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Genetic and Environmental Contributions to Cranial Capacity in Black and White Adolescents

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Data from 236 pairs of twins (472 individuals) aged 13 to 17 years were used to examine genetic and environmental factors influencing cranial size, an indirect estimate of brain volume. Measures were taken of zygosity, head length, head breadth, age, sex, race, height, and weight for 187 males and 285 females, 222 Whites and 250 Blacks. Cranial size was estimated from head length and head breadth using standard equations. Group differences were found. Cranial capacity increased over age 13 to 17 from 1,233 cm^3 to 1,279 cm^3. After adjusting for the effects of age and body size, boys averaged 1,290 cm^3 and girls 1,229 cm^3, Whites averaged 1,269 cm^3 and Blacks 1,251 cm^3. Intraclass correlations were calculated and models fitted of proportionate genetic and environmental contributions to variance. Depending on particular corrections for body size, heritabilities for the sample as a whole ranged from 38% to 51% with 6% to 20% due to common environment and from 42% to 52% due to unique (nonshared) environmental factors, including error variance. The proportionate contributions did not vary systematically by sex and the seemingly higher range of heritabilities estimated for Whites than for Blacks (47% to 56% against 12% to 31%) and the lower range of common environment effects for Whites than for Blacks (28% to 32% against 42% to 46%) did not differ significantly. In conclusion, it is indicated that genetic factors are required to account for the phenotypic variance in cranial capacity and that further research is required on whether environmental factors exert more influence in Black populations than in White populations.

Brain size and cranial capacity are receiving much contemporary attention because of new technologies available to scan the brain and because a small robust relation has been established between intelligence test scores and brain size. The correlation between test scores and brain size estimated from magnetic resonance imaging (MRI) ranges from .35 to .47 with an average of about .40 (Andreasen et al., 1993; Raz et al., 1993; Wickett, Vernon, & Lee, 1994; Willerman, Schultz, Rutledge, & Bigler, 1991). This represents an increment over correlations reported since the turn of the century between head perimeter and measures

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of intelligence that range from .10 to .30 with an average of .20 (Broman, Nichols, Shaughnessy, & Kennedy, 1987; Jensen & Sinha, 1993; Rushton, 1995; Wickett et al., 1994).

The genetic and environmental contributions to brain size in humans have not previously been studied. This work provides an exploratory examination of the heritability of cranial capacity, and by inference brain size, from twins raised together. External head measures correlate between .80 and .98 with brain size in autopsy studies of infants and young children (Brandt, 1978; Bray, Shields, Wolcott, & Madsen, 1969). However, the correlation between cranial capacity and brain size in adults is unknown and may be as low as .50 (Van Valen, 1974).

Investigations of the genetic contribution to physical traits including face and head measurements consistently report heritabilities in the .50 to .90 range with monozygotic twin (MZ) correlations averaging about .90 across different traits and dizygotic twin (DZ) correlations averaging about .50 (Mittler, 1971; Susanne, Defrise-Gusshoven, Van Wanselle, & Tassin, 1983). The most powerful design for investigating genetic influences compares MZ and DZ twins who were separated at birth and raised apart. Bouchard, Lykken, McGue, Segal, and Tellegen (1990) found heritabilities for physical and physiological traits calculated in MZ adult twins raised apart almost as high as in adult twins raised together (.86 vs. .93, .73 vs. .83, for height and weight, respectively). This implied the presence of substantial genetic influences and also that the effects of both shared and unique environment are small.

Similar results emerge from studies of cognitive ability. In samples of adult twins raised apart and together both Bouchard et al. (1990) and Pedersen, Plomin, Nesselroade, and McClearn (1992) showed that 80% of the variance in the general factor of mental ability is genetic and most (if not all) of the environmental variance is of the nonshared, unique to each twin variety. Moreover, Pedersen et al. (1992) suggested that a model with nonadditive genetic variance fit their data best. The assessment of separate unique and shared environmental effects can also be made in studies such as this one of twins raised together.

Controversially, sex, socioeconomic, and racial group differences in brain size and cranial capacity have been found. Ankney (1992) analyzed sex differences from autopsied brain weights from 1,261 adults and showed that at any given surface area or height, brains of White men are about 100 gm heavier than those of White women, and brains of Black men are heavier than those of Black women. Rushton (1992) calculated cranial capacities for a stratified random sample of 6,325 U.S. military personnel measured in 1988 for the fitting of helmets and confirmed Ankney's results with men averaging 110 cm^3 larger cranial capacities than women after correcting for the effects of stature and weight. Also, officers averaged 1,393 cm^3, and enlisted personnel, 1,375 cm^3.

Racial group differences were also found in the U.S. Army data, with Asian Americans, White Americans, and Black Americans averaging, respectively, 1,416 cm^3, 1,380 cm^3, and 1,359 cm^3 after adjustments for the effects of body size, sex, and military rank. Subsequently Rushton (1994) calculated cranial capacities from data based on tens of thousands of people from around the world collated by the International Labour Office in Geneva in 1990. After adjustments for the effects of body size, race, and sex, men averaged 160 cm^3 more than women, and Asians about 70 cm^3 more than Africans, with Europeans intermediate. Other recent analyses of racial group differences in adult brain size, from autopsy and endocranial volume as well as those based on externally measured head sizes, come from Beals, Smith, and Dodd (1984), Ho, Roessmann, Straumfjord, and Monroe (1980), Jensen and Sinha (1993), and Rushton (1993). Rushton (1995) provided a full review going back over 100 years of research.

Brain size relationships show up early in life. In the U.S. National Collaborative Perinatal Project, 19,000 Black infants had smaller head perimeters at birth than 17,000 White infants, although Black babies were also shorter in stature and lighter in weight (Broman et al., 1987). By age 7, catch-up growth favored the Black children in body size but not in head perimeter. Head perimeter at birth correlated with IQ at age 7 in both the Black and White children. Adolescents have also been examined. Lynn (1993) calculated cranial capacities from external head measurements on 748 7- to 15-year-olds gathered by the Philadelphia Growth Center (Krogman, 1970). All the children had been screened for serious illness and dental problems and were middle class from "a solid, stable responsible cross section of the population" (Krogman, 1970, p. 4). After adjusting for the effects of age, stature, and then race or sex, boys averaged 1,300 cm^3 and girls averaged 1,186 cm^3; Whites averaged 1,250 cm^3 and Blacks averaged 1,236 cm^3. There was also an interaction such that the race effect was primarily in males (1,313 cm^3 vs. 1,286 cm^3) rather than females (1,186 cm^3 vs. 1,185 cm^3).

This article examines an adolescent sample uniquely composed of Black and White twins enabling heritability analyses to be conducted. Genetic and environmental analyses may ultimately help us understand the causes of the group differences.

METHODS

Subjects

Data from 236 pairs of twins (472 individuals) ranging in age from 12 to 18 years were analyzed. The sample consisted of 107 monozygotic twin pairs (20 White males, 26 White females, 18 Black males, 43 Black females) and 129 dizygotic twin pairs (20 White males, 21 White females, 24 White opposite sexes, 11 Black males, 28 Black females, 25 Black opposite sexes). The children were a subset of the Georgia Twin Study (Osborne, 1980), which was based on public and private schools in Georgia, Kentucky, and Indiana. Extensive data had been gathered in the 1960s and 1970s on personality, intelligence, and physical characteristics. Heritabilities of about 50% have been reported for IQ in both the

Black and White samples (Osborne, 1978, 1980) and a .30 correlation found between IQ and head measurements in both samples (Jensen, 1994; Osborne, 1992).

Measures

Data were abstracted for those 472 individuals with complete data available for age, sex, race, zygosity, stature, weight, head length, and head breadth from Appendix D of Osborne (1980). Cranial capacities were calculated for each person from the following two equations (Lee & Pearson, 1901): For males,

$$CC\ (\text{cm}^3) = 6.752(L - 11\text{mm}) + 11.421(W - 11\text{mm}) - 1{,}434.06$$

and for females,

$$CC\ (\text{cm}^3) = 7.884(L - 11\text{mm}) + 10.842(W - 11\text{mm}) - 1{,}593.96,$$

where CC is cranial capacity and L and W are length and width in millimeters and 11 mm is subtracted for fat and skin around the skull. These equations give comparable results for different racial groups very similar to those derivable from Lee and Pearson's (1901) "panracial" equation, which also takes head height into account (see Rushton, 1993).

The measurement descriptions are from Appendix B in Osborne (1980) and include *maximum head length* (Column 21, the distance in millimeters between the glabella and the furthest point on the midline on the back of the head measured with a spreading caliper), *maximum head breadth* (Column 22, the greatest transverse distance in millimeters of the head, usually found over the parietal bone, measured with a spreading caliper), *standing height* (Column 24, inches in stocking feet), and *weight* (Column 25, pounds in street clothes without shoes). The data in inches and pounds were transformed by us to centimeters and kilograms. Three separate takes were made of each head measurement and an average computed.

Statistical Analyses

A desirable preliminary to twin analyses is to establish that the scores of MZ and DZ twins have appropriate characteristics, including being similar to each other and to those in the general population (although see Rushton, 1987). Three such assessments were made. First, the distribution of raw scores for cranial capacity, stature, and weight were examined for departure from normality. Second, multivariate analyses of variance (MANOVAs) using the computer software program SPSS-X (1988) were conducted with zygosity as a factor and with cranial capacity, age, stature, and weight as dependent variables. Third, the effects of age, sex, and race were examined on cranial capacity, stature, and weight, and the results examined relative to those expected from the existing literature.

Intraclass correlations were computed between co-twins separately for MZ and DZ twins using SPSS-X. The proportion of total variance due to genetic factors (h^2, heritability) can be estimated from twin intraclass correlations in several ways. First, the intraclass correlation for MZ twins provides one estimate of broad sense heritability that includes both additive and nonadditive genetic (G) effects. The additive component is the sum of the average effects of all the genes that influence a character. Nonadditive effects result from interactions between alleles at a locus (dominance) or among genes at different loci (epistasis). If nonadditive effects are important for a trait, the expected correlation for DZ twins is less than half that for MZ twins. Assuming only additive effects, Falconer's (1989) heritability estimate is calculated as $2(MZ_r - DZ_r)$.

Environmentality can be broken down into two constituent parts, each twin's unique, nonshared, or specific environment (E) and each twin's shared or common environment (C). Because MZ twins are genetically identical, $1 - MZ_r$ constitutes a measure of nonshared environment plus measurement error, as may $1 - 2DZ_r$. The influence of common environment (C) can be estimated (weakly, and assuming there is no assortative mating), by subtracting the MZ_r from double the DZ twin correlation ($C = 2DZ_r - MZ_r$). Nonshared environmental influences, a residual category including error of measurement, can also be obtained by subtraction ($E = 1 - G - C$), which should agree with $1 - MZ_r$.

Although examining intraclass correlations provides insights regarding the relative importance of genetic and environmental factors, structural equation model fitting analyses are more powerful because all of the data are weighted appropriately and tests of alternative models are permitted (Falconer, 1989; Plomin, Defries, & McClearn, 1990). The models just described are to be fit to intraclass correlations using the computer program LISREL VII (Jöreskog & Sörbom, 1989).

The purpose of these analyses was to estimate the proportion of the variance in cranial capacity attributable to genetic factors (G), the twins' shared environment (C), and the twins' nonshared environment (E). Goodness-of-fit was assessed with chi-square. The statistical significance of the effect size attributable to G, C, or E was then tested by comparing a number of reduced models that systematically remove components of variance with the full GCE model. Three reduced models were tested: The GE-only model that predicts no common environmental effect; the CE-only model that predicts no genetic effect; and the E-only model that predicts no genetic or environmental resemblance; that is, zero correlations.

RESULTS

Set out in Table 1 are the mean cranial capacities, heights, and weights by age, sex, and race (2 pairs of 12-year-olds and 26 pairs of 18-year-olds are combined with their adjacent categories). Taking the sample as a whole, no departure from

TABLE 1
Mean Cranial Capacity, Stature, and Weight by Age, Sex, and Race for 472 American Adolescents

	Male						Female					
	White			Black			White			Black		
Age	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*
Cranial Capacity (cm^3)												
13	1,247	99	5	1,251	91	20	1,197	73	11	1,237	60	32
14	1,334	73	25	1,225	57	29	1,192	76	23	1,214	78	39
15	1,325	70	23	1,284	108	12	1,213	77	23	1,202	89	38
16	1,362	89	26	1,334	49	11	1,232	79	30	1,217	82	31
17	1,357	78	25	1,315	93	11	1,224	84	31	1,221	101	27
Stature (cm)												
13	166	13	5	159	7	20	160	9	11	162	7	32
14	169	7	25	168	7	29	163	7	23	162	5	39
15	175	7	23	171	7	12	163	5	23	160	7	38
16	174	8	26	174	8	11	163	7	30	163	5	31
17	181	7	25	174	5	11	162	7	31	160	8	27
Weight (kg)												
13	51	9	5	49	12	20	48	8	11	55	13	32
14	56	10	25	52	8	29	51	8	23	53	10	39
15	60	7	23	58	12	12	53	4	23	52	11	38
16	65	11	26	60	5	11	54	8	30	54	8	31
17	74	11	25	60	7	11	53	8	31	57	15	27

normality was found on age, cranial capacity, stature, or weight. Significant departure from normality occurred on the weight variable for subsamples, especially Black girls. The weight data were normalized using a natural log transform. No main effect to zygosity was found on cranial capacity, but MZ twins were taller than DZ twins, and DZ twins were significantly heavier than MZ twins. Some Race × Sex × Zygosity interactions were also observed. Black children were significantly younger (by about 6 months) than White children.

An analysis of variance (ANOVA) with age, race, and sex as factors and cranial capacity as dependent variable showed that on the raw scores there was a significant effect due to age, $F(4, 452) = 4.24$, $p < .01$; sex, $F(1, 452) = 277.56$, $p < .001$; and race, $F(1, 452) = 8.05$, $p < .01$. Cranial capacity generally increased with age from 13 through 17 years ($M = 1{,}233$, 1,241, 1,256, 1,286, and 1,279 cm^3, for each age, respectively); males averaged larger capacities than females ($M = 1{,}303$ and 1,216 cm^3, respectively); and Whites averaged larger capacities than Blacks ($M = 1{,}278$ and 1,242 cm^3, respectively). Similar results occurred with stature and weight as the dependent variables. Older children averaged taller and heavier than younger children, males averaged taller and heavier than females, and Whites averaged taller and heavier than Blacks. Several two-way Age × Sex and Race × Sex interactions occurred and, with weight, one three-way Race × Age × Sex interaction occurred. Plotting the data from Table 1 showed the girls matured earlier than the boys and the Blacks matured earlier than the Whites, resulting in young Black girls being especially larger in body and head size than expected relative to their counterparts. The unadjusted (raw) means and adjusted (for stature) means for the race and sex differences are given in Table 2.

To examine the sex and race differences in cranial capacity independent of the effects of the other variables a MANOVA was performed with age, stature and $\log_n$ weight (and then sex or race) introduced as covariates. The sex and race differences remained significant, $F(1, 465) = 162.65, p < .001$; $F(1, 465) = 5.31, p < .05$. After adjusting for age, stature, $\log_n$ weight, and then race or sex, the average cranial capacity for boys is 1,290 cm^3, and for girls, 1,229 cm^3, for Whites, 1,269 cm^3, and for Blacks, 1,251 cm^3. There was also a Race × Sex interaction, $F(1, 465) = 5.80, p < .05$, such that Black females had almost as large a cranial capacity as White females. The means adjusted for covariates were 1,307 cm^3 for White males, 1,273 cm^3 for Black males, 1,230 cm^3 for White females, and 1,228 cm^3 for Black females. These results are comparable to those from Lynn's (1993) study of 7- to 15-year-olds where the figures were 1,313, 1,286, 1,186, and 1,185 cm^3 for White males, Black males, White females, and Black females, respectively.

The intraclass correlations obtained for MZ and DZ twins are shown in Table 3. In all cases but one the correlations are significantly different from zero and the MZ correlations exceed the DZ correlations, suggesting the influence of genetic factors. Falconer's (1989) heritability is calculated from the equation $h^2 = 2(MZ_r - DZ_r)$. The possible presence of common environment effects is indicated by the DZ correlations being greater than half the MZ correlations.

Table 4 presents the results of model fitting and estimates of genetic and environmental effects. Because controversy surrounds the appropriate statistical controls to use when examining cranial capacity, with opinions ranging from using none to using all possible (see Jensen & Johnson, 1994), Table 4 contains

TABLE 2

Observed (Unadjusted) and Adjusted (for Age, Stature, $\log_n$Weight) Cranial Capacities (cm^3) for White and Black Adolescents

	Observed		Adjusted	
	Boys	Girls	Boys	Girls
Whites	1,340	1,215	1,307	1,230
Blacks	1,266	1,217	1,273	1,228

TABLE 3
Intraclass Correlations Unadjusted (and Adjusted for Age, Stature, $\log_n$Weight, and then Sex or Race)

Group	Number of Twin Pairs	MZ	DZ	Falconer's h^2
Male	69	0.74* (0.54*)	0.66* (0.28)	16% (52%)
Female	118	0.69* (0.58*)	0.54* (0.23)	30% (70%)
Opposite sex	49	—	0.11 (0.35)	—
White	111	0.83* (0.54*)	0.72* (0.20)	22% (68%)
Black	125	0.67* (0.41*)	0.64* (0.31)	6% (20%)

$^*p < .05$.

separate analyses. Part A presents the data with no age or body size controls at all. Part B presents the results adjusted for age and stature, then sex or race. Part C presents the adjusted data covarying out, in addition, $\log_n$ weight.

Genetic effects contributed substantially to cranial capacity in the sample as a whole (38% to 51%), but seemingly more for Whites (47% to 56%) than for Blacks (12% to 31%). Common environment effects contributed a small amount

TABLE 4
Model Fitting for Estimates of Genetic and Environmental Influence on Cranial Capacity

		Parameter Estimates^a			Fit in χ^2 Units			
Sample	*N* Pairs	G	C	E	GCE^{a,b}	GE^c	CE^c	E^d
		Part A. Adjusted for Sex or Race, but Not Age or Body Size						
Total	236	.38	.20	.42	0.00^e	0.93	3.74	56.15
Males	69	.56	.00	.44	0.00	0.00^e	2.40	16.65
Females	118	.54	.16	.29	0.00^e	0.49	7.06	58.70
Whites	111	.47	.07	.45	0.00^e	0.05	2.24	20.03
Blacks	125	.29	.32	.38	0.00^e	1.38	1.33	37.03
		Part B. Adjusted for Age and Stature, and Then Sex or Race						
Total	236	.51	.06	.43	0.00^e	0.08	6.08	51.40
Males	69	.54	.00	.45	0.00^d	0.00^e	2.31	15.31
Females	118	.74	.00	.26	0.06^d	0.06	13.22	58.69
Whites	111	.56	.00	.42	0.30^e	0.30	4.84	19.61
Blacks	125	.31	.28	.41	0.00^e	1.05	1.39	33.98
		Part C. Adjusted for Age, Stature and $\log_n$Weight, and Then Sex or Race						
Total	236	.38	.10	.52	0.00^e	0.21	2.71	34.79
Males	69	.54	.00	.46	0.11	0.11	2.59	14.39
Females	118	.57	.00	.42	0.00	0.00^e	4.59	31.39
Whites	111	.53	.00	.46	0.04	0.04	3.19	18.16
Blacks	125	.12	.28	.59	0.00^e	0.87	0.14	15.72

[a] G = additive genetic factors, C = common environmental factors, E = unique environmental factors specific to the individual. [b] *df* = 3. [c] *df* = 4. [d] *df* = 5. [e] Best fitting.

of the phenotypic variance for the sample as a whole (6% to 20%) but seemingly less for Whites (0% to 7%) than for Blacks (28% to 32%). Unique (nonshared) environmental effects accounted for a reliable amount of variance in all samples (38% to 59%). Combining both sources of environmental variance seemed to show more environmental influence on Blacks (69% to 87%) than on Whites (42% to 52%). Males and females did not vary systematically. For males, heritabilities ranged from 54% to 56% with common environment at 0%. For females, heritabilities ranged from 54% to 74% and common environment from 0% to 16%.

The full GCE model adequately fitted the data for the sample as a whole and typically also for each of the subgroups. The GE model (predicting no common environmental factor) provided as good a fit as the GCE model. When the E-only model (predicting no genetic effects) was compared to the full GCE model, it failed in all groups. Occasionally (28% of the time) the CE model's fit is significantly worse than that of the GCE model. Genetic factors are required to account for the phenotypic variance in cranial capacity.

We tested whether the genetic architecture in the Black and White groups were statistically different using LISREL. The models were simultaneously fit to both groups, once with the parameters of interest allowed to be different, and once with them constrained to be the same. If the latter produces a significant increase in chi square over the former, it can be concluded that there is a difference in the parameters in question. If not, any apparent difference may plausibly be attributable to chance in sampling. Both the GCE and GE models were tested in this way independently for Parts A through C of Table 4. The results showed no differences in chi-square values, so there is not a significant difference in the heritabilities between Whites and Blacks. Neither are the MZ twin correlations (Table 3) significantly different between Whites and Blacks.

We explored possible underlying processes by analyzing height and weight. The genetic contribution to height with no age or other corrections was 97% for both Whites and Blacks. For weight, however, whereas the heritability for Whites was 95%, for Blacks it was only 55%, with the nonshared environment accounting for the remaining variance. We also looked at the intercorrelations among head and body size measures to see whether these differed by racial group and found they were uniformly lower for Blacks than for Whites. For example, head length correlated with head width, head circumference, stature, and weight in Whites (.37, .83, .53, and .49, respectively, and in Blacks (.15, .64, .36, and .41, respectively). Even the correlation between height and weight showed the same pattern (.72 for Whites vs. .41 for Blacks). Greater measurement error may be operating in the Black sample.

DISCUSSION

The sex and race differences in cranial capacity partially replicate other recent studies (reviewed in the introduction) showing males average larger than females and Whites average larger than Blacks. In this adolescent sample, as in one by Lynn (1993), the Black–White difference was present only for males. This is probably due to the maturational effects we observed, with girls maturing earlier than boys and Blacks maturing earlier than Whites, resulting in young Black girls being especially larger in body and head size than expected relative to their counterparts. Males, especially White males, continue growing through late adolescence. In adults, the studies of the racial differences in brain size mentioned in the introduction and reviewed in Rushton (1995) find the effect across both males and females.

Heritabilities were estimated at between 38% and 51% for the sample as a whole (47% to 56% for Whites vs. 12% to 31% for Blacks), shared environment effects were estimated from 6% to 20% (0% for Whites vs. 28% for Blacks), and unique environmental influences at about 40% for all samples. Perhaps surprisingly for a physical trait like cranial capacity, environmental factors are mostly unique to the individual twin, contributing 40% of the total variance, much more than the environmental influences shared by the twins. This differential environmental effect has been found for numerous behavioral and psychophysiological traits (Plomin et al., 1990). Thus, factors such as illness, prenatal insult, and differential parenting are more important than parental socioeconomic status or the result of being raised in a particular kind of household. However, the unique environment category also includes errors of measurement, which may have been large in this particular study, especially, as we noted, for the Black sample.

The replicated pattern of greater common environmental influence on Blacks compared to Whites found across several adjustments for sex, age, and body size, was interesting and possibly important. It suggested that among Blacks the environment had a suppressant effect on natural growth. In animal studies, lowered heritabilities for body size variables are often interpreted in this way (e.g., Larsson, 1993). This may suggest a greater nutritional disadvantage in Blacks (Loehlin, Lindzey, & Spuhler, 1975) or even the operation of some quite subtle social prejudice (Angel, 1993). However the parameter differences were a long way from statistical significance. Because of the numerous interactions in the raw (uncorrected) data, the small sample sizes in some of the Sex × Race × Zygosity categories, the error apparently involved in taking the head and body size measurements in the Black sample, and the strong environmental effect on body weight in that sample, all interpretations about group differences in genetic architecture (including the null hypothesis) should be viewed with caution.

The group differences in cranial capacity are well replicated. Ankney (1992) proposed that sex differences in brain size relate to those intellectual abilities at which men excel. Briefly, according to Kimura (1992), women excel in verbal ability, perceptual speed, and motor coordination within personal space; men do better on various spatial tests and on tests of mathematical reasoning. Ankney suggested it required more brain tissue to process spatial information and that the sexual dimorphism originated through evolutionary selection of male hunting ability. Rushton (1995) reviewed global literature on race differences in cranial capacity and mental ability and hypothesized that evolutionary pressures in colder climates selected for greater intelligence.

A functional relation between head size and cognitive ability has been implied in two studies showing that the relation exists within families as well as between them. A tendency for a sibling with a larger head to have a higher IQ than a sibling with a smaller head implies a causal relation because it controls for many of the sources of variance that distinguish families, such as cultural background and socioeconomic status (see Jensen, 1980, for a full discussion of this reasoning). However, environmental factors such as nutrition and differential stress during pregnancy could affect both variables.

Jensen and Johnson (1994) examined the head size–IQ relation in some 14,000 children and their full siblings, almost evenly divided by race (White and Black) and sex, on whom data were obtained at ages 4 and 7 years in the Collaborative Perinatal Project. Within each Race × Sex group, IQ was significantly correlated with head circumference after age and body size were partialed out. At age 7 (although not at age 4), the significant positive correlation existed within families ($r = .11$) as well as between families ($r = .20$).

Jensen (1994) examined 143 pairs of adolescent twins from the same Osborne (1980) database used by the present authors. Complete information existed for 17 IQ tests from which the general factor, or psychometric *g*, was extracted and found to correlate with measures of head size including an aggregate of length, width, and circumference within individuals ($r = .30$), within and between MZ twin pairs ($r_s = .21, .38$) and within and between DZ twin pairs ($r_s = .28, .26$). Jensen reasoned that because the between-pair correlations for MZ twins were larger than the within-pair correlations, with the opposite true for DZ twins, pleiotropy was occurring; that is, both variables were affected by the same genes.

Jensen carried out additional analyses and found support for the hypothesis that head size (brain size) differences were the cause of the Black–White difference in mental ability. Jensen and Johnson (1994) matched the 4- and 7-year-old White and Black children on IQ (also on age, height, and weight) and found the race differences in head size disappeared. Jensen (1994) found the difference between White and Black adolescents on each of 17 tests was related to the tests' loadings on the *g* factor, *and on the tests' correlation with head size* (this latter, $r = .533, p < .05$; with unreliability of measurement controlled, $r = .715, p < .01$).

A key test of a causal connection between cranial capacity and intelligence would be a bivariate genetic analysis. Although mental test scores were available in this data set, and correlated .30 with head size (Jensen, 1994; Osborne, 1992), it was not feasible to carry out this analysis using the present data because of (a) the amount of missing data, (b) the small sample sizes in some of the Sex × Race

× Zygosity categories, and (c) the numerous interactions. However, the data were published in the various Osborne (1980) appendices for anyone wishing to analyze them further.

To conclude, cranial capacity among American adolescents, and by inference brain size, differs by sex and race such that boys average larger than girls and White boys average larger than Black boys. Moreover cranial capacity is significantly heritable in the sample as a whole and in the various subcategories. Environmental factors are also important and there is a (nonsignificant) suggestion that these may be stronger in the disadvantaged Black group and thus account for some of the mean race difference in cranial capacity (and, possibly, intelligence test scores). These findings should not be overinterpreted. The relationships require more detailed examination with better assessments of brain size such as magnetic resonance imaging.

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