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Relationship between adiposity and cognitive performance in 9-10 year old children in south India

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Abstract

Background—Studies in high-income countries have shown inverse associations between adiposity and cognitive performance in children. We aimed to examine the relationship between adiposity and cognitive function in Indian children.

Methods—At a mean age of 9.7 years, height, weight, triceps and subscapular skinfold thicknesses and waist circumference were recorded for 540 children born in Mysore, India. Body fat percentage was estimated using bio-impedance. Cognitive function was assessed using 3 core tests from the Kaufman Assessment Battery for children-II edition and additional tests measuring learning, short-term memory, reasoning, verbal and visuo-spatial abilities, attention and concentration. Data on the parents' socio-economic status, education, occupation and income were collected.

Results—According to WHO definitions, 3.5% of the children were overweight/obese (BMI > +1SD) and 27% underweight (BMI < −2SD). Compared to normal children, overweight/obese children scored higher in tests of learning/long-term retrieval, reasoning and verbal ability (unadjusted $p < 0.05$ for all). All the cognitive test scores increased with increase in BMI and skinfold thickness, (unadjusted $\beta = 0.10$ to 0.20 SD; $p < 0.05$ for all). The effects, though attenuated, remained mainly significant after adjustment for age, sex and socio-economic factors. Similar associations were found for waist circumference and percentage body fat.

Conclusions—In this Indian population, in which obesity was uncommon, greater adiposity predicted higher cognitive ability. These associations were only partly explained by socio-economic factors. Our findings suggest that better nutrition is associated with better cognitive function, and that inverse associations between adiposity and cognitive function in high-income countries reflect confounding by socio-economic factors.

Keywords

Adiposity; Children; Cognitive function; India; Birth cohort

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Introduction

Globally, human beings are tending to become heavier and more adipose, as a result of increased food security, wide availability of low-cost energy-dense foods, and increasingly sedentary lifestyles¹. While this has reduced the prevalence of under-nutrition, childhood and adult overweight/obesity has increased considerably over the last 20 years in high-income as well as low- and middle-income countries.[1-3] It is well established that greater adiposity in childhood is associated with an increased risk of chronic cardio-metabolic disease in later life including hypertension, diabetes mellitus and cardiovascular disease.[4,5]

Recent evidence suggests that adiposity may have other adverse effects on health. A number of studies from high-income countries have related adult overweight/obesity to impaired cognitive function.[6-8] This could result from adiposity-related cardio-metabolic dysfunction, resulting in an impaired vascular supply to the brain.[9] However, several studies have now reported reduced cognitive function even in children in relation to overweight/obesity.[10-15] Moreover, some of these studies show a continuous relationship between adiposity and cognitive function that is not limited to overweight children.[10-13] In children this is unlikely to be related to impaired vascular supply to the brain caused by obesity-related cardio-metabolic dysfunction. Other 'biological' explanations have been proposed; for example cytokines released from adipose tissue may impair cognitive function.[9] Alternatively, the association between obesity and cognitive function may be confounded by socio-economic status (SES), which is inversely related to both adiposity[16] and cognitive function in high-income countries.[17]

It would be useful to study the association in a low- and middle-income country, where confounding relationships are different. For example, in India, greater adiposity tends to be associated with higher rather than lower SES.[18,19] All previous studies have used body mass index (BMI) as the measure of adiposity. In the Mysore Parthenon Birth Cohort Study in south India, in addition to BMI, other measures of adiposity including waist circumference, skinfold thickness and percentage body fat (fat%) using bio-impedance have been recorded. Extensive data on potential confounding factors, including parental education, occupation, income and SES have been collected. Using this data we aim to examine the associations between measures of adiposity and cognitive function in healthy 9-10 year old children.

Methods

The Mysore Parthenon Birth Cohort Study has been described previously.[20-22] It was originally designed to establish a cohort of children representative of births in one maternity unit, in order to study the long-term effects of maternal gestational glucose intolerance. A total of 830 pregnant women booking consecutively into the antenatal clinic at the Holdsworth Memorial Hospital (HMH), Mysore, were recruited and underwent an oral glucose tolerance test at 30±2 weeks of gestation (49 had gestational diabetes (GDM)). Of these, 663 delivered live normal babies at HMH. Apart from 25 children who died and 8 who developed serious medical conditions, the children (N=630) were measured annually until the age of 5 years, and every 6 months thereafter.

Cognitive function assessment

During 2007-2008, cognitive function was assessed among 542 available children (86% of the original cohort; Figure 1) aged 9-10 years. The cognitive measures consisted of a series of neuropsychological tests applicable for use in school aged children related to specific cognitive domains (memory, attention, fluid reasoning) consistent with the Carroll model.

[23] The cognitive battery included 3 core tests from Kaufman's assessment battery for children-second edition[24,25] and additional tests[26,27] that underwent an extensive adaptation process and validated to ensure their applicability in the local cultural context. [28,29] These tests measured learning, long-term retrieval/storage (Atlantis), short-term memory (word order), reasoning (pattern reasoning), verbal and visuo-spatial (Kohs block design) abilities, attention and concentration (coding-Wechsler intelligence scale for children-third edition (WISC-III). Descriptions of these tests are presented in Table 1. All tests were administered to each child in a single session of 60 to 90 minutes, in separate rooms free from distraction by one of the 2 trained masters' level child psychologists in the local Kannada language. Intra class correlation coefficients for agreement between the 2 psychologists were 0.89 (intra-rater) and 0.90 (inter-rater).

Adiposity measures

Detailed anthropometry of the children was measured by one of five trained observers. Weight was measured barefoot with light clothing to the nearest 100g using digital scales (Salter, Kent, UK). Height was measured barefoot to the nearest 0.1cm using a wall mounted stadiometer (Microtoise, CMS instruments, London, UK). Waist circumference (WC) (midpoint between lower border of the last rib and iliac crest in the mid-axillary line, free from clothing) was measured to the nearest 0.1cm using anthropometric tape. Triceps and subscapular skinfold thicknesses were measured on the left side of the body excluding cloths to the nearest 0.1mm using Harpenden calipers (CMS instruments, London, UK). In inter-observer variation studies the ratio of the SD of between-observer differences to the SD of between-subject differences was 0.02, 0.02, 0.33, 0.24 and 0.05 for weight, height, WC, triceps and subscapular skinfold thickness measurements respectively. Fat% was measured by bioimpedance using the manufacturer's equations (Bodystat, Quadscan 4000, Isle of Mann, UK). According to WHO age and sex specific growth standards,[30] 9.5 year old children were considered overweight if the age and sex specific BMI is $>18.2 \text{ kg/m}^2$ and $<20.9 \text{ kg/m}^2$ for boys; $>18.7 \text{ kg/m}^2$ and $<22.0 \text{ kg/m}^2$ for girls and obese if BMI is $\geq 20.9 \text{ kg/m}^2$ for boys and $\geq 22.0 \text{ kg/m}^2$ for girls. Children were considered underweight if the age and sex specific BMI is $<13.6 \text{ kg/m}^2$ for boys and $<13.3 \text{ kg/m}^2$ for girls.

Covariates and confounders

We also collected data on the parents' education, occupation and income. Occupation of the main breadwinner was classified as unskilled (eg. labourer, vegetable and fruit vendor), semi-skilled (eg. mechanic, construction worker), skilled (eg. clerk, cashier), semi professional (eg. teacher, diploma engineer, manager, businessman/woman) and professional (eg. doctor, engineer, advocate, lecturer). Income (rupees per month) of the head of the family was categorized as a) <3000 ; b) 3001-5000; c) 5001-8000; d) 8001-10,000 and e) $>10,000$. Current SES was assessed using the Standard of Living Index (SLI) designed by National Family Health Survey-2 [31] which derives a score based on type and size of the house, household sanitary facilities, source of water and power supply, cooking fuel used, ownership of house/property, land, livestock and household assets.

The hospital research ethics committee approved the study and informed consent was obtained from the parents and assent from the children.

Statistical methods

Excluding 2 children with missing BMI and sum of skinfolds (SS) data, 540 children were included in the final analysis. Variables with skewed distributions were either log-transformed (skinfold thickness, SS and visuo-spatial ability) or square-root transformed (pattern reasoning). Differences in exposures (adiposity measures) and outcomes (cognitive

scores) between boys and girls were analysed using unpaired *t*-tests. Confounding variables as well as exposure and outcome variables were used as continuous variables in linear regression to examine the unadjusted associations of confounding variables with exposures and outcomes. Exposure and outcome variables were internally Z-standardized to facilitate interpretation and were used as continuous variables in regression analysis. We also analysed the association between overweight/obesity (categorical variable (0-normal; 1-overweight/obese) and cognitive function. Children's cognitive performance in relation to their adiposity measures (BMI, SS, WC and fat% were examined by multiple regression analysis initially unadjusted (model 1); after adjustment for the child's sex and current age (model 2) and additionally adjusted for SES, parental education, occupation and income (model 3). Differences in the associations between boys and girls were examined using interaction terms. Quadratic terms were used to examine non-linear associations. Stata v 10 (Stata corporation, TX, USA) was used for all analyses.

Results

Anthropometric measures, socio-demographic characteristics and cognitive tests scores of the study participants are depicted in Table 2. Girls had larger skinfold thickness and higher fat% than boys. According to the WHO classification,[30] 8 (3.1%) boys and 11 (3.9%) girls were overweight/obese and 79 (30.3%) boys and 67 (24.0%) girls were underweight. Girls scored better than boys in tests of short-term memory, reasoning, verbal ability (names) and attention and concentration (Table 2).

Association of confounders with adiposity measures and cognitive abilities

Parental education, occupation, income and SLI were positively associated with the children's adiposity measures (Table 3) and all the cognitive test scores (Table 4). These associations were similar in boys and girls and there were no non-linear association of confounders with exposures or outcomes.

Association between adiposity measures and cognitive abilities

Compared to normal children overweight/obese children scored higher in tests of learning, long-term retrieval, reasoning and verbal ability (Table 5). All the cognitive test scores increased with increasing BMI and SS (Table 5). These associations remained similar after adjusting for child's age and sex. They were markedly attenuated after additional adjustment for SES, parental education, occupation and income (Table 5), but remained significant for learning, reasoning and verbal ability. Similar associations of WC and fat% with cognitive function were found (data not shown). The associations were similar in boys and girls and there were no non-linear associations. The results were similar after excluding children born to GDM mothers (data not shown).

Discussion

In this study of Indian children, we found that unlike in the previous studies, different adiposity measures were positively associated with cognitive function (learning, long-term retrieval/storage, memory, reasoning, verbal abilities, attention and concentration) at 9.5 years. These associations were attenuated after controlling for a range of confounders measuring socio-economic factors, but remained significant for many of the cognitive outcomes.

Previous studies on the association between overweight/adiposity and cognitive function were mostly confined to high-income populations. The majority of these studies, both in adults and children, found that overweight/obesity was associated with reduced cognitive

ability and school outcomes.[6-8,11-15] In a large group of children and adolescents between 8 and 16 years of age in the USA, overweight children performed poorly in tests measuring visuospatial organization and general mental ability (block design) even after adjusting for a number of potential confounders.[11] In another study in the USA, continuous measures of both BMI, and body fat measured using DEXA, in 7-9 year old children were negatively associated with scores in a 'No Go' task that requires inhibitory control.[12] This study also found lower academic performance in relation to higher BMI and fat mass. Among pre-school children aged 2-3 years in Germany, obesity was associated with reduced skill attainment.[15] A prospective study in Spain observed that better cognitive performance at age 4 years, specifically executive function and verbal skills, was associated with a lower risk of being overweight at 6 years, suggesting that higher cognitive abilities in early life may prevent future risks of obesity in these children.[32] However, a study in the USA among children and adolescents aged 6-19 years found no association between higher BMI and cognitive functions.[10]

Several possible explanations have been put forward for an association between adiposity and lower cognitive function. It could result from adiposity-related cardio-metabolic dysfunction resulting in impaired vascular supply to the brain.[9] However, this is unlikely to explain the association in children. Moreover, some studies show a continuous relationship between adiposity and cognitive performance that is not limited to overweight children. Higher cognitive function in early childhood could lead to better control of eating impulses, leading to a reduced risk of overweight in late childhood.[32] Alternatively, adiposity could have some adverse effect on brain function, possibly due to the secretion of hormones, pro-inflammatory cytokines or growth factors by adipose tissue that can cross the blood brain barrier.[9] A further possibility is that the association results from confounding by socio-economic factors; in high-income countries, overweight and obesity are more common among children of lower SES, who also tend to have lower cognitive function for a variety of reasons linked to better nutrition, parental intelligence, stimulation and quality of education.[17] The findings in our study make this the most likely explanation.

Unlike high-income countries, the association between SES and adiposity tends to be positive rather than inverse in low- and middle-income countries,[16] which might explain the positive association observed between measures of adiposity and cognitive performance in our study. The prevalence of overweight and obesity was low in our children (3.9%), while the prevalence of underweight was relatively higher (26.9%). In 6-19 year old girls in the USA, underweight, not higher BMI, was associated with poorer performance in tests of memory.[10] In an Indian tribal population, performance in tests of reasoning and problem solving abilities was poorer in 5-12 year old children who were underweight and belonged to lower SES.[33] In our study, higher SES, and related factors such as parental education, occupation and income were associated with better cognitive performance. In the absence of pathological overweight, greater adiposity in our children may represent better nutrition, which is a major determinant of brain function. This may also be related to better fetal and postnatal nutrition in these children: birthweight was positively correlated with size at 9.5 years, including triceps and subscapular skinfold thickness.[34]

A variety of environmental factors predict cognitive performance. Higher SES is associated with better nutrition, better parenting practices, and accessibility to a better learning environment and materials, all of which are shown to predict optimum cognitive development.[17] Parental education is another important factor that determines children's cognitive development.[35,36] Consistent with these effects, the associations in our study were attenuated by adjusting for socio-economic factors and parental education. However, the associations remained significant for many of the cognitive tests. This could be because of other effects of higher SES; we did not measure parental intelligence, the quality of the

home environment or children's schooling quality, which may have played an important role in the observed association. Reverse causation could be another possible explanation of our findings. Children who do well academically may be more sedentary than less cognitively able children.

Strengths and limitations

Strengths of the study were the large sample of children, from a cohort with low rates of loss to follow-up and thus less chances of bias, the availability of several measures of adiposity (not just BMI) measured by a team of standardized researchers, and a validated set of cognitive tests appropriate for an Indian population and covering a range of domains including memory, reasoning, learning, long-term retrieval, visuo-spatial ability and attention and concentration administered by a trained psychologist. Detailed measures of a number of relevant confounding factors were also recorded. A limitation was that few of our children were overweight/obese, and this means that we are unable to exclude a negative association between extreme levels of adiposity and cognitive function. Data on physical activity and energy intake, important determinants of adiposity, were not available. Another limitation was the absence of data to explore other potential mechanisms linking adiposity and cognitive function, such as plasma pro-inflammatory cytokines.

In conclusion, in this cohort of Indian children, unlike in high-income populations, greater adiposity predicted higher cognitive ability at 9-10 years of age. These findings were only partly explained by socio-economic factors. Our findings suggest that in the absence of pathological overweight/obesity, greater adiposity measures may represent better nutrition, and thus better cognitive function. The inverse associations between adiposity and cognitive function in high-income settings probably reflect confounding by socio-economic factors.

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What is known already on this topic?

- In high-income countries, children who were overweight/obese tend to score lower on tests of cognitive function
- There is also continuous relationship between adiposity and cognitive performance that is not limited to overweight children
- It is not clear whether this association is causal or due to confounding. In high-income countries, lower socio-economic status and its related factors influence increased risk of adiposity and also predict lower cognitive function

What this study adds?

- Unlike high-income countries, socio-economic status, parental education and income were positively related to adiposity in this Indian population
- In this cohort, where underweight was more prevalent than overweight/obesity, there was a positive association between adiposity and childhood cognitive function which was only partly explained by socio-economic factors.
- Better nutrition is associated with better cognitive function. Negative associations between adiposity and cognitive function in high-income countries probably reflect confounding by socio-economic factors.

HMH: Holdsworth Memorial Hospital

GDM: Gestational diabetes mellitus

Figure 1. Flow diagram illustrating study participants

Table 1
Description of the cognitive tests used in the study

Tests from KABC-II*		
Name of the test	Description	Cognitive abilities
1. Atlantis	The child is taught nonsense names for fish, plants and shells and is asked to point to the named object among an array of pictures	Learning ability/long-term storage and retrieval, associative memory
2. Word order	The child points to a series of silhouettes of common objects in the same order as mentioned by the examiner; an interference task (colour naming) is added between the stimulus and the response for the more difficult items	Memory span, short term memory, working memory
3. Pattern Reasoning	The child completes a pattern by selecting the correct image from a set of 4 to 6 options shown; most stimuli are abstract, geometric shapes and the difficulty of the task increases as the test progresses.	Reasoning abilities such as induction and deduction and fluid reasoning
Additional tests		
4. Verbal fluency a) Animals b) First names	The child is asked to name as many animals as possible in 1 minute and then asked to name as many first names as possible in 1 minute.	Broad retrieval ability; speed and flexibility of verbal thought process; neuropsychological test of language production
5. Kohs block design	A psychometric test in which the child arranges groups of 4, 9, or 16 multicoloured blocks to copy picture designs presented on test cards.	Visuo-spatial problem solving, visual perception and organization
6. Coding-WISC-III[†]	The child has to substitute specific symbols for numbers presented in boxes, and complete as many items as possible in 2 minutes.	Visual-motor processing speed and coordination, short term memory, visual perception, visual scanning, cognitive flexibility, attention

* K-ABC-II-Kaufman assessment battery for children-second edition;

[†] WISC-III-Wechsler intelligence scale for children-third edition

Table 2
Descriptive statistics (anthropometric measures, cognitive test scores and socio-demographic characteristics) of the study participants

	Boys (n=261)	Girls (n=279)	
<i>Anthropometry</i>	Mean (SD)	Mean (SD)	P
Age (years)	9.7 (0.3)	9.7 (0.3)	0.9
Height (cm)	131.1 (5.5)	130.3(5.9)	0.08
BMI (kg/m ²)	14.5 (1.7)	14.6 (1.9)	0.5
Waist circumference (cm)	54.1 (4.9)	54.6 (5.7)	0.3
Triceps skinfold (mm) ¹	8.1 (6.6, 9.8)	10.4 (8.5,13.2)	<0.0001
Subscapular skinfold (mm) [*]	6.1 (5.3, 7.9)	8.1 (6.4, 10.4)	<0.0001
Sum of skinfolds (mm) ¹	14.6 (12.1, 17.7)	18.6(15.1, 24.2)	<0.0001
Fat (%) from bio-impedance	24.1 (5.9)	30.3 (5.7)	<0.0001
<i>Tests of cognitive function</i>			
Learning, long-term retrieval/storage	67.6 (17.7)	67.7 (16.7)	0.9
Short-term memory	16.1 (2.5)	16.6 (2.5)	0.02
Reasoning ability [*]	9.0 (4.0, 13.0)	11.0 (6.0,14.0)	0.004
Verbal ability-animals	11.9 (3.2)	12.1 (3.4)	0.4
Verbal ability-names	14.7 (4.1)	17.4 (5.2)	<0.0001
Visuo-spatial ability [*]	76.9 (63.7,87.8)	76.6 (63.1, 88.5)	0.7
Attention and concentration	30.2 (7.5)	35.1 (7.9)	<0.0001
<i>Socio-demographic characteristics</i>			
Standard of living index (score)		36.2 (8.3)	
Maternal education (No (%))			
a) <10 y of education		195 (36.2)	
b) 10 y of education		165 (30.6)	
c) >10 y of education		179 (33.2)	
Paternal education (No (%))			
a) <10 y of education		205 (38.0)	
b) 10 y of education		211 (39.2)	
c) >10 y of education		123 (22.8)	
Occupation of the main bread winner (No (%))			
a) Unskilled (eg. labourer, vegetable vendor)		111 (20.6)	
b) Semiskilled (eg. mechanic, construction worker)		105 (19.5)	
c) Skilled (eg. clerk, cashier)		254(47.1)	
d) Semi-professionals (eg. teacher, manager, businessmen)		50 (9.3)	
e) Professionals (eg. doctor, engineer, advocate, lecturer)		19 (3.5)	
Income of the head of the family(No (%))			
a) Rs. 3000		150 (27.8)	
b) Rs. 3001-5000		118 (21.9)	
c) Rs. 5001-8000		95 (17.6)	
d) Rs. 8001-10000		74 (13.7)	
e) > Rs. 10,000		102 (18.9)	

* Skewed variables; values are median (inter quartile range (IQR)); P value for the difference between boys and girls derived using *t*-tests, in which skewed variables were log or square root transformed.

Table 3
Mean (SD) of adiposity measures according to groups of confounding variables

Confounding variables		Adiposity measures			
	n	BMI (kg/m ²)	Sum of skinfolds (mm)*	Waist circumference (cm)	Body fat (%)
Standard of living index (score)					
<33	194	14.5 (1.8)	16.3 (13.1, 19.7)	54.2 (5.2)	26.7 (6.6)
33-40	188	14.4 (1.5)	15.3 (12.9, 19.8)	53.6 (4.6)	26.8 (6.3)
>40	157	15.0 (2.1)	17.7 (13.9, 22.7)	55.4 (6.0)	28.6 (6.8)
β (95% CI)		0.03 (0.01, 0.04)	0.005 (0.001, 0.01)	0.07 (0.01, 0.12)	0.09 (0.02, 0.16)
p		0.008	0.007	0.02	0.008
Maternal education (completed years)					
<10	195	14.3 (1.6)	15.1 (12.7, 18.9)	53.5 (4.6)	25.9 (6.1)
10	165	14.4 (1.8)	16.0 (13.0, 20.5)	53.6 (5.0)	26.8 (6.7)
>10	179	15.1 (2.0)	18.3 (14.9, 24.9)	56.0 (6.0)	29.3 (6.5)
β (95% CI)		0.10 (0.06, 0.14)	0.03 (0.02, 0.03)	0.32 (0.19, 0.44)	0.38 (0.22, 0.54)
p		<0.001	<0.001	<0.001	<0.001
Paternal education (completed years)					
<10	205	14.2 (1.5)	15.3 (12.4, 18.9)	53.2 (4.4)	26.1 (6.1)
10	211	14.6 (1.9)	17.0 (13.7, 21.5)	54.7 (5.4)	28.1 (6.7)
>10	123	15.1 (2.1)	17.7 (13.9, 23.2)	55.6 (6.2)	27.8 (6.9)
β (95% CI)		0.07 (0.04, 0.11)	0.01 (0.01, 0.02)	0.21 (0.11, 0.31)	0.20 (0.08, 0.32)
p		<0.001	<0.001	<0.001	0.002
Occupation of the main bread winner (categories)					
Unskilled (eg. labourer, vegetable vendor)	111	14.4 (1.6)	15.3 (17.7, 19.7)	53.9 (5.0)	26.5 (6.4)
Semiskilled (eg. mechanic, construction worker)	105	14.5 (2.1)	16.0 (12.9, 21.0)	54.7 (5.7)	27.7 (7.0)
Skilled (eg. clerk, cashier)	254	14.6 (1.8)	16.6 (13.4, 20.5)	54.1 (5.3)	27.3 (6.4)
Semi-professionals (eg. teacher, manager, businessmen)	50	14.8 (1.8)	17.4 (13.9, 24.4)	54.8 (5.0)	27.4 (7.4)
Professionals (eg. doctor, engineer, advocate, lecturer)	19	15.5 (2.0)	21.0 (13.9, 23.5)	57.1 (5.7)	29.4 (6.2)
β (95% CI)		0.14 (0.03, 0.25)	0.03 (0.01, 0.05)	0.30 (-0.01, 0.62)	0.36 (-0.03, 0.75)

Confounder variables		Adiposity measures				
		n	BMI (kg/m ²)	Sum of skinfolds (mm)*	Waist circumference (cm)	Body fat (%)
Income of the head of the family (categories)						
p			0.01	0.004	0.060	0.071
	Rs. 3000	150	14.3 (1.5)	15.4 (12.9, 18.4)	53.3 (4.5)	26.0 (6.5)
	Rs. 3001-5000	118	14.5 (1.4)	16.4 (13.6, 20.9)	54.0 (4.5)	27.0 (5.9)
	Rs. 5001-8000	97	14.8 (2.2)	16.0 (12.9, 22.1)	54.8 (6.2)	27.9 (5.9)
	Rs. 8001-10000	74	14.8 (2.3)	17.5 (14.7, 21.4)	55.5 (6.2)	28.8 (7.2)
	> Rs. 10,000	102	14.8 (1.9)	17.2 (13.3, 23.3)	55.1 (5.5)	27.9 (7.2)
	β (95% CI)		0.07 (0.02, 0.11)	0.02 (0.01, 0.03)	0.25 (0.12, 0.38)	0.30 (0.14, 0.45)
p			0.002	<0.001	<0.001	<0.001

* Transformed variable; values are median (IQR); β is the effect size (unadjusted) on the adiposity measure and P values were derived using confounding variables and adiposity measures as continuous variables in linear regression.

Table 4
Mean (SD) of cognitive test scores according to groups of confounding variables

Cognitive function tests (score)									
Confounding variables	n	Learning, long-term retrieval	Short-term memory	Reasoning*	Verbal ability animals	Verbal ability names	Visuo-spatial ability*	Attention and concentration	
Standard of living index (score)									
< 33	194	63.2 (17.0)	15.9 (2.2)	8.0 (4.0, 11.0)	11.3 (3.1)	14.9 (4.0)	71.1 (60.0, 82.0)	31.1 (8.3)	
33-40	188	68.1 (16.4)	16.3 (2.5)	10.0 (4.0, 14.0)	12.0 (3.2)	16.3 (4.8)	77.6 (63.7, 88.5)	32.5 (7.6)	
>40	157	72.9 (16.7)	17.2 (2.7)	12.0 (9.0, 17.0)	13.1 (3.4)	17.4 (5.6)	84.0 (66.9, 93.9)	35.1 (8.0)	
β (95% CI)		0.46 (0.29, 0.63)	0.07 (0.04, 0.09)	0.04 (0.02, 0.05)	0.08 (0.05, 0.12)	0.11 (0.06, 0.16)	0.01 (0.004, 0.01)	0.20 (0.12, 0.28)	
p		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Maternal education (completed years)									
< 10	195	64.0 (17.0)	15.8 (2.1)	7.0 (4.0, 11.0)	11.5 (3.3)	15.3 (4.5)	71.9 (59.2, 83.0)	30.9 (8.1)	
10	165	66.6 (16.2)	16.2 (2.6)	10.0 (4.0, 13.0)	11.6 (3.1)	15.9 (4.5)	76.6 (63.0, 86.7)	32.4 (7.3)	
>10	179	72.8 (17.0)	17.2 (2.7)	12.0 (9.0, 16.0)	13.0 (3.3)	17.2 (5.5)	84.1 (71.1, 94.8)	35.1 (8.3)	
β (95% CI)		1.03 (0.62, 1.44)	0.20 (0.14, 0.26)	0.09(0.06, 0.11)	0.19 (0.10, 0.27)	0.28 (0.16, 0.40)	0.02 (0.01, 0.02)	0.50 (0.30, 0.70)	
p		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Paternal education (completed years)									
< 10	205	63.5 (16.7)	15.8 (2.4)	8.0 (4.0, 11.0)	11.4 (3.1)	15.1 (4.2)	71.7 (59.2, 83.4)	30.9 (8.1)	
10	211	68.5 (15.9)	16.5 (2.4)	10.0 (6.0, 14.0)	12.0 (3.2)	16.4 (4.8)	77.6 (63.7, 88.4)	33.0 (7.2)	
>10	123	73.4 (18.2)	17.1 (2.7)	12.0 (7.0, 17.0)	13.1 (3.5)	17.3 (5.7)	84.4 (67.5, 94.8)	35.1 (8.9)	
β (95% CI)		0.89 (0.57, 1.20)	0.13 (0.08, 0.17)	0.07 (0.05, 0.09)	0.15 (0.09, 0.21)	0.19(0.10, 0.28)	0.01 (0.01, 0.02)	0.36 (0.21, 0.51)	
p		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	
Occupation of the main bread winner (categories)									
Unskilled (eg. labourer, vegetable vendor)	111	64.1 (17.5)	16.0 (2.3)	7.0 (3.0, 13.0)	11.0 (3.1)	15.3 (4.4)	71.7 (58.7, 83.1)	30.6 (7.8)	
Semiskilled (eg. mechanic, construction worker)	105	68.6 (16.2)	16.2 (2.1)	10.0 (5.0, 15.0)	11.9 (3.3)	15.6 (4.7)	75.6 (63.7, 88.7)	33.5 (8.0)	
Skilled (eg. clerk, cashier)	254	67.2 (17.2)	16.3 (2.6)	10.0 (4.0, 13.0)	12.2 (3.3)	16.4 (4.8)	76.2(64.1, 88.0)	32.9 (7.6)	
Semi-professionals (eg. teacher, manager, businessmen)	50	73.1 (14.8)	17.3 (2.4)	12.0 (8.0, 15.0)	12.9 (2.7)	16.8 (5.8)	83.3 (72.5, 98.2)	34.3 (9.2)	
Professionals (eg. doctor, engineer, advocate, lecturer)	19	76.3 (19.0)	18.2 (3.8)	15.0 (10.0, 19.0)	13.6(4.9)	18.1 (6.5)	86.3 (77.5, 95.4)	33.7 (12.1)	
β (95% CI)		1.74 (0.73, 2.75)	0.31 (0.17, 0.46)	0.16(0.10, 0.22)	0.39 (0.20, 0.59)	0.42 (0.13, 0.70)	0.03 (0.01, 0.04)	0.62 (0.14, 1.10)	
p		0.001	<0.001	<0.001	<0.001	0.005	<0.001	0.01	
Income of the head of the family (categories)									
Rs. 3000	150	62.5 (16.1)	16.0 (2.3)	7.0 (3.0, 11.0)	11.4(3.1)	15.3 (4.4)	69.7 (59.2, 81.3)	30.2 (7.9)	

Cognitive function tests (score)								
Confounding variables	n	Learning, long-term retrieval	Short-term memory	Reasoning *	Verbal ability animals	Verbal ability names	Visuo-spatial ability *	Attention and concentration
Rs. 3001-5000	118	66.4 (16.8)	16.2 (2.2)	9.0 (5.0, 12.0)	12.0 (3.0)	16.4 (4.5)	76.9 (59.2, 87.2)	33.4 (8.2)
Rs. 5001-8000	97	69.1 (17.3)	15.9 (2.3)	9.0 (4.0, 14.0)	11.6 (3.4)	15.7 (4.5)	77.5 (64.8, 85.9)	32.4 (7.7)
Rs. 8001-10000	74	71.5 (18.4)	16.7 (2.5)	11.5 (6.0, 17.0)	12.9 (2.2)	16.1 (5.5)	83.7 (66.3, 94.0)	34.8 (7.1)
> Rs. 10,000	102	72.9 (15.8)	17.5 (3.1)	13.0 (10.0, 17.0)	12.9 (3.6)	17.4 (5.6)	83.5 (72.5, 95.5)	34.4 (8.5)
β (95% CI)		1.06 (0.66, 1.47)	0.11 (0.05, 0.17)	0.08 (0.05, 0.10)	0.12 (0.04, 0.20)	0.13 (0.01, 0.25)	0.01 (0.01, 0.02)	0.46 (0.26, 0.64)
p		<0.001	<0.001	<0.001	0.003	0.04	<0.001	<0.001

* Transformed variable; values are median (IQR); β is the effect size (unadjusted) on the cognitive test scores and P values were derived using confounding variables and cognitive function scores as continuous variables in linear regression.

Table 5
Associations of adiposity measures (BMI and sum of skinfolds) with childhood cognitive ability

Tests of cognitive function								
Adiposity measures	N	Learning, long-term retrieval	Short-term memory	Reasoning ability	Verbal ability animals	Verbal ability names	Visuo-spatial ability	Attention and concentration
		Mean (SD)	Mean (SD)	Median (IQR)	Mean (SD)	Mean (SD)	Median (IQR)	Mean (SD)
Overweight/obesity status (WHO classification: BMI>+1SD)								
0 - No	521	67.3 (17.1)	16.4 (2.5)	10.0 (5.0, 14.0)	12.0 (3.3)	16.0 (4.9)	76.9 (63.7, 88.2)	32.6 (8.1)
1 - Yes	19	76.5 (16.4)	17.1 (2.0)	15.0 (9.0, 19.0)	14.4 (4.0)	19.3 (5.0)	77.6 57.7, 95.8)	35.6 (7.9)
<i>*β</i> _{Model 1}		0.53	0.27	0.72	0.73	0.67	0.07	0.37
(95% CI)		(0.07, 1.00) [†]	(−0.19, 0.72)	(0.26, 1.16) [‡]	(0.27, 1.18) [‡]	(0.21, 1.12) [‡]	(−0.39, 0.53)	(−0.09, 0.83)
<i>*β</i> _{Model 2}		0.53	0.26	0.70	0.73	0.64	0.07	0.34
(95% CI)		(0.08, 1.00) [†]	(−0.20, 0.71)	(0.26, 1.15) [‡]	(0.27, 1.18) [‡]	(0.20, 1.08) [‡]	(−0.39, 0.53)	(−0.08, 0.77)
<i>*β</i> _{Model 3}		0.32	0.05	0.46	0.56	0.51	−0.17	0.18
(95% CI)		(−0.12, 0.77)	(−0.39, 0.49)	(0.03, 0.89) [‡]	(0.11, 1.01) [‡]	(0.08, 0.95) [‡]	(−0.61, 0.27)	(−0.24, 0.60)
Quartiles of BMI (kg/m ²)								
<13.3	135	63.9 (16.3)	15.8 (2.6)	8.0 (4.0,12.0)	11.5 (3.3)	15.4 (5.3)	72.4 (59.2,86.8)	31.3 (8.2)
>13.3 - 14.3	134	68.5 (15.5)	16.7 (2.6)	10.0 (6.0,13.0)	11.9 (3.3)	16.0 (4.5)	77.5 (66.9,88.4)	32.5 (7.5)
>14.3 −15.5	137	65.1 (18.9)	16.1 (2.3)	10.0 (4.0,14.0)	12.1 (3.2)	16.4 (5.0)	75.6 (63.0,86.7)	32.1 (8.6)
>15.5	134	73.2(16.4)	17.0 (2.5)	12.0 (7.0,15.0)	12.7 (3.4)	16.7 (4.7)	80.8 (63.0,93.1)	34.9 (7.9)
<i>β</i> _{Model 1}		0.20	0.15	0.19	0.18	0.13	0.09	0.16
(95% CI)		(0.11, 0.29) [§]	(0.06, 0.23) [§]	(0.10, 0.28) [§]	(0.09, 0.27) [§]	(0.04, 0.22) [‡]	(0.005, 0.18) [‡]	(0.07, 0.25) [§]
<i>β</i> _{Model 2}		0.20	0.15	0.19	0.18	0.12	0.09	0.16
(95% CI)		(0.11, 0.29) [§]	(0.06, 0.23) [§]	(0.10, 0.28) [§]	(0.10, 0.27) [§]	(0.04, 0.21) [‡]	(0.004, 0.18) [‡]	(0.08, 0.24) [§]
<i>β</i> _{Model 3}		0.16	0.09	0.13	0.14	0.08	0.03	0.12
(95% CI) [§]		(0.07, 0.25) [§]	(0.005, 0.18) [‡]	(0.04, 0.21) [‡]	(0.05, 0.23) [‡]	(−0.003, 0.17)	(−0.06, 0.12)	(0.04, 0.21) [‡]
Quartiles of sum of skinfolds (mm)								
<13.3	136	66.8 (17.1)	16.0 (2.7)	9.0 (4.0,13.0)	11.4 (3.3)	14.9 (4.5)	72.8 (62.0,85.7)	30.5 (7.8)
>13.3 - 16.3	134	64.4 (15.7)	16.1 (2.2)	8.0 (4.0,12.0)	12.0 (2.9)	15.8 (4.8)	75.0 (63.7,80.0)	32.6 (7.8)
>16.3 −20.9	138	66.1 (18.6)	16.4 (2.4)	10.0 (5.0,13.0)	11.9 (3.3)	16.4 (4.7)	77.6 (64.1,88.3)	32.0 (7.5)
>20.9	132	73.5 (15.8)	17.1 (2.7)	12.0 (9.0,16.0)	12.9 (3.6)	17.4 (5.2)	82.5 (63.6,91.5)	35.8 (8.6)

Tests of cognitive function									
Adiposity measures	N	Learning, long-term retrieval	Short-term memory	Reasoning ability	Verbal ability animals	Verbal ability names	Visuo-spatial ability	Attention and concentration	
Overweight/obesity status (WHO classification: BMI > +1SD)		Mean (SD)	Mean (SD)	Median (IQR)	Mean (SD)	Mean (SD)	Median (IQR)	Mean (SD)	
β Model 1		0.16	0.15	0.22	0.16	0.18	0.12	0.22	
(95% CI)		(0.07, 0.24) [§]	(0.06, 0.23) [‡]	(0.14, 0.31) [§]	(0.07, 0.24) [§]	(0.10, 0.27) [§]	(0.03, 0.20) [‡]	(0.14, 0.31) [§]	
β Model 2		0.18	0.13	0.20	0.17	0.10	0.14	0.14	
(95% CI)		(0.09, 0.27) [§]	(0.04, 0.22) [‡]	(0.11, 0.29) [§]	(0.07, 0.26) [§]	(0.01, 0.19) [‡]	(0.04, 0.23) [‡]	(0.05, 0.22) [‡]	
β Model 3		0.13	0.06	0.13	0.11	0.04	0.06	0.09	
(95% CI)		(0.04, 0.22) [‡]	(-0.03, 0.15)	(0.04, 0.22) [‡]	(0.02, 0.21) [‡]	(-0.05, 0.14)	(-0.03, 0.15)	(-0.001, 0.17)	

β is the effect size (SD) on the cognitive test score per SD change in the predictor derived using adiposity measures (BMI and sum of skinfolds) as a continuous variable in multiple linear regression.

Model 1: unadjusted; Model 2: adjusted for the child's sex and current age; Model 3: model 2 + parent's education, occupation, income and SES

* β is the effect size (SD) on the cognitive test score per unit change in the predictor derived using adiposity measure (overweight/obesity) as a dichotomous variable in multiple linear regression.

[‡] $P < 0.05$;

[‡] $P < 0.01$;

[§] $P < 0.001$