Cranial Size and IQ in Asian Americans From Birth to Age Seven

J. PHILIPPE RUSHTON
University of Western Ontario

The Collaborative Perinatal Project is a longitudinal study of over 53,000 children followed from birth to 7 years. Up to now, studies have analyzed data on the 17,000 European American children and the 19,000 African American children. Here data are reported and analyzed for a sub-sample of 100 Asian Americans. The Asian sub-sample averaged a higher IQ (110) at age 7 than did the white (102) or the black sub-samples (90). At birth, 4 months, 1 year, and 7 years, the Asians averaged a larger cranial capacity than did the whites or blacks despite being smaller in stature and lighter in weight (at age 7, Asian z scores from -0.20 to -0.40 in height and weight). Head circumference (or cranial capacity) at birth correlated .46 with head circumference (or cranial capacity) at age 7 which correlates .21 with IQ test scores at age 7. The Asians also averaged a higher parental socioeconomic status at birth than did the whites or blacks (Asian z scores = +0.41 and 1.27 respectively). Socioeconomic status related to cranial capacity and to IQ scores but not to stature or to weight, neither of which correlated with IQ. Males averaged larger body and cranial sizes than did females (and, by 12 months, larger cranial sizes even after correction for body size).

Brain-size and IQ are most clearly shown to be related using Magnetic Resonance Imaging (MRI), which creates a three dimensional image of the brain in living subjects. Rushton and Ankney's (1996) review of the literature found an overall correlation of .44 between MRI-measured brain size and IQ in eight separate studies with a total sample size of 381 non-clinical adults. This correlation is roughly equivalent to the strength of the relationship between socioeconomic status of origin and IQ. Rushton and Ankney (1996) also found the brain size/IQ relation in seven MRI studies of *clinical* adults (N = 312) with an overall correlation of .24. In 15 studies using external head measurements with adults (N = 6,437) the overall correlation was .15; in 17 studies using external head measurements with children and adolescents (N = 45,056), the overall correlation was .21. The relationship between a subtest's correlation with brain size and its g-loading (from the general factor that emerges from factor analysis of mental ability tests) is even larger—over .60 (Jensen, 1994, 1998;

Direct all correspondence to: J. Philippe Rushton, Department of Psychology, University of Western Ontario, London, Ontario N6A 5C2, Canada <Rushton@sscl.uwo.ca.>.

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Wickett, 1997; Wickett, Vernon & Lee, 1996). This shows that the more a subtest loads on the *g*-factor, the higher its correlation with brain size.

Individual differences in brain size at birth predict individual differences in brain size at 8 months, 1 year, 4 years, and 7 years as well as IQ scores at age 7. This conclusion is based on the results of the National Collaborative Perinatal Project which followed 19,000 African American children and 17,000 European American children from birth to 7 years (Broman, Nichols, Shaughnessy & Kennedy, 1987). Head circumference was measured at all ages and the Wechsler Intelligence Scale for Children individually administered at age 7. For both the black children and the white, head circumference at birth predicted head circumference at 7 years from .39 to .47 ($p < .001$) and head circumference at both ages correlated with IQ at age 7 from .12 to .24 ($p < .001$). (The importance of correlations of this size is taken up in the discussion).

Mean racial differences in brain size show up early in life. Data from the Collaborative Perinatal Project found, despite substantial overlap in the distributions, that white children had a larger head circumference at birth, 4 months, 1 year, 4 years, and 7 years than did black children, the mean difference being about 0.36 cm or approximately 0.2 *SD* (Broman, 1989; Rushton & Ankney, 1996, Table 1). The greater average head size of white children is not simply a function of greater average body size because, although white children are born taller in stature and heavier in weight than black children, by age 7 "catch-up growth" leads black children to be larger in body size than white children (2.27 cm or 0.40 *SD* taller at age 7; Broman et al., 1987, p. 161, Table 8-19). From 7 to 17 years, the mean white-black difference in cranial capacity is about 16 cm^3 (Lynn, 1993; Rushton & Osborne, 1995) and in adulthood the mean difference varies from 34 cm^3 to over 100 cm^3 (Beals, Smith & Dodd, 1984; Ho, Roessmann, Straumfjord & Monroe, 1980; Rushton, 1992, 1994). Recently, an MRI study carried out in Britain has confirmed this white-black difference in brain size, although little information was provided on ethnic background and no details on how, or if, the samples were matched for age, sex, or body size (Harvey, Persaud, Ron, Baker & Murray, 1994).

Less well known than the white-black difference in average brain size (and less well established) is that Asians have an average brain size greater than that of whites, although the mean difference sometimes only emerges after correcting for body size. (Typically Asians are shorter in stature and lighter in weight than are Europeans). Fortunately, familiarity with these data may be increasing; the Chair of the recent American Psychological Association's (APA) Task Force Report on Intelligence (Neisser et al., 1996) subsequently acknowledged that, with respect to "racial differences in the mean measured sizes of skulls and brains (with East Asians having the largest, followed by Whites and then Blacks)...there is indeed a small overall trend" (Neisser, 1997, p. 80). Because the literature for Asian samples is not so well known, I will briefly review it according to measurement procedure: (a) brain mass at autopsy, (b) volume of empty skulls using filler, and (c) volume estimated from external head sizes.

Using brain mass at autopsy, Tobias (1970) critically reviewed the early literature and concluded that all interracial comparisons were "invalid," and "meaningless," because 14 crucial variables had been left uncontrolled. However, when Rushton (1988) averaged the midpoints of a range of scores provided by Tobias (1970, p. 6, Table 2), the "Mongoloid Series" (Tobias's term) averaged 1,368 grams and the Caucasoids 1,378 grams. When body size was taken into account, by calculating the "millions of excess nerve cells" (derivable from equations based on brain/body-weight relationships), Mongoloids averaged 8,990 million excess neurons compared to 8,650 million for Caucasoids (Tobias, 1970, p. 9, Table 3).

Using endocranial volume, Beals et al. (1984, p. 307, Table 5) analyzed about 20,000 skulls from around the world. No information on height or weight was available, so these estimates are uncorrected for body size. East Asians averaged 1,415 cm^3 (SD = 51), Europeans averaged 1,362 cm^3 (SD = 35), and Africans averaged 1,268 cm^3 (SD = 85).

Using external head measures to calculate cranial capacities, Rushton (1991) analyzed 24 international (male) military samples collated in 1978 by the U.S. National Aeronautics and Space Administration (NASA) and found that East Asians averaged 1,460 cm^3 (SD = 47) and Europeans 1,446 cm^3 (SD = 58). Subsequently, Rushton (1992) analyzed a stratified random sample of 6,325 U.S. Army personnel measured in 1988 for fitting helmets and found that Asian Americans averaged 1,416 cm^3 (SD = 104 cm^3), European Americans 1,380 cm^3 (SD = 92), and African Americans 1,359 cm^3 (SD = 95). Finally, Rushton (1994) analyzed data from tens of thousands of people from around the world collated in 1990 by the International Labour Office in Geneva and found that East Asians from the Pacific Rim averaged 1,308 cm^3 (SD = 37), Europeans 1,297 cm^3 (SD = 38), and Africans 1,241 (SD = 38).

No precise answer is possible, of course, to the question of how large the average racial differences in brain size are. The world database was summarized by Rushton (1995, pp. 126-132, Table 6.6) from (a) autopsies, (b) endocranial volume, (c) head measurements, and (d) head measurements corrected for body size, and found in cm^3 or equivalents: East Asians and their descendants = 1,351, 1,415, 1,335, 1,356 (mean = 1,364); Europeans and their descendants = 1,356, 1,362, 1,341, 1,329 (mean = 1,347); and Africans and their descendants = 1,223, 1,268, 1,284, and 1,294 (mean = 1,267). The review found the overall mean for Asians to be 17 cm^3 more than that for Europeans and 97 cm^3 more than that for Africans. Within-race differences, due to method of estimation, averaged 31 cm^3.

Mean IQ scores parallel those in average brain size, with Asians in both Asia and in North America averaging an IQ of about 106, whites in Australasia, Europe, and North America averaging about 100, blacks in North America and the Caribbean averaging about 85, and blacks in sub-Saharan Africa averaging about 70 (Lynn, 1991, 1997; Herrnstein & Murray, 1994; Rushton, 1995). Like the Asian-European brain size contrast, the Asian-European IQ difference is less well known and less well accepted. The current paper adds jointly to the literature on Asian brain size and IQ by providing new data on Asian Americans as infants and young children from the Collaborative Perinatal Project.

METHOD

The National Collaborative Perinatal Project, a large-scale epidemiological study sponsored by the National Institutes of Health, collected data over a 16-year period from 12 medical centers throughout the United States. Between 1959 and 1974, the offspring from 53,043 pregnancies were followed from gestation through age eight by multidisciplinary research teams who assessed the physical growth and cognitive development of the children at birth, 4 months, 8 months, 1 year, 4 years, and 7 years (Broman, Nichols & Kennedy, 1975; Nichols & Chen, 1981; Broman et al., 1987). At age 7, the Wechsler Intelligence Scale for Children was individually administered by specially trained psychometricians employed by the Collaborative Perinatal Project.

In both their social and medical characteristics, the registrants were representative of patients receiving parental care in collaborating medical centers, all of which were in urban areas. In the original study, 45% of women self-reported as being white, 47% as black. The total sample had a median age of 24 at the time of enrollment. Mean socioeconomic index scores on a 95-point scale based on head of household's education, occupation and family income were 57 (*SD* = 19) for whites and 38 (*SD* = 18) for blacks. Some of the data on the children and their siblings were recently analyzed by Jensen and Johnson (1994) who found a within-family head-size/IQ correlation of .11 at age 7 in both the white and the black samples.

Previous analyses of the Perinatal Project have been limited to children whose mothers self-identified as either black or white. To obtain the data on Asians, in October of 1996, this author visited the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) in Bethesda, Maryland, where the data are stored on microfiche. All children identified as having Asian mothers who also had IQ scores available at age 7 were included in the Asian subsample. (Identification numbers for this purpose were provided by the NINCDS.) For each subject the measures recorded included race/nationality of mother, race/nationality of father, sex of child, child's IQ at age 7, and child's height, weight, and head circumference at birth, 4 months, 1 year, and 7 years and the socioeconomic index score based on education and occupation of head of household and on family income. The study sample consisted of 53 girls and 47 boys. Most of the Asians were Chinese, Korean, and Japanese, but there were also several Filipinos.

Head circumference was recorded and also transformed into cranial capacities so as to make the results directly comparable to those cited in the Introduction reporting volumes. There are no agreed on methods for transforming cranial circumference into cranial volume or brain weight although formulas (essentially regression equations) do exist. Jensen and Johnson (1994, p. 319, Table 6) reported cranial capacities based on formulas given by Lee and Pearson (1901, p. 262). Other formulas are given by Epstein and Epstein (1978) and by Jørgensen, Paridon and Quaade (1961). Unfortunately, these equations include either a subjective component in reading from a graph (Epstein & Epstein, 1978) or give uninterpretable results for newborns.

One simple solution to the problem of how to transform head circumferences into head volumes at different ages is to use the formula for the volume of a hemisphere:

$$\text{Volume (cm}^3) = C^3/12\pi^2 \text{ or } C^3/118.4$$

where C is circumference, and π is the constant 3.1416. Of course, such a formula can provide only a rough approximation because the head is not a perfect sphere and there is considerable variation in head shape. However, the formula gives results directly comparable to brain weights derived at postmortem and to cranial capacities derived from external head measures thereby facilitating comparisons with results from studies using volume measures (Rushton & Ankney, 1996).

I examined the validity of the above formula by comparing (sex-combined) cranial capacities calculated for 17,000 white children from head circumference data given by Broman et al. (1987) with brain weights from autopsies listed by Voigt and Pakkenberg

(1983, pp. 291-293, Table I; p. 294, Table II). At birth, 4 months, 1 year, and 7 years the resulting cranial capacities are 332, 578, 806, and 1154 cm^3, respectively, compared to brain weights of 373, 582, 919, and 1,296 grams. The brain-weights just presented, however, are approximately 9% above the weight *in vivo* because as Voigt and Pakkenberg (1983, p. 299) note, brain weight increases post-mortem, mostly during the first 12 hours after death. Thus, "real" brain weights at birth, 4 months, 1 year, and 7 years are 339, 530, 836, and 1,179 grams, respectively, which transform to cranial capacities (1 cm^3 = 1.036 g; Hofman, 1991) of 351, 549, 866, and 1,221 cm^3, only about 6% higher than those I calculated from head circumferences.

The validity of head perimeter had earlier been shown by Van Valen (1974) who estimated a 0.50 correlation with autopsy data. More recently, Wickett (1997) used MRI to measure brain volume in 73 male university students, and found correlations of from .50 to .73 with head circumference and other external head measures. Moreover, he found the discrepancy between total volume from MRI and those from external head measures to be only 60 to 80 cm^3.

Table 1. Means, Standard Deviations, and Sex Differences for Head Circumference (HC), Cranial Capacity (CC), Height, Weight, IQ and SES on 100 Asian American Children from the Collaborative Perinatal Project

	Boys			*Girls*			*Combined*			*Sex Differences*
Variable	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*	*p*
Birth										
HC (cm)	47	34.1	1.5	52	34	1.3	99	34.1	1.4	ns+
CC (cm^3)	47	337	43	52	332	38	99	335	41	ns+
Height (cm)	47	50	2.8	51	49.6	2.2	98	49.8	2.5	ns
Weight (kg)	47	3.17	0.43	52	3.14	0.39	99	3.16	0.41	ns
SES	47	68	22	53	64	22	100	66	22	ns
4 Months										
HC (cm)	42	41.5	1.3	52	40.5	1.4	94	41	1.4	.005+
CC (cm^3)	42	606	56	52	565	57	94	586	60	.005+
Height (cm)	42	63.5	2.7	50	61.3	3.6	92	62.3	3.4	0
Weight (kg)	42	6.92	0.88	51	6.23	0.69	93	6.54	0.85	0
1 Year										
HC (cm)	41	46.3	1.6	45	45.4	1.7	86	45.9	1.7	.05*
CC (cm^3)	41	844	90	45	794	93	86	819	94	.05*
Height (cm)	41	75.4	4.7	45	74.4	6.3	86	74.9	5.6	ns
Weight (kg)	42	10.11	1.29	44	9.63	1.81	86	9.86	1.58	ns
7 Years										
HC (cm)	46	52	1.4	52	51.3	1.6	98	51.6	1.5	.05*
CC (cm^3)	46	1193	96	52	1140	102	98	1167	102	.05*
Height (cm)	45	121.4	5.5	52	118.5	5.1	97	120	5.5	0.01
Weight (kg)	45	23.21	3.23	52	21.73	2.89	97	22.4	3.12	0.02
IQ Wechsler	47	114	15	53	106	14	100	110	15	0.01

Notes: CC = $HC^3/118.4$

+after controlling for height and weight the sex difference is (or remains) not significant

*after controlling for height and weight the sex difference remains significant

RESULTS

Table 1 lists the sample size, mean and standard deviation on each variable for the boys, girls, and combined samples. Note that small differences in head circumference correspond to larger differences in cranial capacity. Head circumference (or cranial capacity) at birth correlated .46 with head circumference (or cranial capacity) at age 7; head circumference (or cranial capacity) correlated .21 with IQ test scores at age 7. Cranial size at birth did not correlate with IQ at age 7 (.03). At 7 years, height and weight correlated with cranial capacity (r = .31 and .36, respectively, p <.01), but not with IQ scores (r = .10 and .03).

Socioeconomic Status

Parental social class was measured at birth and at age 7 with both these estimates correlating .78. Socioeconomic status at birth correlated with IQ at age 7 (r = .55, p <.01) and with cranial capacity at age 7 (r = .23, p < .01). Socioeconomic status was uncorrelated with stature or weight whether measured at birth or at 7 years.

Sex Differences

Also shown in Table 1 are the significance levels for sex differences based on one-tailed t-tests. From birth onwards, boys averaged larger heads, were taller, and had heavier bodies than did girls, although the differences do not reach statistical significance until 4 months of age (or until 12 months if height and weight or $\log_n$ weight are statistically controlled). Figure 1 plots the sex differences in mean cranial size uncorrected for body size across the four age periods of this longitudinal study along with those from the U.S. Army reported by Rushton (1992, p. 405, Table 1). According to these data and those of Ankney (1992), males begin life with a cranial capacity about 3 cm^3 larger than do females and grow quickly to become 40 to 50 cm^3 larger. The sex difference then remains stable until the adolescent growth spurt, which ends at maturity, with males being about 160 cm^3 greater.

Low Birth Weight Babies and "Catch-up Growth"

Two children (both boys) were born with birth weights and head circumferences more than 3 standard deviations below the mean and were transferred to wards for the premature. Removing these outliers only fractionally altered the birth means and standard deviations, the sex differences, and the correlations between head size and IQ. For example, with the outliers removed, head circumference at birth correlated with head circumference at age 7 (r = .51, p <. 01), and with IQ at age 7 (r = .04, *ns*); head circumference at 7 years correlated with IQ at 7 years (r = .24, p < .05).

The two outliers provide a useful illustration of the phenomenon of "catch-up growth." At birth, the two boys averaged 1.816 kilograms in body weight with a head circumference of 29.25 cm—both measures 3 standard deviations below the mean. However, these disadvantages (for example, in cranial size) were reduced to -0.77 *SD* by 4 months, to -0.60 *SD* by 1 year, and to only -0.10 *SD* by 7 years. At age 7, one boy had an IQ of 115 and the other of 111.

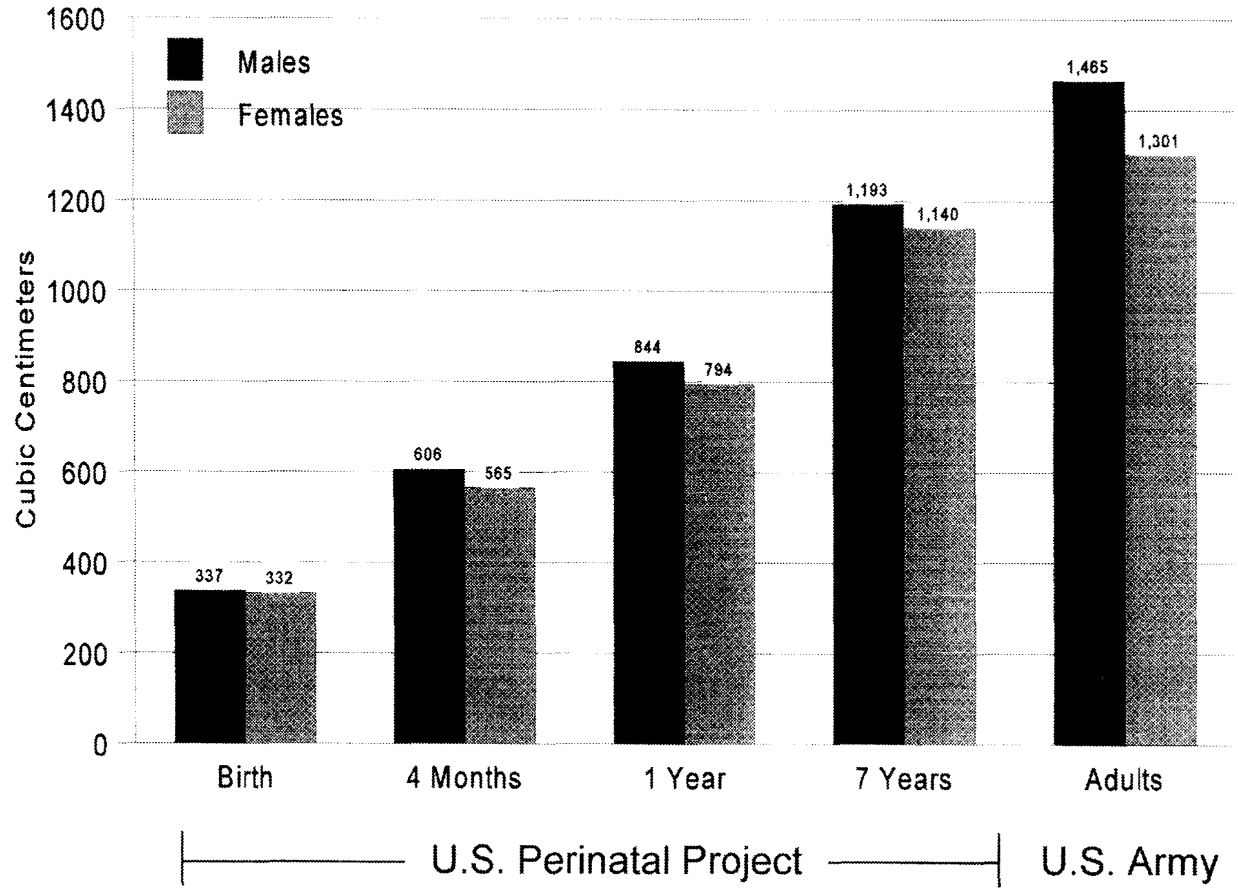

Figure 1. Mean Sex Differences in Cranial Capacity (cm^3) For Asian Americans at Birth, 4 Months, 1 Year, 7 Years and at Adulthood

Table 2. Means and Standard Deviations for Head Circumference (HC), Cranial Capacity (CC), Height, Weight, SES and IQ for Sex-Combined Samples of Asian American, European American, and African American Children from the Collaborative Perinatal Project

	Asian Americans			*European Americans*			*African Americans*		
Variable	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*
Birth									
HC (cm)	99	34.1	1.4	16877	34	1.5	18883	33.4	1.7
CC (cm^3)	99	335	41	16877	332	-	18883	315	-
Height (cm)	98	49.8	2.5	16805	50.4	2.6	18835	49.3	2.8
Weight (kg)	99	3.2	0.4	17414	3.3	0.5	19385	3.1	0.5
SES	100	66	22	17000	57	19	19000	38	18
4 Months									
HC (cm)	94	41	1.4	15,905[a]	40.9	1.4	17,793[a]	40.4	1.6
CC (cm^3)	94	586	60	15,905[a]	578	-	17,793[a]	557	-
Weight (kg)	93	6.5	0.8	15,805[a]	6.4	0.9	17,689[a]	6.1	0.9
1 Year									
HC (cm)	86	45.9	1.7	14724	45.7	1.5	16786	45.6	1.5
CC (cm^3)	86	819	94	14724	806	-	16786	801	-
Height (cm)	86	749	5.6	14,926[a]	74.6	3.2	17,006[a]	73.7	3.3
7 Years									
HC (cm)	98	51.6	1.5	16949	51.5	1.5	18644	51.2	1.6
CC (cm^3)	98	1167	102	16949	115	-	18644	1134	-
Height (cm)	97	119.9	5.5	17,240[a]	121	5.6	18,899[a]	122.9	6.5
Weight (kg)	97	22.4	3.1	17,249[a]	23.7	4.1	18,924[a]	24	4.9
IQ Wechsler	100	110	15	17432	102	15	19419	90	13

Notes: $CC = HC^3/118.4$

Data on Eruopean Americans and African Americans have been calculated from Broman, Nichols, Shaughnessy, and Kennedy (1987: p. 27, Table 3-3; p. 84, Table 5-7; p. 104, Table 6-10; p. 109, Table 6-15; p. 161, Table 8-19; p. 190, Table 8-53; p. 220, Table 9-28; p. 226, Table 9-34; p. 233, Table 9-41; p. 247, Table 9-54).

[a]Includes 2% with severe neurological damage.

Race Differences

At age 7 the Asian American children averaged an IQ of 110 (*SD* = 15), at least a half-standard deviation higher than the IQ for the white children from the same Perinatal Project. To examine whether the racial differences in mean IQ are reflected in differences in mean cranial capacity, Table 2 presents the cranial size data for (sex-combined) samples of European and African American children from the Perinatal Project (Broman et al., 1987). (Note: Asian volumes calculated on individuals; whites and blacks from means). Figure 2 plots these differences (uncorrected for body size) across the four age periods and, for comparative purposes, adds those from the U.S. Army reported by Rushton (1992, p. 405, Table 1). At each age, the mean Asian cranial capacity is higher than the mean for whites, which is higher than the mean for blacks.

Because data on individuals were available only for the Asians, it was not possible to carry out analysis of covariance to see whether the 3-way racial gradient in cranial capacity is significant after controlling for body size. However, the differences would likely be very significant with such large samples (whites = 17,000; blacks = 19,000). We also know from Rushton (1992) that the race differences from the U.S. Army data shown in Figure 2 are highly significant.

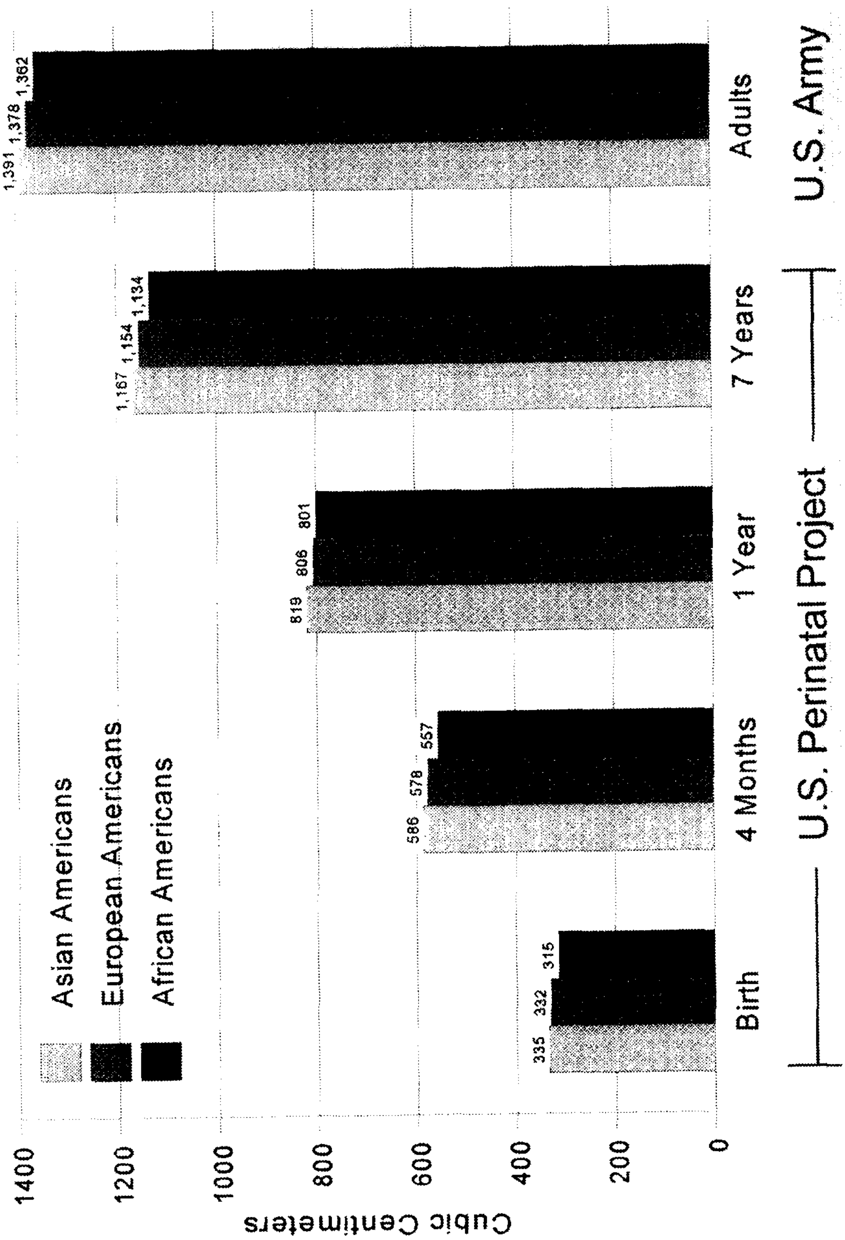

Figure 2. Mean Cranial Capacity (cm^3) by Race at Birth, 4 Months, 1 Year, 7 Years, and at Adulthood

The following analysis also implies the significance of the differences. Figure 3 shows the deviations in *z* score terms (using the Asian *SD* as the only one available for most measures) for the 3 racial groups from the average for both cranial and body size measures. Asians average a larger cranial capacity but a smaller body size than the average, Africans show the opposite pattern, while Europeans occupy an intermediate position. The exact probability of getting this particular ranking twice in a row is 1/6 x 1/6 = .028. At birth, Asian Americans averaged a cranial capacity 3 cm^3 (0.03 *SD*) larger than did whites, although they were 0.25 *SD*s lighter in weight and 0.24 *SD*s shorter in stature (outliers not excluded). Moreover, Asians averaged a cranial capacity 20 cm^3 (0.22 *SD*) larger than blacks although here the body-size measures favored the Asians who were 0.20 *SD*s taller and 0.25 *SD*s heavier. By age 7, "catch-up growth" in height and weight favored black children the most and white children the next most; yet Asians averaged a cranial capacity 6 cm^3 larger than the whites and 26 cm^3 larger than the blacks, despite being smaller than either in body size.

Mixed-Race Children

A novel piece of information available on the 100 Asian children is the race of the father. I divided the sample into a "pure" Asian group having both Asian mothers and Asian fathers (N = 63) and a "mixed" group (N = 37) of Asian mothers and other race fathers (mainly white, but including 5 blacks). At 7 years of age the unmixed Asians averaged an IQ of 114 versus one of 103 for the mixed-Asians ($t = 3.51$; $p < .001$) and a cranial capacity of 1,170 cm^3 versus one of 1,155 cm^3 for the mixed-race group. However, this 15 cm^3 difference was not significant. Adjusting the means for body size widened the gap, although still not significantly, with the non-mixed Asians averaging 1,173 cm^3 and the mixed-Asians averaged 1,149 cm^3. Taking the 5 children with black fathers out and making them a separate category the means for Asian-Asians, Asian-whites, and Asian-blacks were (unadjusted for height and $\log_n$ weight = 1,170, 1,155 and 1,158; and adjusted for body size 1,173, 1,154, and 1,115). However, these differences were not found to be significant.

DISCUSSION

Is it reasonable to expect brain size and cognitive ability to be related? Yes, because, based on a partial count of representative areas of the brain, Haug (1987, p. 135) found a correlation of .479 ($N = 81$, $p < .001$) between number of cortical neurons and brain size in humans. His sample included both men and women. The regression relating the two measures is: number of cortical neurons (in billions)= 5.583 + 0.006 (cm^3 brain volume). The difference between the low end of the normal distribution (1,000 cm^3) and the high end (1,700 cm^3) works out to be 4.2 billion neurons.

The best estimate is that the typical human brain contains about 100 billion (10^{11}) neurons classifiable into perhaps as many as 10,000 different types, resulting in 100,000 billion synapses (Kandel, 1991). Even storing information at the low average rate of one bit per synapse, which would require two levels of synaptic activity (high-or-low; on-or-off), the structure as a whole would generate 10^{14} bits of information. Contemporary supercomputers, by comparison, typically have a memory of about 10^9 bits.

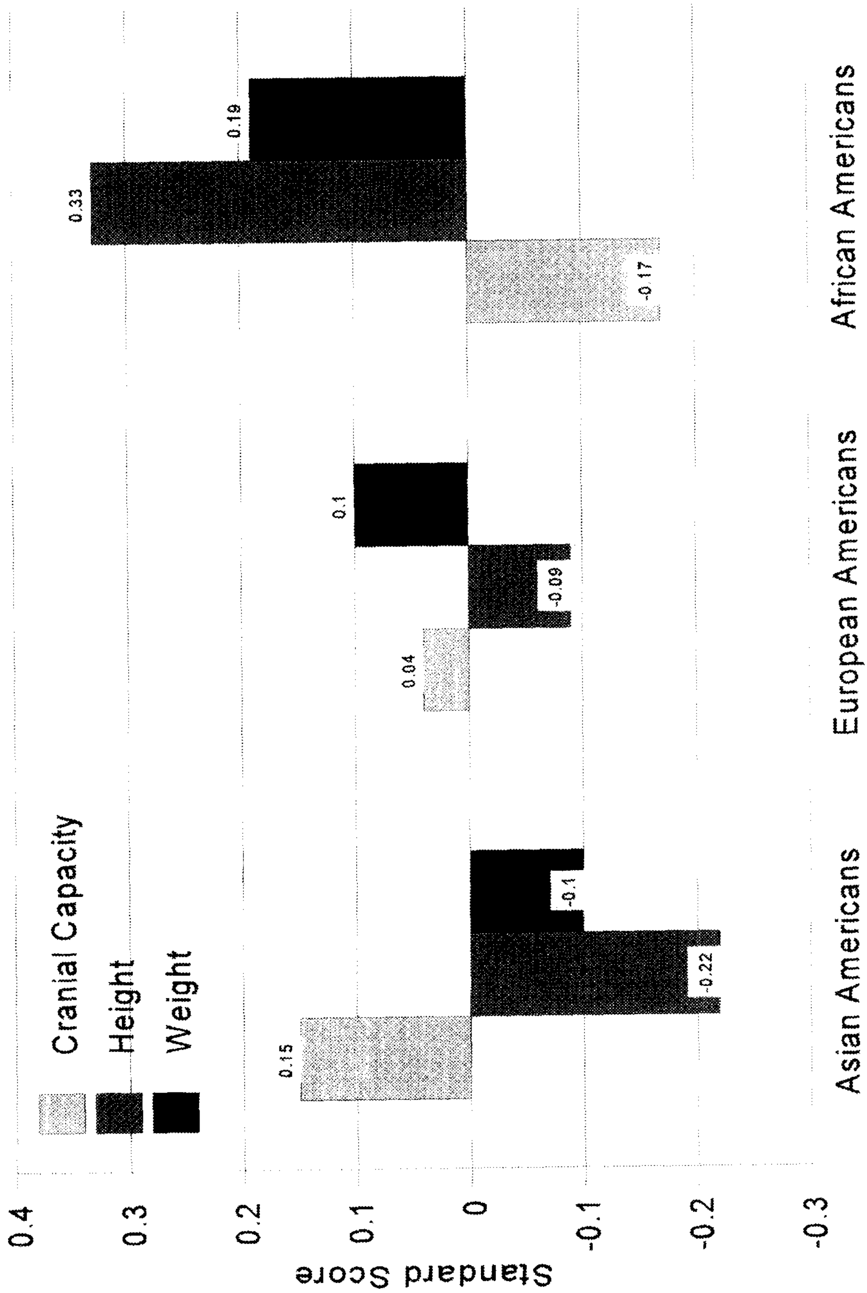

Figure 3. Mean Race Differences in Cranial Capacity, Height, and Weight at Age 7

It is understandable that correlations between IQ and overall brain size will be modest. First, much of the brain is not involved in producing intelligence; thus, variation in size/mass of that tissue will lower the magnitude of the correlation. Second, IQ is not a perfect measure of intelligence and, thus, variance in IQ scores is an imperfect measure of variation in intelligence. Although brain size accounts for only a small percentage of variation in cognitive ability, it is important to note, following Hunter and Schmidt (1990), that small correlations can have large effects. For example, although the MRI-established brain-size/IQ correlation is only about .40, when squared, it shows that 16% of the variance is explained; further regression equations show that every 1 standard deviation increase in brain size increases IQ by 0.40 standard deviations on average.

The phenomenon of "catch-up growth" following deficits caused by malnutrition or illness demonstrates that development is guided by constant self-corrections until some targeted end-state is reached. Deprived children, if moved to a satisfactory environment, subsequently develop very rapidly. They regain the growth trajectory they would have been on if the diversion had not occurred, following which growth slows down and development proceeds at the normal pace. Developmental processes are constantly involved in a match-to-model process with an inherent growth equation.

The data on catch-up growth, when applied to the Asian-white-black mean differences, argues in favor of the existence of genetic factors. The reason for this is that by age 7, Asians are above average in brain size but below average in body size whereas the opposite pattern is found for blacks and an intermediate pattern is found for whites. If major environmental insult or nutritional deprivation was the cause of the differences, as has often been posited for low birth-weight infants, one would not expect the particular pattern of catch- up growth that is demonstrated by these data. Moreover, malnutrition does not usually influence brain weight (Voigt & Pakkenberg, 1983, p. 299), suggesting that evolution has selected brains to be especially well conserved. Additional recent evidence for a genetic contribution to racial differences in mean IQ can be found in Jensen (1998), Levin (1997), Lynn (1997), Rowe and Cleveland (1996), and Rushton (1997).

One of the major findings of the Collaborative Project has been that low birth-weight babies are not as much at risk as has often been supposed. Broman (1989) reviewed the overall findings pointing out that although mean raw scores at 8 months of age on the Bayley Scales increased linearly with birthweight as predicted, with the lightest group (<2,000 grams) scoring about two standard deviations below the heaviest group (>3,501 grams), birthweight explained only 5% to 6% of the variance in test scores in this population of 31,000 infants. By age 4, in a regression analysis with six covariates (gestational age, birthweight, head circumference, sex of child, ethnicity, and maternal education), birthweight explained less than 1% of the variance in IQ scores. Ethnicity and maternal education were the best predictors, accounting for 16% and 6% of the variance, respectively. In contrast to birthweight, head circumference at birth was frequently retained in multivariate analyses, indicating a greater independent contribution to cognitive outcome at both ages (Broman, 1989). These results show that birthweight has less of an effect on measures of cognitive development at age 4 years than at 8 months. The most important predictors of cognitive performance were characteristics of the family.

Is it reasonable to infer, from all that has been said above, that differences in IQ scores among races are due to variation in "cortical neurons" and not, for example, to social class? Readers will no doubt differ in their assessments. Given the theoretical, methodological, and empirical imprecision of the area, some will say that advancing a gene-based theory is unwarranted. My own judgment is that the current study adds yet another item of information inclining to support the genetic conclusion (Rushton, 1995, 1997). Future research, using modern imaging techniques while controlling for more variables, may resolve outstanding questions. For instance, why do males and females not differ in IQ although they do differ in cranial capacity and in number of cortical neurons (Pakkenberg & Gundersen, 1997; cf. Lynn, 1994)?

In conclusion, this study adds new material to the growing body of empirical research on the relation of brain size to individual differences in IQ and to the mean differences between racial groups. It corroborates the relation between cranial capacity and IQ for a new data set—a sample of 7-year-old Asian Americans and replicates the higher average IQ and greater average cranial capacity of Asian Americans relative to European and African Americans (Rushton & Ankney, 1996). It also corroborates male-female differences in brain size (Ankney, 1992) which in this sample are clearly in evidence by 12 months of age even after controlling for height and weight. The sample, however, is a small one and of unknown representativeness to Asian Americans in general. Hopefully, further studies will determine whether these relationships are replicated in other samples.

REFERENCES

Ankney, C. D. (1992). Sex differences in relative brain size: The mismeasure of woman, too? *Intelligence, 16,* 329-336.

Beals, K. L., Smith, C. L., & Dodd, S. M. (1984). Brain size, cranial morphology, climate and time machines. *Current Anthropology, 25,* 301-325.

Broman, S. H. (1989). Infant physical status and later cognitive development. In M. H. Bornstein and N. A. Krasnegor (Eds.), *Stability and continuity in mental development.* Hillsdale, NJ: Erlbaum.

Broman, S. H., Nichols, P. L., & Kennedy, W. A. (1975). *Preschool IQ: Prenatal and early developmental correlates.* Hillsdale, NJ: Erlbaum.

Broman, S. H., Nichols, P. L., Shaughnessy, P., & Kennedy, W. (1987). *Retardation in young children.* Hillsdale, NJ: Erlbaum.

Epstein, H. T., & Epstein, E. B. (1978). The relationship between brain weight and head circumference from birth to age 18 years. *American Journal of Physical Anthropology, 48,* 471-474.

Harvey, I., Persaud, R., Ron, M. A., Baker, G., & Murray, R. M. (1994). Volumetric MRI measurements in bipolars compared with schizophrenics and healthy controls. *Psychological Medicine, 24,* 689-699.

Haug, H. (1987). Brain sizes, surfaces, and neuronal sizes of the cortex cerebri: A stereological investigation of man and his variability and a comparison with some species of mammals (primates, whales, marsupials, insectivores, and one elephant). *American Journal of Anatomy,* 180, 126-142.

Herrnstein, R. J., & Murray, C. (1994). *The bell curve.* New York: Free Press.

Ho, K. C., Roessmann, U., Straumfjord, J. V., & Monroe, G. (1980). Analysis of brain weight. I and II. *Archives of Pathology and Laboratory Medicine,* 104, 635-645.

Hofman, M. A. (1991). The fractal geometry of convoluted brains. *Journal für Hirnforschung, 32,* 103-111.

Hunter, J. E., & Schmidt, F. L. (1990). *Methods of meta-analysis: Correcting error and bias in research findings.* Newbury, CA: Sage.

Jensen, A. R. (1994). Psychometric *g* related to differences in head size. *Personality and Individual Differences,* 17, 597-606.

Jensen, A. R., & Johnson, F. W. (1994). Race and sex differences in head size and IQ. *Intelligence, 18,* 309-333.

Jensen, A. R. (1998). *The g factor.* Westport, CT: Praeger.

Jørgensen, J. B., Paridou, E., & Quaade, F. (1961). The correlation between external cranial volume and brain volume. *American Journal of Physical Anthropology, 19,* 317-320.

Kandel, E. R. (1991). Nerve cells and behavior. In E. R. Kandel, J. H. Schwartz, and T. M. Jessell (Eds.), *Principles of neural selection* (3rd ed.). New York: Elsevier.

Lee, A., & Pearson, K. (1901). Data for the problem of evolution in man: VI. A first study of the correlation of the human skull. *Philosophical Transactions of the Royal Society of London, 196A*, 225-264.

Levin, M. (1997). *Why race matters*. Westport, CT: Praeger.

Lynn, R. (1991). Race differences in intelligence. *Mankind Quarterly, 31*, 255-296.

Lynn, R. (1993). Further evidence for the existence of race and sex differences in cranial capacity. *Social Behavior and Personality, 21*, 89-92.

Lynn, R. (1994). Sex differences in intelligence and brain size: A paradox resolved. *Personality and Individual Differences, 17*, 257-271.

Lynn, R. (1997). Geographical variation in intelligence. In H. Nyborg (Ed.), *The scientific study of human nature: Tribute to Hans J. Eysenck at eighty*. London: Elsevier Science Ltd.

Neisser, U. (1997). Never a dull moment. *American Psychologist, 52*, 79-81.

Neisser, U., Boodoo, G., Bouchard, T. J. Jr., Boykin, A. W., Brody, N., Ceci, S. J., Halpern, D., Loehlin, J. C., Perloff, R., Sternberg, R. J., & Urbina, S. (1996). Intelligence: Knowns and unknowns. *American Psychologist, 15*, 77-101.

Nichols, P. L., & Chen, T.-C. (1981). *Minimal brain dysfunction: A prospective study*. Hillsdale, NJ: Erlbaum.

Pakkenberg, B., & Gundersen, H.J.G. (1997). Neocortical neuron number in humans: Effect of sex and age. *Journal of Comparative Neurology, 384*, 312-320.

Rowe, D. C., & Cleveland, H. H. (1996). Academic achievement in African Americans and Whites: Are the developmental processes similar? *Intelligence, 23*, 205-228.

Rushton, J. P. (1988). Race differences in behaviour: A review and evolutionary analysis. *Personality and Individual Differences, 9*, 1009-1024.

Rushton, J. P. (1991). Mongoloid—Caucasoid differences in brain size from military samples. *Intelligence, 15*, 351-359.

Rushton, J. P. (1992). Cranial capacity related to sex, rank, and race in a stratified random sample of 6,325 U.S. military personnel. *Intelligence, 16*, 401-413.

Rushton, J. P. (1994). Sex and race differences in cranial capacity from International Labour Office data. *Intelligence, 19*, 281-294.

Rushton, J. P. (1995). *Race, evolution, and behavior. A life-history perspective*. New Brunswick, NJ: Transaction.

Rushton, J. P. (1997). *Race, evolution, and behavior. A life-history perspective*. (Softcover Edition). New Brunswick, NJ: Transaction.

Rushton, J. P., & Ankney, C. D. (1996). Brain size and cognitive ability: Correlations with age, sex, social class and race. *Psychonomic Bulletin and Review, 3*, 21-36.

Rushton, J. P., & Osborne, R. T. (1995). Genetic and environmental contributions to cranial capacity estimated in black and white adolescents. *Intelligence, 20*, 1-13.

Tobias, P. V. (1970). Brain-size, grey matter and race—fact or fiction? *American Journal of Physical Anthropology, 32*, 3-26.

Van Valen, L. (1974). Brain size and intelligence in man. *American Journal of Physical Anthropology, 40*, 417-424.

Voigt, J., & Pakkenberg, H. (1983). Brain weight of Danish children. *Acta Anatomica, 116*, 290-301.

Wickett, J. C. (1997). *The biological basis of general intelligence*. Unpublished Ph.D. thesis; University of Western Ontario, London, Ontario, Canada.

Wickett, J. C., Vernon, P. A., & Lee, D. H. (1996). General intelligence and brain volume in a sample of healthy adult male siblings. *International Journal of Psychology, 31*, 238-239. (Abstract).