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Association of birthweight and head circumference at birth to cognitive performance in 9-10 year old children in South India: prospective birth cohort study

Sargoor R. Veena, **Ghattu V. Krishnaveni**, **Andrew K. Wills**, **Anura V. Kurpad**, **Sumithra Muthayya**, **Jacqueline C. Hill**, **Samuel C. Karat**, **Kiran K. Nagarajaiah**, **Caroline H.D. Fall**, and **Krishnamachari Srinivasan**
Epidemiology Research Unit [S.R.V., G.V.K., S.C.K., K.K.N.], Holdsworth Memorial Hospital, Mysore-570021, Karnataka, India; MRC Epidemiology Resource Centre [A.K.W., J.C.H., C.H.D.F.], Southampton General Hospital, Southampton, SO166YD, UK; St. John's Research Institute [A.V.K., S.M., K.S.], St. John's National Academy of Health Sciences, Bangalore-560034, Karnataka, India

Abstract

To examine whether birthweight and head circumference at birth are associated with childhood cognitive ability in South-India, cognitive function was assessed using 3 core tests from the Kaufman Assessment Battery for children and additional tests measuring long-term retrieval/storage, attention and concentration, visuo-spatial and verbal abilities among 505 full-term born children (mean age 9.7-y). In multiple linear regression adjusted for age, sex, gestation, socio-economic status, parent's education, maternal age, parity, BMI, height, rural/urban residence, and time of testing, Atlantis score (learning ability/long-term storage and retrieval) rose by 0.1 SD per SD increase in newborn weight and head circumference respectively ($p<0.05$ for all) and Kohs' block design score (visuo-spatial ability) increased by 0.1 SD per SD increase in birthweight ($p<0.05$). The associations were reduced after further adjustment for current head circumference. There were no associations of birthweight and/or head circumference with measures of short-term memory, fluid reasoning, verbal abilities and attention and concentration. In conclusion higher birthweight and larger head circumference at birth are associated with better childhood cognitive ability. The effect may be specific to learning, long-term storage and retrieval, and visuo-spatial abilities, but this requires confirmation by further research.

Recent evidence links poor fetal growth to lower 'human capital' outcomes such as school achievement and adult income or assets (1). One mechanism could be sub-optimal fetal brain development, leading to decreased cognitive ability in individuals with reduced intra-uterine growth. A variety of adverse factors during pregnancy associated with lower birthweight could impair neurogenesis, which begins in early gestation and the processes of gliogenesis, cell migration and dendrite formation, which occur throughout gestation (2,3). Head circumference at birth has been shown to correlate with brain size (4).

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Corresponding Author: Sargoor R. Veena, BSc, MBBS Epidemiology Research Unit Holdsworth Memorial Hospital P.O. Box 38 Mandi Mohalla, Mysore 570021, South India Phone: 0091-821-2529347 Fax: 0091-821-2565607 veenasr@gmail.com.

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Studies reporting associations between lower birthweight or head circumference at birth and poorer cognitive function in later life (childhood or adulthood) have mainly focussed on ‘high-risk’ individuals (born low birthweight, premature, or IUGR) (5,6). However, several recent studies, including one systematic review (7), have reported associations between birthweight and cognitive functions even in children who were born at full-term, and across the normal range of birthweight and/or head circumference (8-14). Data from developing countries is scarce. While it has been shown, as in high-income countries, that low birthweight and/or IUGR babies have poorer childhood cognitive ability compared to normal weight babies (15-17) no studies have assessed cognitive function across the full range of birth size. Mean birth weight in India is around 2.7 kg, almost 800 g lower than among white Caucasian babies in high-income countries (18,19). This is thought to be mainly due to modifiable factors such as maternal stunting, dietary inadequacy and infections (20). Evidence that small size at birth is associated with impaired cognitive development would strengthen advocacy for policies to invest in maternal health.

Studies have shown that childhood cognitive function is strongly influenced by the family’s socio-economic status (SES) (5,7,10,12,21). These factors are also related to birth size, and may act partially through fetal development, but could equally influence cognitive function through genetic mechanisms or through post-natal nutrition, stimulation, growth and development. It is important to be able to adjust for these and other confounding variables in order to assess the potential importance of pre-natal development on cognitive ability in children.

The Mysore Parthenon Study (19,22) provides an opportunity to examine associations between birth measurements and cognitive function in healthy 9-10 y old children in an Indian population and control for potentially important confounders, including parental educational achievement and SES. Our objectives were to test the hypothesis that lower birthweight and smaller head circumference at birth, are associated with poorer scores in tests of cognitive function, independent of socio-economic factors.

Methods

Study design and Participants

The Mysore Parthenon study (19,22) is a prospective birth cohort study, designed to examine the incidence and determinants of gestational diabetes in India and its short and long-term effects in the offspring. Between June 1997 and August 1998, women booking consecutively into the antenatal clinic of the Holdsworth Memorial Hospital (HMH), Mysore, were recruited for the study. HMH is a general hospital and not a specialist referral unit. It is one of three large maternity units in Mysore and is situated in a relatively poor area of the city. Women who deliver at HMH are from all socio-economic groups, with the majority from the middle and lower middle class. Although patients pay for treatment, HMH offers concessions for the poorest and provides a niche between the free government hospitals and private nursing homes. Of 1233 recruited women satisfying the eligibility criteria (singleton pregnancy; <32 wks gestation determined by last menstrual period date or a first trimester ultrasound scan; and no prior history of diabetes), 830 (67%) participated and 674 delivered at HMH (Figure 1). Neonatal anthropometry was performed on 663 live born babies without major congenital anomalies. All the children (excluding 25 deaths and 8 with major medical problem) were followed up, with repeat anthropometry, annually on the child’s birthday (± 4 wks) till the age of 5 and thereafter every 6 months after the birthday (± 4 wks). These children were invited for assessment of their cognitive function at the age of 9-10 y (September 2007-May 2008). Of the 630 children, 542 (86%) underwent cognitive assessment and the remaining 88 (14%) were lost to follow-up (Figure 1). Excluding 37 preterm children, the current analysis is restricted to 505 (239 boys and 266 girls) full-term

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children. The study was approved by the HMH research ethics committee and informed verbal consent was obtained from parents and children.

Neonatal Anthropometry

Neonatal birthweight and occipito-frontal head circumference were measured according to a standard protocol, within 72-h of birth (19). Birthweight was measured to the nearest 5 g using a digital weighing scale (Seca, Hamburg, Germany). Head circumference was measured in triplicate to the nearest 1 mm, using a blank fibre-glass tape, which was marked and measured against a fixed ruler. The average of three readings was used.

Cognitive tests

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 the Kaufman Assessment Battery for children-second edition, 2004 (KABC-II) (24) and additional tests (25-28) that underwent an extensive adaptation process to ensure their applicability in the local cultural context. The adaptation initially included judgemental (qualitative) procedure consisting of iterations of translating, piloting and modifying the instrument (instructions, examples and items) based on the construct, language, culture, theory and familiarity applicable to the local cultural context (29). This was followed by a statistical (quantitative) procedure evaluating the adequacy of the adapted version using structural equation modelling, split half technique measuring internal consistency of cognitive domains with subtests, correlation tests for those domains without subtests and MANOVA to test the performance of the adapted version against gender and age. Subtests showed relatively high loadings on the general cognitive factor, reliabilities, largely replicating the Cattell-Horn-Carroll model underlying the original KABC-II and external relations with demographic characteristics such as children's age, gender, and scholastic achievement were as expected (30). The description of these cognitive tests are summarised in Table 1 and covered the domains of short-term memory, long-term memory and retrieval ability, visuo-spatial ability and language production. All tests were administered to each child in a single session of 60 to 90 min at the epidemiology research unit, HMH, in separate rooms free from distraction by one of the 2 trained masters' level child psychologists (unaware of children's birth measurements) in the local Kannada language.

Covariates

At the time of recruitment details of maternal age, parity, and area of residence (urban or rural) were recorded. None of the mothers had ever smoked or consumed alcohol. At 30 ± 2 wks gestation, the women had a 100g oral glucose tolerance test (OGTT) and detailed anthropometric measurements were measured by one of two trained observers using standardised methods as described previously (22). Season of birth (Summer: March-June (average temperature maximum: 33°C and minimum: 21°C); Rainy: July-October (29°C and 19°C) and Winter: November-February (29°C and 18°C) were recorded at the time of birth. We also collected details of the parent's educational level in completed years and current SES using the Standard of Living Index (SLI), a standardized questionnaire designed by National Family Health Survey-2 (31). For the children's current anthropometry, data collected at the 9.5-y follow-up for 479 children, and at the 9-y follow-up for the remaining 24 children were used.

Statistical Methods

Variables not satisfying normality assumptions were either log transformed (maternal BMI and Kohs block design score) or square root transformed (pattern reasoning score). Sex

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specific SD scores for birth measurements were calculated using internally generated growth charts which were constructed using the LMS (L=skewness; M=median; S=coefficient of variation) method (32). Scores for cognitive tests were z-standardised to facilitate interpretation. Comparisons of birthsize, current size and cognitive scores between boys and girls were made using t test. Associations of covariates with birth measurements (exposures) and cognitive ability (outcomes) were initially assessed using multiple linear regression, adjusting for sex and current age. For categorical covariates, (parity and season at birth), the largest category was used as the reference and tests of general association (Wald) were performed. Associations between birth measurements and cognitive function were then analysed using multiple linear regression, adjusting for variables that were associated with either birth measurements or cognitive outcomes. A series of models were used: model 1: gestational age at birth, the children's sex and current age; model 2: model 1 parameters plus the family's SES and parental education; model 3: model 2 parameters plus urban or rural residence, maternal age, BMI, height, parity and time of the day when cognitive tests were administered. Differences between the various cognitive tests in their associations with birth size were assessed by testing whether the difference in the Z-score for each test from the mean Z-score of the other tests was associated with birth size, using linear regression. Stata version 10 (Stata corporation, Texas, USA) was used for all analyses.

Results

Characteristics of the study cohort are summarized in Table 2. At birth boys were heavier and had larger head circumference than girls. Birth measurements (mean (SD)) were similar in those who took part in the study to those who did not (birthweight 2.905 (0.428) kg v 2.892 (0.432); $p = 0.8$ and head circumference 33.9 (1.3) cm v 33.7 (1.5); $p=0.3$). At the time of the study, boys were taller and had larger head circumference than girls. Girls scored better than boys in tests of word order, pattern reasoning, verbal fluency-names and coding. Correlations between the various cognitive test scores ranged from 0.2 to 0.3.

One percent of mothers were illiterate, approximately 34% had received only primary school education; 51% had completed secondary school education, and 14% were graduates/postgraduates/professionals. Corresponding figures for fathers were 3%, 34%, 40% and 23% respectively. Approximately 33% of children were born during winter, 35% during summer, and 32% during the rainy season.

Associations between confounding variables and birth measurements

Birthweight and head circumference increased with increasing gestational age, SES, parental education, maternal age, height and BMI, parity and were higher in those whose mothers had gestational diabetes (GDM) ($p<0.05$ for all; data not shown). There was no association of rural/urban residence or season of birth with birthweight and head circumference.

Associations between confounding variables and cognitive outcomes

All the cognitive scores increased with increasing SES and parental educational level ($p<0.001$ for all; data not shown). The cognitive performance of urban children was better than rural children in all the tests except verbal ability and attention and concentration ($p<0.01$ for all). Scores for tests of visuo-spatial ability and fluid reasoning increased with increasing maternal age ($p<0.001$for both). Children of multiparous mothers performed less well in tests of long-term storage and retrieval ability, planning and fluid reasoning and verbal abilities ($p<0.01$ for all) compared to primiparous children. Children examined in the morning (n=465) performed better compared to those examined in the afternoon (n=40; p for difference=0.03). There were no associations of maternal BMI, height, and season of birth with cognitive outcomes.

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Associations between birth measurements and cognitive outcomes

Multiple linear regression analyses describing the associations between birth measurements and cognitive performance are presented in Table 3. The regression co-efficient (β) is the SD change in outcome per SD increase in birth measurements. Birthweight and head circumference, were positively associated with learning ability/long-term storage and retrieval and visuo-spatial ability test scores, adjusted for the children's age, sex and gestation, (model 1). The associations were similar in boys and girls. These effects remained similar after adjusting for SLI and parental education (model 2), and on further adjustment for maternal age, BMI, height, parity, time of testing and urban/rural residence (model 3). The associations were diminished after adjusting for the children's current head circumference (model 4). The associations did not change even after excluding children born to GDM mothers. There were no associations with the other cognitive measures. There were differences between the association of scores for learning ability/long-term storage and retrieval and the other cognitive tests in relation to head circumference at birth (β=0.7 (95% CI: 0.20, 1.26); p=0.007) and birthweight (β=0.5 (95% CI:-0.04, 1.02); p=0.071) and similarly for the association of birthweight with verbal-ability scores (β=0.5 (95%CI: −0.02, 1.08; p=0.059).

Discussion

This is the first study from India examining associations between neonatal birth measurements and cognitive performance in 9-10 y old healthy children born at full-term. We found that birthweight and head circumference at birth were positively associated with 2 tests of cognitive function measuring learning, long-term storage and retrieval and visuo-spatial ability, after controlling for a range of potential confounders. The associations were reduced after adjusting for current (9.5 y) head circumference, suggesting that cognitive performance may be influenced by prenatal environmental or genetic factors that determine both head size at birth and post-natal head growth.

Strengths of the study were that in a large sample of children, we had standardised anthropometric measurements at birth, a battery of cognitive function tests specifically adapted for, and validated in, a South Indian population, and collected data on a variety of potential confounding factors including gestational age, parity, parents' education, rural/urban residence, standard of living index, and seasonality at birth. Unlike a number of earlier studies, which focussed on low birthweight or pre-term babies, our findings relate to healthy full-term babies. A limitation of the study was loss to follow-up (14%), which could have introduced selection bias. However, birth measurements were similar in children who participated in the study and in those lost to follow-up. Another limitation was non-availability of information about the children's current diet, and other possible parental confounders such as maternal psycho-social stress or parents' intellectual ability. A hospital-based study in India, where patients choose their healthcare facilities based on what they can afford, will not be representative of the whole population. The families visiting HMH would be representative of the 'middle-class' section of society, and would not include either the very poor or the very wealthy.

The positive associations of birthweight and/or head circumference at birth with subsequent cognitive abilities are consistent with findings from several previous studies (8-14), though some other studies found no associations (33,34). In a Finnish cohort, among the various birth measurements, head circumference had the most robust association with tests of cognitive abilities (11). Our findings suggest that, even though brain growth is relatively protected in utero and tends to be the last organ to experience growth restriction (35), variations in fetal growth can be associated with variations in brain growth and development. Associations in our study between birth size and learning ability, long-term storage and retrieval, and visuo-spatial ability but not with other cognitive domains may indicate an impact of pre-natal factors and /or a greater influence of post-natal environmental processes, such as parent's educational attainment, on some aspects of cognitive measures (36). The association with visuo-spatial ability in our study is in agreement with an earlier study (11). Our finding that some, but not all, aspects of cognitive function are related to birth size are also supported by the fact that the inter-correlations among the various cognitive tests used in our study were modest (ranging from 0.2 to 0.3), consistent with an earlier factor analysis of KABC, suggestive of relative independence of various cognitive measures (37). Furthermore, in our study there was some evidence of differences among the various cognitive tests, in their association with birth size. These differential effects could indicate domain-specific effects; however, they could also have arisen from multiple statistical testing and/or low statistical power. Further research is needed, in this and other populations, to investigate the specificity of associations between size at birth and the different cognitive domains. While interpreting the clinical importance of our findings, it should be kept in mind that the effect size of the associations between head circumference at birth and later cognitive abilities were small.

Our findings are consistent with other studies in that the associations between birth measurements and cognitive performance were largely independent of socio-environmental circumstances (7,9,18,38), suggesting that they are not fully explained by socio-economic confounding. Our findings that the associations of birthweight and head circumference with cognitive abilities were reduced after adjusting for current head size is also consistent with findings from another study (10) suggesting that a common causal pathway links size at birth, post-natal head growth, and childhood cognitive function.

In conclusion, the factors associated with intellectual developments are highly complex and interrelated but our results are consistent with the conclusion that prenatal head growth influences cognitive function, as measured at the age of 9-10 y. Head circumference has been used as a surrogate marker of brain volume in newborns and children (4) and has been used in previous studies that measured cognitive function (39), but a given head circumference is associated with a range of brain volumes due to age dependent changes in the relationship between head circumference and brain volume (40). While head circumference was an excellent predictor of brain volume in children up to 6 y of age, the relationship was modest in older children and adults. In addition, the brain volume is considered an imperfect measure of functional capacity of the various regions of the brain (41). Nevertheless, studies on children with attention deficit hyperkinetic disorder, a disorder with prominent cognitive dysfunction have shown that such children have smaller brain volume compared to healthy controls (42). In older adults, people with larger head circumference may have reduced risks of cognitive decline (43). While studies have shown that both genetic and environmental factors may impact maximal brain growth (44,45), identification of critical early environmental influences may be important in optimizing an individual's genetic potential for intellectual abilities and thus on overall 'capacity' in the population at large.

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Abbreviations

GDM	Gestational diabetes mellitus
HMH	Holdsworth Memorial Hospital
KABC	Kaufman Assessment Battery for children
SES	Socio-economic status

References

1. Victora CG, Adair L, Fall C, Hallal PC, Martorell R, Richter L, Sachdev HS. Maternal and Child Undernutrition Study Group. Maternal and child undernutrition: consequences for adult health and human capital. Lancet. 2008; 371:340–357. [PubMed: 18206223]
2. Tanner, JM. Fetus into man: Physical growth from conception to maturity. Harvard University Press; Cambridge: 1990.
3. Webb SJ, Monk CS, Nelson CA. Mechanisms of postnatal neurobiological development: implications for human development. Dev Neuropsychol. 2001; 19:147–171. [PubMed: 11530973]
4. Cooke RW, Lucas A, Yudkin PL, Pryse-Davies J. Head circumference as an index of brain weight in the fetus and newborn. Early Hum Dev. 1977; 1:145–149. [PubMed: 617306]
5. Hack M, Klein NK, Taylor HG. Long-term developmental outcomes of low birth weight infants. Future Child. 1995; 5:176–196. [PubMed: 7543353]
6. Bhutta AT, Cleves MA, Casey PH, Cradock MM, Anand KJ. Cognitive and Behavioural Outcomes of School-Aged Children Who Were Born Preterm: a meta-analysis. JAMA. 2002; 288:728–737. [PubMed: 12169077]
7. Shenkin SD, Starr JM, Deary IJ. Birth weight and cognitive ability in childhood: a systematic review. Psychol Bull. 2004; 130:989–1013. [PubMed: 15535745]
8. Brennan TL, Funk SG, Frothingham TE. Disproportionate intra-uterine head growth and developmental outcome. Dev Med Child Neurol. 1985; 27:746–750. [PubMed: 4092847]
9. Richards M, Hardy R, Kuh D, Wadsworth ME. Birth weight and cognitive function in the British 1946 birth cohort: longitudinal population based study. BMJ. 2001; 322:199–203. [PubMed: 11159613]
10. Gale CR, O'Callaghan FJ, Bredow M, Martyn CN. The influence of head growth in fetal life, infancy, and childhood on intelligence at the ages of 4 and 8 years. Pediatrics. 2006; 118:1486–1492. [PubMed: 17015539]
11. Heinonen K, Räikkönen K, Pesonen AK, Kajantie E, Andersson S, Eriksson JG, Niemelä A, Vartia 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–e1333. [PubMed: 18450875]
12. Silva A, Metha Z, O'Callaghan FJ. The relative effect of size at birth, postnatal growth and social factors on cognitive function in late childhood. Ann Epidemiol. 2006; 16:469–476. [PubMed: 16165368]
13. Tong S, Baghurst P, McMichael A. Birthweight and cognitive development during childhood. J Paediatr Child Health. 2006; 42:98–103. [PubMed: 16509907]
14. Broekman BF, Chan YH, Chong YS, Quek SC, Fung D, Low YL, Ooi YP, Gluckman PD, Meaney MJ, Wong TY, Saw SM. The influence of birth size on intelligence in healthy children. Pediatrics. 2009; 123:e1011–e1016. [PubMed: 19482733]
15. Grantham-McGregor SM, Lira PI, Ashworth A, Morris SS, Assuncao AM. The development of low birth weight term infants and the effects of the environment in northeast Brazil. J Pediatr. 1998; 132:661–666. [PubMed: 9580767]
16. Villar J, Smeriglio V, Martorell R, Brown CH, Klein RE. Heterogeneous growth and mental development of intrauterine growth-retarded infants during the first 3 years of life. Pediatrics. 1984; 74:783–791. [PubMed: 6493873]

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17. Chaudhari S, Otiv M, Chitale A, Pandit A, Hoge M. Pune low birth weight study--cognitive abilities and educational performance at twelve years. Indian Pediatr. 2004; 41:121–128. [PubMed: 15004297]
18. Yajnik CS, Fall CH, Coyaji KJ, Hirve SS, Rao S, Barker DJ, Joglekar C, Kellingray S. Neonatal anthropometry: the thin-fat Indian baby. The Pune Maternal Nutrition Study. Int J Obes Relat Metab Disord. 2003; 27:173–180. [PubMed: 12586996]
19. Krishnaveni GV, Hill JC, Veena SR, Leary SD, Saperia J, Chachyamma KJ, Karat SC, Fall CH. Truncal adiposity is present at birth and in early childhood in South Indian children. Indian Pediatr. 2005; 42:527–538. [PubMed: 15995269]
20. Sachdev, HP. Low birth weight in South Asia. In: Gillespie, SR., editor. Malnutrition in South Asia: A Regional Profile. UNICEF, ROSA; Kathmandu: 1997. p. 23-50.
21. Richards M, Hardy R, Kuh D, Wadsworth ME. Birthweight, postnatal growth and cognitive function in a national UK birth cohort. Int J Epidemiol. 2002; 31:342–348. [PubMed: 11980795]
22. Hill JC, Krishnaveni GV, Annamma I, Leary SD, Fall CH. Glucose tolerance in pregnancy in South India: Relationships to neonatal anthropometry. Acta Obstet Gynecol Scand. 2005; 84:159–165. [PubMed: 15683377]
23. Carroll, JB. Human cognitive abilities: A survey of factor-analytic studies. Cambridge University Press; New York: 1993. p. 143-440.
24. Kaufman, AS.; Kaufman, NL. Kaufman Assessment Battery for Children. Second Edition: Manual. Pearson; San Antonio: 2004.
25. Korkman M, Kemp SL, Kirk U. Effects of age on neurocognitive measures of children ages 5 to 12: A cross-sectional study on 800 children from the United States. Dev Neuropsychol. 2001; 20:331–354. [PubMed: 11827092]
26. Kohs, SC. Intelligence measurement: a psychological and statistical study based upon the Block-design tests. Macmillan; Oxford: 1923.
27. Wigg CM, Duro LA. The Koh's block tests as an important instrument to investigate the visuo-spatial impairments in myotonic dystrophy. Part I. Quantitative and qualitative analysis. Arq Neuropsiquiatr. 1999; 57:547–555. [PubMed: 10667275]
28. Wechsler, D. Manual for the Wechsler Intelligence Scale for Children. 3rd edition. Manual Psychological Corporation; San Antonio: 1991.
29. Malda M, van de Vijver FJ, Srinivasan K, Transler C, Sukumar P, Rao K. Adapting a cognitive test for a different cultures: An illustration of qualitative procedures. Psychol Sci. 2008; 50:451–468.
30. Malda M, van de Vijver FJ, Srinivasan K, Transler C, Sukumar P. Traveling with cognitive tests: testing the validity of a KABC-II adaptation in India. Assessment. 2009 (in press).
31. International Institute for Population Sciences (IIPS). Operations Research Centre (ORC). Macro 2001 National Family Health Survey (NFHS-2), India 1998-1999. IIPS; Karnataka, Mumbai: p. 24-31.
32. Cole TJ, Green PJ. Smoothing reference centile curves: the LMS method and penalized likelihood. Stat Med. 1992; 11:1305–1319. [PubMed: 1518992]
33. Martyn CN, Gale CR, Sayer AA, Fall C. Growth in utero and cognitive function in adult life: follow up study of people born between 1920 and 1943. BMJ. 1996; 312:1393–1396. [PubMed: 8646096]
34. Sorensen HT, Sabroe S, Olsen J, Rothman KJ, Gillman MW, Fischer P. Birth weight and cognitive function in young adult life: historical cohort study. BMJ. 1997; 315:401–403. [PubMed: 9277604]
35. Yajnik CS. Obesity epidemic in India: intrauterine origins? Proc Nutr Soc. 2004; 63:387–396. [PubMed: 15373948]
36. Klenberg L, Korkman M, Lahti-Nuuttila P. Differential development of attention and executive functions in 3-to-12 year old Finnish children. Dev Neuropsychol. 2001; 20:407–428. [PubMed: 11827096]
37. Valencia RR, Rankin RJ. Factor analysis of the K-ABC for groups of Anglo and Mexican American children. J Educ Meas. 1986; 23:209–219.

38. Lawlor DA, Bor W, O'Callaghan MJ, Williams GM, Najman JM. Intrauterine growth and intelligence within sibling pairs: findings from the Mater-University study of pregnancy and its outcomes. J Epidemiol Community Health. 2005; 59:279–282. [PubMed: 15767380]

39. Vernon, PA.; Wickett, JC.; Bazana, PG.; Stelmark, RM. The neuropsychology and psychophysiology of human intelligence. In: Sternberg, RJ., editor. Handbook of Intelligence. Cambridge University Press; Cambridge: 2000. p. 245-264.

40. Bartholomeusz HH, Courchesne E, Karns CM. Relationship between head circumference and brain volume in healthy normal toddlers, children and adults. Neuropediatrics. 2002; 33:239–241. [PubMed: 12536365]

41. Drachman DA. Hat size, brain size, intelligence and dementia: What morphometry can tell us about brain function and disease? Neurology. 2002; 59:156–157. [PubMed: 12136048]

42. Castellanos FX, Lee PP, Sharp W, Jeffries NO, Greenstein DK, Clasen LS, Blumenthal JD, James RS, Ebens CL, Walter JM, Zijdenbos A, Evans AC, Gledd JN, Rapoport JL. Developmental trajectories of brain volume abnormalities in children and adolescents with attention-deficit/hyperactivity disorder. JAMA. 2002; 288:1740–1748. [PubMed: 12365958]

43. Gale CR, Walton S, Martyn CN. Foetal and postnatal head growth and risk of cognitive decline in old age. Brain. 2003; 126:2273–2278. [PubMed: 12821508]

44. Toga AW, Thompson PM. Genetics of brain structure and intelligence. Annu Rev Neurosci. 2005; 28:1–23. [PubMed: 15651931]

45. Gale CR, O'Callaghan FJ, Godfrey KM, Law CM, Martyn CN. Critical periods of brain growth and cognitive function in children. Brain. 2004; 127:321–329. [PubMed: 14645144]

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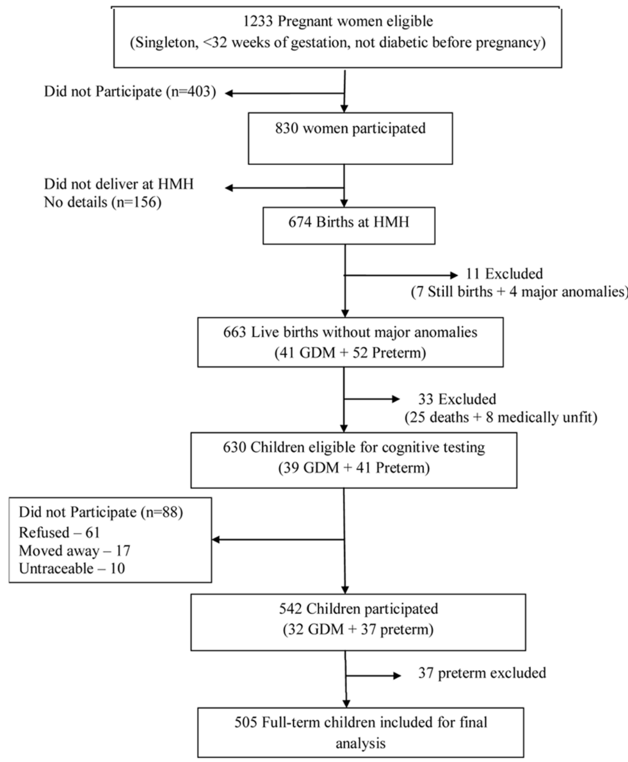

Figure 1.
Flow diagram depicting the study participants.

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Table 1

Description of the cognitive tests used in the study

Tests from KABC-II* **(24)**		
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 (25) 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 (26, 27)	A psychometric test in which the child arranges groups of 4, 9, or 16 multi-coloured blocks to copy picture designs presented on test cards.	Visuo-spatial problem solving, visual perception and organization
6. Coding-WISC-III** (28)	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

Characteristics of the study cohort

	Boys (n=239)		Girls (n=266)		
Birth measurements	**Mean**	**(SD)**	**Mean**	**(SD)**	**P***
Birthweight (kg)	2.955	(0.433)	2.860	(0.420)	0.01
Head circumference (cm)	34.2	(1.3)	33.6	(1.2)	<0.0001
Gestational age (wk)	39.5	(1.2)	39.7	(1.1)	0.09
Measurements at the time of cognitive testing					
Age (y)	9.7	(0.3)	9.7	(0.3)	0.7
Height (cm)	131.4	(5.5)	130.4	(5.9)	0.057
BMI (kg/m^2)	14.6	(1.7)	14.7	(2.0)	0.6
Head circumference (cm)	50.8	(1.4)	50.5	(1.5)	0.064
Tests of cognitive function					
Atlantis (score)	67.6	(17.9)	68.2	(16.8)	0.7
Word order (score)	16.2	(2.6)	16.7	(2.5)	0.02
Pattern reasoning (score)**	9	(4, 13)	11	(6, 14)	0.004
Verbal fluency (score) – test1 – animals	11.9	(3.2)	12.3	(3.4)	0.2
– test2 – first names	14.8	(4.1)	17.5	(5.2)	<0.0001
Kohs Block Design (score)**	77.5	(63.7, 88.3)	76.4	(63.7, 88.5)	0.6
Coding-WISC-III (score)	30.4	(7.5)	35.1	(8.1)	<0.0001
Maternal characteristics at recruitment in pregnancy					
Age (y)	23.9	(4.2)			
Parity (No (%)) –0	256	(50.7)			
–1	170	(33.7)			
–2 or more	79	(15.6)			
Height (cm)	154.3	(5.3)			
BMI (kg/m^2)**	23.2	(21.0, 26.0)			
Glucose tolerance test (No (%)) – Normal	450	(93.6%)			
–Abnormal	31	(6.4%)			
Parent's current socio-economic status					
Standard of living index (score)	36.5	(8.2)			

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Birth measurements		Boys (n=239) Mean	(SD)	Girls (n=266) Mean	(SD)	P*
Maternal education (No (%))						
	a) <10 y of education	177	(35.1%)			
	b) 10 y of education	155	(30.8%)			
	c) >10 y of education	172	(34.1%)			
Paternal education (No (%))						
	a) <10 y of education	187	(37.1%)			
	b) 10 y of education	199	(39.5%)			
	c) >10 y of education	118	(23.4%)			
Residence (No (%))	a) Urban	368	(72.9%)			
	b) Rural	137	(27.1%)			

* P value for the difference between boys and girls derived using t test;

** transformed variable; values are median and inter quartile range;

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Table 3

Associations between birth measurements and cognitive tests: Multiple linear regression analysis

Cognitive Tests							
Birth Measurements	Atlantis (SD)	Word Order (SD)	Pattern Reasoning (SD)	Verbal Fluency Animals (SD)	Verbal Fluency First Names (SD)	Kohs block design (SD)	Coding-WISC-III (SD)
	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)	B (95% CI)
Birthweight (SD)							
Model 1	0.1 (0.03, 0.22)**	0.1 (−0.03, 0.16)	0.1 (−0.003, 0.18)	0.04 (−0.05, 0.13)	−0.01 (−0.10, 0.08)	0.2 (0.07, 0.25)**	0.03 (−0.05, 0.12)
Model 2	0.1 (−0.001, 0.18)	0.02 (−0.07, 0.11)	0.03 (−0.05, 0.12)	0.01 (−0.09, 0.10)	−0.04 (−0.13, 0.05)	0.1 (0.02, 0.20)*	−0.005 (−0.09, 0.08)
Model 3	0.1 (0.02, 0.21)*	0.03 (−0.06, 0.13)	0.04 (−0.05, 0.14)	0.03 (−0.07, 0.13)	−0.05 (−0.15, 0.05)	0.1 (0.03, 0.22)*	−0.04 (−0.14, 0.05)
Model 4	0.06 (−0.04, 0.16)	−0.02 (−0.12, 0.08)	0.005 (−0.09, 0.10)	−0.01 (−0.11, 0.10)	−0.06 (−0.16, 0.04)	0.09 (−0.01, 0.19)	−0.07 (−0.17, 0.02)
Head circumference (SD)							
Model 1	0.2 (0.07, 0.26)**	0.1 (0.01, 0.19)*	0.06 (−0.04, 0.15)	0.02 (−0.07, 0.12)	0.02 (−0.08, 0.11)	0.1 (0.04, 0.23)**	0.02 (−0.07, 0.11)
Model 2	0.1 (0.03, 0.21)**	0.05 (−0.04, 0.15)	−0.01 (−0.09, 0.08)	−0.02 (−0.11, 0.08)	−0.02 (−0.11, 0.07)	0.08 (−0.01, 0.17)	−0.03 (−0.12, 0.06)
Model 3	0.1 (0.04, 0.23)**	0.07 (−0.02, 0.16)	0.001 (−0.09, 0.09)	−0.01 (−0.10, 0.09)	−0.01 (−0.10, 0.09)	0.08 (−0.01, 0.18)	−0.05 (−0.14, 0.04)
Model 4	0.08 (−0.02, 0.19)	0.004 (−0.10, 0.11)	−0.06 (−0.16, 0.04)	−0.06 (−0.17, 0.04)	−0.05 (−0.15, 0.06)	0.04 (−0.06, 0.14)	−0.12 (−0.22, −0.02)*

*p≤0.05;

**p≤0.01

Model 1 adjusted for sex, gestation and child’s age at the time of study;

Model 2 adjusted for model 1 parameters + SLI, parent’s education;

Model 3 adjusted for model 2 parameters + parity, maternal age, BMI, height at pregnancy, urban/rural residence and time of testing;

Model 4 adjusted for model 3 parameters + child’s current head circumference.