, Denmark) for his helpful comments and constructive suggestions on an earlier draft of this paper.

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## Supporting information

Additional Supporting Information may be found in the online version of this article:

**Table S1.** The fact FIQ data of studies on obesity in the children and adolescents.

**Table S2.** The fact VIQ data of studies on obesity in the pre-school and school-age children.

**Table S3.** The fact PIQ data of studies on obesity in the pre-school and school-age children.

**Table S4.** Sensitivity and subgroup analysis of the relationship between the intelligence score and obesity in the school-age children.

**Appendix S1.** Search strategy used for CNKI, Wanfang DATA databases, CINAHL, EMBASE and MEDLINE.

**Appendix S2** Quality assessment extraction form.

**Appendix S3** Quality assessment (grade) of the 24 included studies.

**Appendix S4** Funnel Plot and Begg's Test of meta-analysis of the relationship between the intelligence score and obesity in the school-age children.

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