PERGAMON

Personality and Individual Differences 29 (2000) 591–620

PERSONALITY AND INDIVIDUAL DIFFERENCES

www.elsevier.com/locate/paid

Review Paper

Size matters: a review and new analyses of racial differences in cranial capacity and intelligence that refute Kamin and Omari

J. Philippe Rushton*, C. Davison Ankney

Department of Psychology, University of Western Ontario, London, Ontario, N6A 5C2, Canada

Received 6 August 1999; received in revised form 9 November 1999; accepted 22 November 1999

Abstract

We provide a case by case examination of Kamin and Omari's critical review (*South African Journal of Psychology*, 1998, *28*, 119–128) concluding that race differences in head size were too small to explain their differences in IQ. Although Kamin and Omari make several valid points and identified an "anomalous" finding in two samples (that Blacks averaged greater head circumference than Whites), in the main their review is highly misleading. We find, among other things, that Kamin and Omari: (1) ignored the relation between brain size and IQ established by magnetic resonance imaging and the race differences in brain size established by MRI, autopsies, and endocranial volume; (2) erred in attributing to arithmetic errors and uncontrolled differences in sex ratio the differences in head size found from birth to age seven in the National Collaborative Perinatal Project; (3) neglected data showing that young Black girls mature faster than White girls which explains why Black girls sometimes average cranial sizes equal to or greater than their White age peers; and (4) seized upon ad hoc "alternative" findings and explanations for particular studies. When the principle of aggregation is employed and data averaged across the numerous studies, the race differences in average cranial capacity clearly emerge. New analyses in this article also confirm that whereas Blacks average proportionately longer heads, Whites and Asians average proportionately wider and higher heads, which explains why different equations for estimating cranial volume sometimes produce different results. We conclude that brain volume bears a strong relation to cognitive ability, and that increasing encephalization over evolutionary time led to progressively more spherically shaped heads with corresponding increases in head width and head height.

Keywords: Brain size; Evolutionary theory; Human origins; Intelligence; Race differences

* Corresponding author. Tel.: +1-519-661-3685; fax: +1-519-850-2302.
E-mail address: rushton@julian.uwo.ca (J.P. Rushton).

0191-8869/00/$ - see front matter
PII: S0191-8869(99)00256-1

Contents

1. Introduction

Since at least 1759 when Soemmering filled skulls with water, Europeans and their descendants (hereafter Whites) have been found to average larger craniums than Africans and their descendants (hereafter Blacks). Sand was used as packing material in 1831, millet in 1837, mustard seed in 1839, and lead shot in 1849 (see Todd, 1923). By the 1870s, Black–White differences in brain size were considered so well established that Charles Darwin (1871) cited them as evidence in favor of his then controversial theory of human origins. Even Franz Boas, who is often described as the "true" founder of American anthropology for being the first to challenge "Eurocentric racism", accepted the data on race differences in brain size and drew important conclusions about relative intellectual performance based on the amount of overlap in the distributions. Boas (1894) found that only 27% of Blacks exceeded the White brain size average, rather than the 50% that should have done had the races been equal. Arguing that "the greater the central nervous system, the higher the faculty of the race and the greater its aptitude to mental development," Boas concluded: "We might, therefore, anticipate a lack of men of high genius (among Blacks)."

A variety of modern research procedures (MRI, autopsies, endocranial volume, external head measures) have confirmed these early studies of racial differences in brain size. Using MRI, Harvey, Persaud, Ron, Baker and Murray (1994) found that 41 Africans and West Indians had a smaller average brain volume than did 67 Caucasians. Using brain mass at autopsy, Ho, Roessmann, Straumfjord and Monroe (1980) summarized data for 1261 individuals and reported a mean brain weight of 1323 g for White Americans and 1223 g for Black Americans. Using endocranial volume, Beals, Smith and Dodd (1984) analyzed about 20,000 skulls from around the world and found that East Asians, Europeans, and Africans average cranial volumes of 1415, 1362, and 1268 cm^3 respectively. Using external head measurements from a stratified random sample of 6325 US Army personnel, Rushton (1992) found that Asian Americans, European Americans, and African Americans averaged 1416, 1380, and 1359 cm^3, respectively.

Are these findings attributable simply to race differences in body size? The world database from: (a) autopsies, (b) endocranial volume, (c) head measurements, and (d) head measurements corrected for body size were summarized by Rushton (1995, pp. 126–132, Table 6.6). The results in cm^3 or equivalents were: East Asians and their descendants — 1351, 1415, 1335 and 1356 (mean of 1364); Europeans and their descendants — 1356, 1362, 1341 and 1329 (mean of 1347); and Africans and their descendants — 1223, 1268, 1284 and 1294 (mean of 1267). 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 the method of estimation, averaged 31 cm^3.

Further evidence that the observed racial differences in brain size are real, comes from the parallel findings of measured intelligence. East Asians, tested in North America and in Pacific Rim countries typically average IQs in the range of 101 to 111. Caucasoid populations in North America, Europe and Australasia typically average IQs of from 85 to 115 with an overall mean of 100. African populations living south of the Sahara, in North America, in the Caribbean, and in Britain typically have mean IQs of from 70 to 90 (Jensen, 1998; Lynn, 1997; Rushton, 1995). Jensen (1998, p. 443) calculated an "ecological" correlation (widely used in

epidemiological studies) of +0.99 between median IQ and mean cranial capacity across the three populations of "Mongoloids," "Caucasoids," and "Negroids."

Modern research employing magnetic resonance imaging (MRI) which creates, in vivo, a three-dimensional image of the brain, confirms the correlation between brain size and IQ. Rushton and Ankney (1996) reviewed the evidence and found an overall correlation of 0.44 between MRI measured brain size and IQ in eight separate studies. Additional MRI studies have since confirmed the relationship (Flashman, Andreasen, Flaum & Swayze, 1998; Gur et al., 1999; Tan et al., 1999; Wickett, Vernon & Lee, in press). Lower, but still significant correlations are found between external head size and IQ ($r = 0.20$). These results should now be regarded as securely established.

Racial differences in brain size and intelligence start early in life. The National Collaborative Perinatal Project, to which we will return later, followed more than 35,000 American children from birth to age seven (Broman, Nichols, Shaugnessy & Kennedy, 1987). Analyses shown in Fig. 1 revealed that Asian Americans (i.e., 'Orientals') had larger average cranial capacities than Whites, and Whites had larger cranial capacities than Blacks at birth, 4 months, 1 year, and 7 years. The same differences were present among adults (Rushton, 1992). At 7 years of age, head circumference and IQ correlated $r = 0.20$ in all three races and Asian American children averaged an IQ of 110, White children an IQ of 102, and Black children an IQ of 90. Moreover, Asian Americans, who averaged the largest craniums, were the shortest in stature and the lightest in weight, whereas Blacks, who averaged the smallest craniums, were the tallest in stature and the heaviest in weight (see Fig. 2).

1.1. The Kamin and Omari (1998) critique

After reviewing the literature, Lynn (1991), Rushton and Ankney (1996), and Jensen (1998) concluded that population differences in cranial volume provided an explanation for population differences in cognitive ability. Kamin and Omari (1998; henceforth K&O) have attempted to refute this conclusion. While conceding "that there might be a very modest relation between head size and measured intelligence" (p. 119), K&O specifically challenged the findings of Black–White differences in cranial size estimated from external head measures (by Jensen, 1994; Jensen & Johnson, 1994; Lynn, 1990, 1993; Rushton, 1992, 1993, 1994; Rushton & Osborne, 1995). K&O claimed significant errors in the published results, and reported that although American Whites have greater head height than American Blacks, Blacks have greater head length and greater head circumference. They concluded that estimates of cranial capacity are determined by differences in head shape and that "possible relations between head size and measured IQ are so small that they cannot possible explain Black–White differences in IQ" (p. 119).

The re-analysis presented here shows that K&O's review fell far short of telling the whole story. For example, K&O ignored the criterion of preponderance of evidence, omitting all mention of the data gathered from autopsy, endocranial volume, or MRI which converge on the same conclusion as the studies they criticized. Moreover, they violated the criterion of considering the total information by omitting data on Asian head size even though Asians (and their descendants) averaged larger cranial size than either Europeans or Africans. K&O were

also inconsistent in whether they included non-American Blacks and Whites, i.e., Africans and Europeans, respectively.

The remainder of this paper provides a case by case analysis of all the major studies of race differences in external head measures. Each of the original data bases under discussion is described, the published analyses of them, followed by K&O's critique, and then our (R&A) reply. Section 2 discusses the National Collaborative Perinatal Project's longitudinal study of 35,000 children; Section 3, Krogman's (1970) Philadelphia Growth Study of adolescents; Section 4, Osborne's (1980) Georgia Twin Study of adolescents; Section 5, Herskovits's (1930) survey of international data; Section 6, the US National Aeronautics and Space Administration's (1978) compilation of international military data; Section 7, the 1988 US Army survey of a stratified random sample of 6325 military personnel; Section 8, the 1990 International Labour Office world survey; and finally, Section 9 presents new analyses of head shape based on the 1988 US military data. First though, we need to describe the Lee and Pearson (1901) equations which many of these studies used to calculate cranial capacity from external head measures.

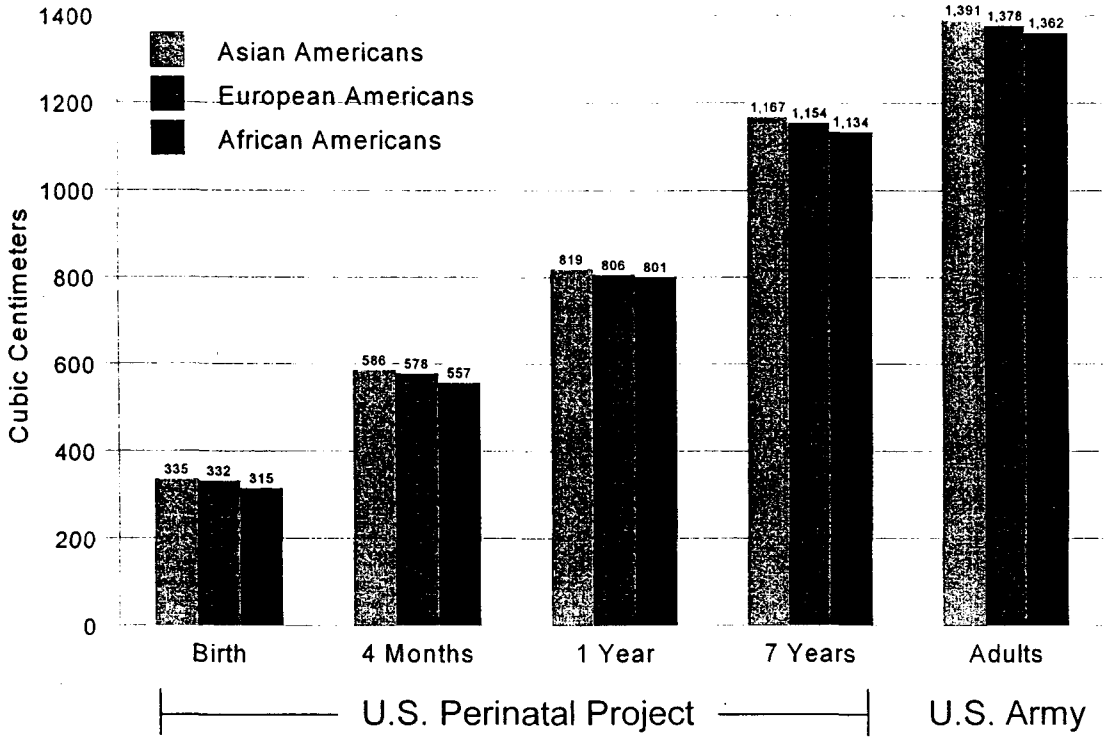

Fig. 1. Mean cranial capacity (cm^2) by race at birth, 4 months, 1 year, 7 years, and at adulthood. The adult data in Fig. 1 are from Rushton's (1992) study of 6325 US military personnel and have been corrected for body size using analysis of covariance. From Rushton (1997, p. 15, Fig. 2). Copyright 1997 by Ablex Publishing Corporation. Reprinted with permission.

1.2. The Lee and Pearson (1901) equations

Lee and Pearson (1901) carried out extensive work using external skull measures (length, width, and height) to predict cranial capacities measured with mustard seed. Their equations yielded estimates well within the 5% error of measurement given by the mustard seed technique. Lee and Pearson (1901) recommended Eqs. (1) and (2) the most, referred to as both the "mean formula" (p. 243) and the "panracial equation" (p. 260). Using head length, breadth, and height, and with 11 mm subtracted for fat and skin around the skull (p. 252) they were an average of separate equations obtained for 199 German skulls (medieval Bavarians), 150 Ainu skulls (from ancient Japan), and 343 Naqada skulls (from ancient Egypt). When applied to German, Ainu, and Naqada skulls, they produced errors of only 1 or 2%.

Lee & Pearson (1901) also provided other equations, based only on head length and breadth, including the German Eqs. (3) and (4) (pp. 235–236, Table VII and VIII, Nos. 5), and the Ainu Eqs. (5) and (6) (pp. 234–235, Table V and VI, Nos. 5). They also provided an appendix with equations for estimating cranial capacity from head circumference (7) and (8) (pp. 261–264), although they reported there was no obvious way of subtracting for fat and skin. Subsequently, Rushton (1993) and K&O (1998) amended Eqs. (3)–(6) by subtracting 11 mm for fat and skin around the skull, and Jensen and Johnson (1994, p. 319, Table 6) modified Lee and Pearson's Eqs. (7) and (8) to create Eqs. (9)–(11) by increasing the subtractive constants to

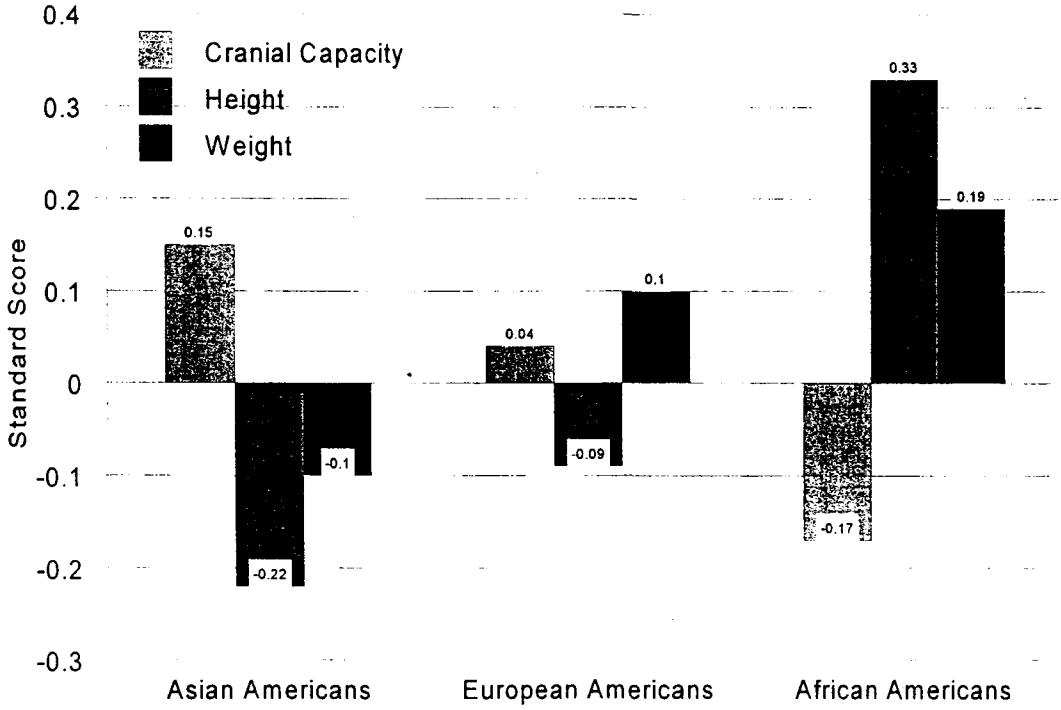

Fig. 2. Mean race differences in cranial capacity, height, and weight at age 7. From Rushton (1997, p. 17, Fig. 3). Copyright 1997 by Ablex Publishing Corporation. Reprinted with permission.

reflect the fact that 7-year-olds have obtained only 90% of adult cranial capacity. (Lee and Pearson's constant divided by Jensen and Johnson's constant is 0.90). Finally, Rushton (1997) provided yet another cranial capacity-from-circumference equation, one suitable for very young children (Eq. (12) using the volume of a hemisphere. Where L, B, H, and C are length, breadth, height, and circumference in mm, the equations were:

Panracial equations

$$\text{Males: Capacity } (cm^3) = 0.000337\ (L - 11\ mm)(B - 11\ mm)(H - 11\ mm) + 406.01 \quad (1)$$

$$\text{Females: Capacity } (cm^3) = 0.0004\ (L - 11\ mm)(B - 11\ mm)(H - 11\ mm) + 206.6 \quad (2)$$

German equations

$$\text{Males: Capacity } (cm^3) = 6.752\ (L - 11\ mm) + 11.421\ (B - 11\ mm) - 1434.06 \quad (3)$$

$$\text{Females: Capacity } (cm^3) = 7.884\ (L - 11\ mm) + 10.842\ (B - 11\ mm) - 1593.96 \quad (4)$$

Ainu equations

$$\text{Males: Capacity } (cm^3) = 13.555\ (L - 11\ mm) + 5.562\ (B - 11\ mm) - 1842.61 \quad (5)$$

$$\text{Females: Capacity } (cm^3) = 9.084\ (L - 11\ mm) + 7.21\ (B - 11\ mm) - 1288.1 \quad (6)$$

Circumference equations

$$\text{Males: Capacity } (cm^3) = 7.060(C) - 2220.98 \quad (7)$$

$$\text{Females: Capacity } (cm^3) = 5.974(C) - 1705.73 \quad (8)$$

$$\text{Males: Capacity } (cm^3) = 70.60(C) - 2464.95 \quad (9)$$

$$\text{Females: Capacity } (cm^3) = 59.74(C) - 1912.18 \quad (10)$$

$$\text{Sex combined: Capacity } (cm^3) = 65.17(C) - 2188.57 \quad (11)$$

$$\text{Sex combined: Capacity } (cm^3) = C^3/12\pi^2 \text{ or } C^3/118.4 \quad (12)$$

2. The National Collaborative Perinatal Project

The American National Collaborative Perinatal Project, a large-scale longitudinal 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 children from 53,043 pregnancies were followed from gestation through age eight by multi disciplinary research teams who assessed the physical growth and cognitive development of children at birth, 4 months, 8 months, 1 year, 4 years, and 7 years (Broman, Nichols and Kennedy, 1975; Broman et al., 1987; Nichols & Chen, 1981). At age four the Stanford-Binet Intelligence Test, and at age seven the Wechsler Intelligence Scale for Children, were individually administered by specially trained psychometricians. In the original study, 47% of women self-reported as being Black, 45% as White, and $<1\%$ as Asian, with mean socioeconomic scores on a 95-point scale of 38 (SD = 18), 57 (SD = 19), and 66 (SD = 22), respectively.

2.1. Lynn's (1990) study

Lynn (1990) was the first to introduce evidence from Broman et al.'s (1987) data on 7-year-olds into the race/brain-size/IQ debate. Lynn calculated mean head circumference for 17,241 White and 18,907 Black 7-year-olds from a table given by Broman et al. (1987, p. 161), and reported that Whites averaged 51.72 cm and Blacks 50.91 cm in circumference, a difference of 0.81 cm and about 0.5 SD in magnitude. Lynn also reported that: the Black and White children showed an IQ difference favoring whites of approximately 1 SD; Black children were slightly taller than White children, indicating that the greater head size of White children was not a function of greater body size; and that the correlations between head circumference and IQ were 0.24 for White children and 0.19 for Black children, similar to those also found by Lynn (1990) in three new samples of Irish and English children.

2.2. K&O critique

K&O charged that Lynn (1990) had made an arithmetic error in his report which overestimated the magnitude of the Black–White difference in cranial capacity by two thirds. K&O calculated that the correct White–Black difference was only 0.27 cm, one third of the magnitude reported by Lynn, and about one sixth of a SD. K&O attributed this remaining White advantage to a higher proportion of boys in the White sample, as boys have a larger head circumference than girls, although they claimed that there was no way of retrieving the sex difference data from Broman et al. (1987).

2.3. R&A reply

Although correcting Lynn's arithmetic error reduced the magnitude of the race difference, it did not eliminate it. Moreover, we were able to retrieve the proportionate sex ratios from Broman et al. (1975, p. 31, Table 3.9) and found these were quite similar (51.88 male for Whites and 50.04 for Blacks). These do not explain away the race difference in head size because, although Blacks averaged smaller crania, they were taller and heavier than Whites. Lynn (1990, p. 796) had made this point quite clear stating: "Black children are slightly taller than white children indicating that the greater head size of white children is not a function of greater body size." Other studies cited by K&O, like the one by Rushton and Osborne (1995)

(see Section 4.4) reiterated Lynn's point about the larger body size of Blacks in this sample, and Rushton (1997) showed that East Asians ("Mongoloids") from this study group (53 girls and 47 boys) had a sex bias *opposite* to the one claimed by K&O. (Recall from Fig. 2 that the Asians averaged the largest crania but were the smallest in body size of all three groups.) How could K&O have missed the point about Black children being larger in size than the White children, when it destroyed their argument based on biased sex ratios?

2.4. Jensen and Johnson's (1994) study

Jensen and Johnson (1994) retrieved individual head circumference scores from 14,000 pairs of 4- and 7-year-old siblings from the National Collaborative Perinatal Project and adjusted each score for differences in age, height, and weight. They first confirmed that within each race-by-sex group, IQ showed 0.20 significant correlations with head circumference, and extended the finding (at age seven only) to *within* families ($r = 0.11$) as well as *between* families ($r = 0.20$). They concluded that a tendency for the sibling with a larger head to have a higher IQ than the sibling with a smaller head was of special interest because it controlled for between-family variance in cultural background and socioeconomic status. Their conclusion was that there is an "intrinsic" correlation between the mental and physical variables.

Jensen and Johnson (1994) also confirmed Lynn's (1990) finding that the White 7-year-olds averaged a larger brain size than the Black 7-year-olds. They showed that the effect held up on individually entered data even when controlling for age, height, weight, and sex. Jensen and Johnson also found that White and Black children matched on IQ showed zero difference in average head size. Finally, Jensen and Johnson found a disordinal race × sex interaction: "The race difference in head circumference is highly significant but differs markedly for males and females, white males having about one third of a SD larger circumference than black males and white females having about one eighth SD *smaller* head circumference than black females" (p. 329). Jensen and Johnson attributed this interaction to the faster growth rate of Black girls compared to White girls.

Jensen and Johnson (1994, p. 319, Table 6) also estimated cranial capacities (cm^3) from the head circumference data so as to facilitate comparisons with other studies reporting brain volume. Using Eqs. (9) and (10), Jensen and Johnson observed results comparable to those based on autopsy brain weights (Ho et al., 1980). Thus at age seven, White males averaged 1201 cm^3, Black males 1163 cm^3, White females 1131 cm^3, and Black females 1137 cm^3. (Quite small differences in circumference correspond to much larger differences in capacity.)

2.5. K&O critique

K&O argued that Jensen and Johnson's (1994) observed race × sex interaction in which Black girls had larger crania than White girls disconfirmed the main effect due to race. They further noted that similar disordinal race × sex interactions for cranial size were well established in the literature and had been found for samples of 7- to 17-year-olds as early as 1899 (following Paterson, 1930, pp. 86–89), but they denied that these were due to race differences in speed of maturation. They also took Jensen and Johnson to task for attempting

to estimate cranial capacities from Lee and Pearson's circumference equations, citing Lee and Pearson's lack of confidence in them.

2.6. R&A reply

K&O's obfuscatory method is illustrated by their refusal to acknowledge the evidence of race × sex interactions in speed of maturation. Yet, in Rushton and Osborne's (1995, pp. 6–7, Table 1) study, clearly read by K&O (see Section 4.1), this exact interaction was tabulated in speed of growth in 12- to 18-year-olds: Girls matured earlier than boys and Blacks matured earlier than Whites, resulting in young Black girls being larger in body size than their White counterparts. Age × race × sex differences on numerous measures of speed of maturation are, in fact, very well established (Eveleth & Tanner, 1990; Herman-Giddens et al., 1997; Krogman, 1970, see Section 3). K&O misled their readers on this point. Moreover, K&O's selective and misleading argument is also apparent in their failure to acknowledge Jensen and Johnson's findings of either the *within*-families correlation between head size and IQ or the fact that when Whites and Blacks were matched on IQ, they showed virtually no difference in head circumference.

3. Krogman's (1970) Philadelphia Growth Study

Krogman (1970) carried out a "mixed" or "modified" longitudinal/cross-sectional study on 169 White males, 224 Black males, 135 White females, and 220 Black females, falling into nine age categories aged from 7 to 15 years in Philadelphia, Pennsylvania. Measures were made of height, weight and various body size dimensions including head length, width, and height. Krogman found that Blacks grew at a faster rate than Whites.

3.1. Lynn's (1993) study

Lynn (1993) estimated cranial capacities of White and Black children from Krogman's data by applying Lee and Pearson's Eqs. 1 and 2, using stature as a covariate. Lynn reported significant effects due to race and sex, with a marginally significant interaction between them, finding mean capacities for White boys of 1318 cm^3, for Black boys of 1286 cm^3, for White girls of 1180 cm^3, and for Black girls of 1188 cm^3. After adjustment for height by analysis of covariance, Lynn reported mean capacities for White boys of 1313 cm^3, for Black boys of 1286 cm^3, for White girls of 1186 cm^3, and for Black girls of 1185 cm^3.

3.2. K&O critique

K&O labeled "false" (p. 121) Lynn's claim that Krogman's data indicated a significant race effect. K&O recalculated the means and reported that Lynn's unadjusted means were erroneously high for White boys (1318 instead of 1308 cm^3) and for White girls (1180 instead of 1176 cm^3). After analysis of covariance, K&O reported that the correctly adjusted means favored White boys over Black (1303 to 1286 cm^3), but Black girls over White (1186 to

1182 cm^3). Neither the race effect nor the interaction was significant; only the effect of sex. K&O also pointed out that Krogman's data was far from ideal because of a lack of independence, with some children followed longitudinally and others added in cross-sectionally, to varying degrees.

3.3. R&A reply

We recalculatd Krogman's data and confirmed that the means reported by K&O are correct and Lynn's were mistakenly high for Whites. The true adjusted for stature means are 1243 cm^3 for Whites and 1236 cm^3 for Blacks, which although in Lynn's predicted direction, do not reach significance. As K&O point out, only the sex difference was statistically significant (which, following Ankney, 1992, is of interest in its own right). We note, however, that K&O prove to be inconsistent in taking body size into account. Although they followed Lynn in this case and carried out an analysis of covariance (perhaps so they could point to an error that had occurred), thereafter they submitted no further data to analysis of covariance. Instead K&O dismissed the technique, saying only that they considered it "inadequate."

4. Osborne's (1980) Georgia Twin Study

Osborne (1980) gathered extensive data in the 1960s and 1970s on personality, intelligence, and physical characteristics (including head length, breadth, and circumference) for 496 pairs of twins, 328 (69%) of whom were White and 149 (31%) of whom were Black. The twins ranged in age from 12 to 20 years, with an average age at testing of 15.2 years (SD = 1.5 years). The data were gathered in public and private schools in Georgia, Kentucky, and Indiana, and extensive appendices of these data were provided in the monograph. A battery of 17 diverse tests of intelligence were given, although not all subjects were given all tests. Osborne reported heritabilities of about 50% for IQ in both the Black and the White samples. Later, Osborne (1992) reported correlations of about 0.30 between IQ and head size in both the Blacks and the Whites.

4.1. Jensen's (1994) study

Jensen (1994) used Osborne's data to examine the relation between head size and psychometric *g*, with race, sex, and age regressed out. For 286 individuals with complete data on the 17 mental tests, Jensen found *g* correlated significantly ($r = 0.30$) with an aggregate of head length, width and circumference, not only within individuals, but also *within* twin pairs (0.25), thereby replicating his earlier finding that the sibling with a larger head averaged a higher IQ than the one with the smaller head (see Section 2.4). Moreover, the correlation between the vector for the multiple R aggregate of head length, width, and circumference with each of the 17 tests and the vector for the *g*-loadings of each of these tests was 0.642 ($P < 0.01$), one-tailed). Hence, the head-size/IQ relation is reflected most strongly in tests that are the most highly loaded on *g*.

Regarding race, Jensen found the magnitude of the White–Black differences on the tests to

be related to the tests' g loading (0.48; $P < 0.05$) thereby supporting "Spearman's (1927) hypothesis" that Black–White differences are greatest on the g-factor. Also, the greater the difference between White and Black children on each of the 17 tests, the higher was that test's correlation with head size ($r = 0.715$, $P < 0.01$). Jensen concluded that brain size was a causal variable mediating the relation between g and the Black–White difference on the cognitive tests.

4.2. K&O critique

K&O examined Osborne's data and found that *Blacks averaged equal to or larger than Whites in head circumference*, with Black girls significantly larger than White girls and Black boys nonsignificantly larger than White boys. The greater head circumference of Blacks compared to Whites occurred despite the fact that the Black children were 6 months younger and smaller in body size than the White children. K&O charged that, though he had the data before him, Jensen chose not to report the White and Black mean circumferences. K&O argued that these results undermined Jensen's claim that the White–Black difference in test scores related to the smaller head size of Blacks.

4.3. R&A reply

We defer our reply to K&O to Section 4.6 following K&O's similar criticisms of Rushton and Osborne's (1995) study which more directly compared Blacks and Whites in cranial volume. Jensen's (1994) study was mainly concerned with the relation between psychometric g and head size, and not race differences per se.

4.4. Rushton and Osborne's (1995) study

Rushton and Osborne (1995) examined the data on Osborne's 13- to 17-year-old twins (using head length and breadth and Eqs. Nos. 3 and 4) and estimated the heritability of cranial capacity to be approximately 50% in both races. Race and sex differences were also reported: Whites = 1278 and Blacks = 1242 cm^3; with a race × sex interaction such that in Whites, boys = 1340 and girls = 1215 cm^3, and in Blacks, boys = 1226 and girls = 1217 cm^3. Rushton and Osborne also carried out an analysis of covariance after finding several significant age × sex, race × sex, and age × race × sex interactions in body size and cranial capacity. They reported five such interactions: (1) girls matured earlier than boys; (2) Blacks matured earlier than Whites; (3) young Black girls were larger in body size than young White girls; (4) Whites were older than Blacks; and (5) White boys were taller and heavier than Black boys. Analysis of covariance for age, stature, weight, and sex reduced the race difference in cranial capacity by half (Whites = 1269 and Blacks = 1251 cm^3; again with a race × sex interaction such that in Whites, boys = 1307 and girls = 1230 cm^3, while in Blacks, boys = 1273 and girls = 1228 cm^3). After correcting for body size, therefore, the initial advantage of Black girls disappeared.

4.5. K&O critique

K&O strikingly reported (Section 4.2) that the Black children in Osborne's (1980) study actually had *larger head circumferences* than did the White children. K&O charged that Rushton and Osborne (1995), like Jensen (1994) before them, neglected to inform their readers about this strong piece of evidence which runs counter to their position. K&O also argued that Rushton and Osborne used a wrong equation in their analysis of sex differences (fusing Nos. 3 & 4) and thereby overestimated female capacities by some 40 cm^3.

K&O further claimed that the German Eqs. (3) and (4) used by Rushton and Osborne were biased against Blacks because they were weighted (in their multipliers) to favor wide rather than long heads. They labeled "false" the claim by Rushton and Osborne that Lee and Pearson's German Eqs. (3) and (4) give comparable results to panracial Eqs. (1) and (2), citing Lee and Pearson (p. 241) that it was "absolutely impossible" to generalize from one race to another unless equations were used (like Nos. 1 & 2) that took head height into account. When K&O re-examined Osborne's data using the Ainu Eqs. (5) and (6), they reduced the magnitude of the Black–White difference in cranial capacity (for males by almost half, and for females by slightly increasing the Black advantage). K&O attributed the remaining greater capacity in White boys to their larger body size. They did not, however, follow Rushton and Osborne in submitting their data to analysis of covariance claiming that "Not only is the choice of formula arbitrary, it is also not clear that covarying for stature and for weight adequately controls for the relation between body size and head size" (pp. 121–122).

4.6. R&A reply

K&O are correct when they report that Rushton and Osborne (1995) inadvertently used a wrong formula and *over*estimated female cranial capacities by about 40 cm^3. More importantly, K&O are also correct when they claim that Blacks (both male and female) in Osborne's study averaged larger head circumferences than did their White counterparts. Our (R&A) analysis confirmed these differences even after covarying for age, height and weight. K&O's data on race differences in circumference are, therefore, inconsistent with the results Rushton and Osborne reported based on volume. As we shall see (Section 7) a similar inconsistency arises in the data from the US Army, with volume showing a White advantage and circumference showing either "no difference" or, for women, a Black advantage. Does this inconsistency then invalidate the conclusion that the preponderance of evidence supports a true race difference in cranial capacity?

To begin with, circumference can be large, but if the forehead then recedes steeply backwards (as it does more often in Blacks than in Whites; see Baker, 1974; Rushton, 1995) it thereby overestimates brain size relative to volumetric measures. Large circumference can also result from thicker cranial bones, which are present for Blacks in both frontal and occipital regions, as measured by CT scans (McShane, 1983). The circumference measures among Blacks (especially Black girls) in Osborne's (1980) study seem especially subject to error due to then popular hair styles, which are quite noticeable on inspecting slides of Osborne's subjects. Whereas spreading calipers able to penetrate the hair were used to take the measures of head length and head width (from which cranial volume was calculated), a steel tape was used to

measure head circumference (Osborne, 1980, p. 182). As we shall note in Section 7, the US Army survey specifically cautions about the problem of hair style in taking head circumference measures.

The greater validity of cranial volume over circumference measures in Osborne's sample is validated by their higher internal validities using correlations with age and body size as criteria. This was generally true for Blacks, but especially so for Black girls. Thus, *cranial volume* correlated with age, stature, weight, head length, and head width in White boys with a mean of **0.51** (0.23, 0.33, 0.48, 0.69 and 0.82, respectively); in White girls with a mean of **0.48** (0.12, 0.39, 0.41, 0.73 and 0.77, respectively); in Black boys with a mean of **0.57** (0.36, 0.38, 0.61, 0.68 and 0.84, respectively); and in Black girls with a mean of **0.39** (−0.33, 0.25, 0.54, 0.70 and 0.77, respectively). The correlations with *circumference* were significantly lower: in White boys with a mean of **0.43** (0.17, 0.32, 0.40, 0.76 and 0.51, respectively); in White girls with a mean of **0.42** (0.00, 0.40, 0.43, 0.77 and 0.51, respectively); in Black boys with a mean of **0.47** (0.25, 0.37, 0.48, 0.71 and 0.52, respectively); and in Black girls with a mean of **0.23** (−0.23, 0.13, 0.31, 0.56 and 0.36, respectively).

We also performed three-way analyses of variance to examine the effects of age, race, and sex on the volume measures and contrasted the results with those found using circumference. Whereas the volume measure showed the expected increment with age, the circumference measure did not. Indeed, the 13- and 14-year-old Black girls had larger head circumferences than did the 16- and 17-year-old Black girls. We also observed a greater number of two- and three-way interactions with circumference as the dependent variable than we did with volume. In short, circumference proved to be a less reliable indicator in this sample than was volume, especially among Blacks, and particularly among Black girls.

Curiously, although K&O (p. 126) made much of the greater circumferences of Blacks in the Osborne study they were well aware of the problems in accurately measuring head circumference as reported in the literature. They cite two earlier researchers to that effect:

> Murdoch and Sullivan (1923, p. 214) explained: 'Head circumference is very difficult to take and is subject to gross errors of observation due to differences in technique and to differences in the amount of hair on the subjects.' Todd (1923, p. 145) wrote that: 'Circumference alone ... cannot be expected to give good results. Indeed all of the measurements, if applied to the head itself, are not comparable or reliable as anyone would testify who has tried to carry them out on one of our typical Negro women.'

K&O also claimed that Rushton and Osborne's choice of the German Eqs. (3) and (4) was arbitrary and did not give comparable results to the panracial Eqs. (1) and (2) which took head height into account and on which Whites have a marked advantage. But Rushton and Osborne (p. 4) had clearly referred to Rushton's (1993) earlier work which cited Passingham (1979) as a precedent for their use, and empirically tested Eqs. (3) and (4) against Eqs. (1) and (2) using both White and East Asian military samples. Rushton (1993) found results within 25 cm^3 (less than 2% difference) from those obtained using the panracial equations. Further, K&O's use of the Ainu Eqs. (5) and (6) did not eliminate the Black–White difference in the Osborne data, but merely reduced it.

More generally K&O misled their readers about the larger head measures in Black girls by

ignoring the race × sex interaction for body size. K&O's stated rationale for not correcting cranial capacities for body size and age (i.e., that the formulas used to make the corrections were arbitrary) is unpersuasive. Corrected measures could differ substantially from the uncorrected, and it is always desirable to report both results. Indeed, since the Black children were younger, and the White males larger, the correction might theoretically have eradicated the White advantage in volume, and accentuated the Black advantage in circumference.

5. Herskovits's (1930) international data

Herskovits (1930) collected data for nearly 1000 African American adult males (mostly university students and those from well-to-do families). He compared the results to measurements made by earlier investigators on other populations from around the world in order to examine "the biological phenomenon of racial mixture" (p. 1). He found that on 28 anthropometric traits, American Blacks typically fell between Africans, on the one hand, and the White and Amerindian peoples, on the other, thus validating the "mixed-race" hypothesis as well as his methods of assessment. Measures were provided of head length and width (and occasionally height) for 26 populations. Herskovits (1930, pp. 8–9, 43–44) provided incomplete data for the 26 populations on stature but reported that Davenport and Love's (1921) army data from World War 1, the largest anthropometric survey of African Americans at the time, showed 6454 "Negro troops" averaging virtually identical in height (171.99 cm), to 96,596 "White troops" (171.97 cm). Herskovits's own sample of Black Americans averaged 170.49 cm.

5.1. Rushton's (1990, 1993) studies

Rushton (1990, 1993) first categorized the data from Herskovits's 26 populations by race or geographic area and then performed two reanalyses. In the second analysis, Rushton subtracted the 11 mm from Eqs. (3) and (4) for living tissue and showed that this adjusted equation predicted independent criteria better than the uncorrected equation he had used in 1990. Rushton (1990, 1993) justified the use of Lee and Pearson's German equation by citing its contemporary use by Passingham (1979) and (in 1993) by empirically testing it against panracial Eqs. (1) and (2) in both White and East Asian military samples, finding results within 25 cm^3 (less than 2% difference). Regardless of which equations were used, or which of several averaging procedures was adopted, the 17 "Negroid" samples consistently averaged smaller head sizes than the Caucasoids or the Amerindian and Pacific Island people.

5.2. K&O critique

K&O (p. 123) claimed that Herskovits's data failed to support the claim that *American* Blacks (in contrast to African Blacks) had smaller cranial capacities than American Whites. K&O pointed out that the American Black cranial capacity of 1422 cm^3 was virtually identical to that of a White group of "American Bohemians" (1423 cm^3), even if it was significantly lower than that found for a sample of White "Old Americans" (1454 cm^3). K&O also found that using the Ainu equations reduced the difference between the Old Americans (1476 cm^3)

and the American Blacks (1453 cm^3) by half, and further that it lowered the American Bohemian average to 1360 cm^3, 87 cm^3 below that for Black Americans. K&O also drew attention to a large sample of Swedes (N = 46,975) who averaged lower (1393 cm^3) than did the American Blacks (1422 cm^3). They suggested that unmeasured body size differences could account for any remaining population differences in cranial size.

5.3. R&A reply

Herskovits's head size data set was compiled from the results of different investigators at different times using different techniques. By choosing selectively among the many samples and taking them as representative of a "race", any racial ranking one likes can be artificially created. It is misleading for K&O to separate out a sample of 46,975 Swedes with a smaller cranial capacity than the American Blacks, while ignoring numerous other samples ("Foreign-born Scotch," "Oxford students," "Foreign-born Bohemians," "Hawaiians," and "Half-blood Sioux," to name but a few). It is more appropriate to use the principle of aggregation and combine samples. When Herskovits's data were aggregated, as we have reported, statistically

Table 1
Cranial size and height measures from Herskovits (1930) for various male samples classified by race or geographical region

			Head		Cranial Capacity (cm^3)	
		Stature (cm)	Length (mm)	Width (mm)	German Equation	Aino Equation
Amerindians and Pacific Islanders						
77	Half-blood Sioux	173.50	194.40	154.30	1,441	1,440
86	Hawaiians	171.60	191.25	158.93	1,472	1,423
	Mean	172.55	192.83	156.62	1,457	1,432
Caucasoids and European						
727	Old Americans	174.30	197.28	153.76	1,454	1,476
263	Scotch foreign-born	172.10	196.70	153.80	1,451	1,469
493	Aberdeen students	171.70	194.80	153.40	1,433	1,441
46,975	Swedes	172.20	193.84	150.40	1,393	1,411
1,000	Cambridge students	174.90	193.51	153.96	1,431	1,426
450	Foreign-born Bohemians	167.50	189.80	159.10	1,465	1,405
	Mean	172.12	194.32	154.07	1,438	1,438
Negroids and African						
961	American Negroes	170.50	196.52	151.38	1,422	1,453
34	Lotuko	178.30	192.90	141.30	1,283	1,348
55	Kajiji	168.30	192.31	144.56	1,316	1,358
19	Ekoi	166.86	191.05	143.16	1,297	1,302
72	Kagoro	160.11	188.19	142.43	1,263	1,290
48	Ashanti	164.21	187.33	145.01	1,287	1,293
30	Acholi	174.00	187.30	141.80	1,250	1,275
	Mean	168.90	190.80	144.23	1,303	1,331

significant differences in brain size were found, with North American Indians and Caucasoids averaging larger than Negroids. Carefully selecting outliers cannot negate this general finding.

Body size had been left out of Rushton's (1990, 1993) analyses because of incompleteness of the data. Because K&O implied the data would be otherwise had it been taken into account, Table 1 provides the data on stature among those groups where it was available. As can be seen, the tallest group was from sub-Saharan Africa — the Lotuko, who averaged 178.3 cm. So too was one of the next tallest, the Acholi, who averaged 174.0 cm. Even though analysis of variance showed no significant differences between the populations in height, for completeness we nonetheless covaried it in this now third reanalysis of Herskovits's data. Treating each population as an independent entry, with means adjusted for stature showed: Amerindian and Pacific Islanders = 1456 cm^3 (N = 2; unadjusted mean = 1457 cm^3); Caucasoids = 1438 cm^3 (N = 6; unadjusted mean = 1438 cm^3) and Negroids = 1303 cm^3 (N = 7; unadjusted mean = 1302 cm^3). We also recalculated the results using the Ainu equations as K&O urged in Section 4.5 only to find a similar (if attenuated) pattern as in our original analysis: Amerindian and Pacific Islanders = 1426 cm^3 (N = 2; unadjusted = 1432 cm^3); Caucasoids = 1434 cm^3 (N = 6; unadjusted = 1438 cm^3); and Negroids = 1341 cm^3 (N = 7; unadjusted 1331 cm^3).

6. NASA (1978) data

An extremely comprehensive source of head- and body-size data is that compiled by the US National Aeronautics and Space Administration (1978, NASA), which surveyed some 91 military and civilian populations. Measures were tabulated of head length, breadth, and height, as well as stature, weight, and other variables.

6.1. Rushton's (1991a) study

Rushton (1991a) examined the 24 samples (4 Mongoloid, 20 Caucasoid) from the 91 in the NASA (1978) source book that contained complete data on head length, breadth, and height and used Eqs. (1) and (2) to calculate cranial capacity. Before adjustments by analysis of covariance for body size, the Mongoloids averaged cranial capacities of 1343 cm^3 and the Caucasoids 1467 cm^3, a two standard deviation difference in favor of the latter. However the Mongoloids were three standard deviations smaller in body size. After adjustment for body size the Mongoloids averaged 1460 cm^3 and the Caucasoids 1446 cm^3, but the difference was not significant. The power of the test, however, was low given that N = 24, rather than the N = 57,378 it would have been had the raw data been available. A secondary analysis in terms of Jerison's (1973) equations for encephalization quotients (EQs) produced a significantly higher EQ for Mongoloids (7.26 vs 6.76; $P < 0.05$).

6.2. K&O critique

Although K&O did not critique this particular study by Rushton (1991a), perhaps because their review focused on Black–White differences, they did cite (on p. 122) the criticisms of its method of controlling for body size made by Willerman (1991) and Reed and Jensen (1993).

Later in their paper K&O (p. 125) used the same NASA source book to draw a single sample of White women and another of Black women to bolster their claim (Sections 2.5, 4.2 and 7.2) that Black females average greater head length and/or head circumference, whereas White females average greater head breadth.

6.3. R&A reply

Selectively pulling out single samples from a total of 91 does not produce reliable evidence. This tactic, also used by K&O in their discussion of Herskovits's data (see Section 5.2), only provides a convenient means of obscuring general conclusions, K&O also selectively ignored Rushton's (1991a) finding that Mongoloid populations averaged higher cranial capacities than Caucasoids (as well as Rushton's (1991b) reply to Willerman's critique).

7. US military data (1988)

In 1988, the US Army carried out an anthropometric survey on a stratified random sample of 8000 military personnel for the purpose of sizing clothing and work stations (Clauser, Tebbetts, Bradtmiller, McConville & Gordon, 1988; Gordon et al., 1989). Individual body size and head measurements were available separately for men and women, officers and enlisted personnel, and those who identified themselves in the US Army questionnaires as being White, Black, Hispanic, Asian/Pacific, American Indian, or Mixed/Other. New and improved methodologies were employed, including an automated device to measure the head and face, so as to avoid problems found with earlier methods (such as head circumference) which required caveats such as "Use enough tension to compress the hair", and "*Caution*: The plane of the tape will be higher in front than it is in the back but should not be tilted to either side" (Clauser et al., 1988, p. 130).

7.1. Rushton's (1992) study

Rushton (1992) used a stratified random sample of 6325 of these military personnel to test for racial differences in cranial capacity using Eqs. (1) and (2). For the entire sample, the unadjusted size of the cranium was 1375 cm^3. The range was from 981 cm^3 (a Black woman) to 1795 cm^3 (a White man). Because the measurements had been gathered on individuals, specific adjustments could be made to the raw data for the effects of age, stature, and weight, and then sex, rank or race. When averaged, the races differed significantly in both unadjusted (raw) and adjusted cranial capacities. Analysis of variance of unadjusted cranial capacity showed that Asian Americans averaged 1391 cm^3, European Americans, 1378 cm^3, and African Americans, 1362 cm^3. After adjusting for the effects of stature, weight, sex, and military rank, the differences became larger: Asian Americans averaged 1416 cm^3, European Americans 1380 cm^3, and African Americans 1359 cm^3. Numerous corrections for body size did not diminish the racial differences in cranial capacity. Although the mean values changed with particular adjustments for body size, rank or sex, in no case was there any departure from the significant racial ordering: Asians > Europeans > Africans.

7.2. K&O critique

K&O did not dispute Rushton's findings but claimed that analyses of covariance were inadequate and that confounding variables nullified their meaning (e.g., the White officers included more pilots, who had been selected by different anthropometric criteria). More importantly, K&O (p. 125) carried out an analysis of a head circumference measure (not analyzed by Rushton and limited to Black and White enlisted personnel), and reported that Blacks (both males and females) had *significantly greater head circumferences than did Whites.* K&O also reported a race × sex interaction such that the Black advantage in head circumference was larger in females than males and then argued that because the interaction occurred in adults it invalidated the supposition by Lynn, Jensen, and Rushton that the interaction observed in children was due to a more rapid maturation by Blacks and by girls (see Sections 2.4–2.6 and 3.1–3.3). In other words, K&O maintained that Black females typically had larger head circumferences than White females at all age levels. Finally, K&O used Lee and Pearson's circumferential Eqs. (9) and (10) to calculate cranial capacity, with the result that Blacks then averaged significantly larger than did Whites.

K&O (p. 125, Table 2) present a summary of the means from the sample of 6000 US Army personnel. This shows that Blacks have proportionately longer but flatter heads than Whites or Asians, and that Asians in turn have wider heads than either Blacks or Whites. K&O concluded that it was all arbitrary, that "whites and blacks have differently shaped heads, and the shape difference varies between the sexes. Different estimates of cranial capacity are the consequences of different shaped heads"(p. 126).

7.3. R&A reply

K&O's analyses of the 1988 US Army data are correct. Black enlisted personnel (both male and female) averaged a larger head circumference than did their White counterparts and a race × sex interaction occurred such that the Black advantage was greater for females. We (R&A) carried out an analysis of covariance and found the Black female advantage in head circumference remained even after controlling for age, height, and weight. (The Black male advantage did not remain after correction for age and body size; when the sex-combined sample was used there was no significant race difference in circumference either before or after corrections.) K&O have identified another example of the anomaly they observed in Section 4.2. When cranial volume is calculated from head dimensions like length and width (and in this case height), and plugged into Eqs. like (1) and (2), the typical Asian–White–Black average difference is found, but when circumference measures are used, Blacks sometimes have the advantage.

K&O's complaint about analysis of covariance being unable to control for the effects of extraneous variables (such as age, body size, and military rank), however, is simply wrong. Although K&O wrote in a tone that suggested Rushton was either unaware of race × sex interactions or that these were an embarrassment to him, Rushton (1992, p. 406) in fact tested and found several two-way interactions (but not three-way, or four-way) and consequently carried out separate regressions of cranial capacity on stature and on body weight for each race × sex category.

The real question is how to resolve the contradictory ordering of racial differences in cranial capacity when estimated from circumference or from different weights of length × width × height (see Section 4.6 for earlier discussion). Race differences in head shape, with Blacks having proportionately longer, and narrower (especially in the front), and flatter heads than Whites and Asians, and with Asians in turn having more spherically-shaped heads than Whites, has been known for decades (Beals et al., 1984). Head shape is also correlated with overall brain volume, which also requires explanation. We will address cranial shape and size in Section 9 and present new analyses.

8. International Labour Office data

Jurgens, Aune, and Pieper (1990) collated 337 anthropometric studies from across the world. They published estimated medians (as well as 5th and 95th percentiles) for head length, head breadth, and head circumference from the world population, broken down into 20 different regions. The measurements from men and women aged 25–45 had been gathered over a 30-year period. Some 300 references had been examined from seven sources: tailors' and shoemakers' measurements, anthropology, medical records, sports, growth surveys, forensic and legal investigations, and ergonomic studies. Information was taken exclusively from studies carried out after 1960 in order to help standardize the measures and to limit the effects of the secular growth trend, that is, the trend for each generation to become taller, especially in the industrialized countries, and also to limit the effects of migration and other demographic changes. Growth trends that could be detected were standardized by correcting forward to the year 2000. Since the studies of military personnel reviewed here in Sections 6 and 7 above were not included, the International Labour Office data are independent of previously analyzed sets.

8.1. Rushton's (1994) study

Rushton (1994) again used the German version of the Lee and Pearson Eqs. (3) and (4) for length and breadth to calculate an estimated capacity for each of the 20 regions. He then grouped 14 of the regions into three racial categories: "East Asian or Mongoloid," "European or Caucasoid," and "African or Negroid." (Six other regions of origin were omitted to eliminate ambiguous categories). Analysis of variance showed significant effects for both sex and race, with no interaction. Men had larger cranial capacities than women, and Europeans had larger capacities than East Asians, who in turn had larger capacities than Africans. When stature was entered as a covariate, East Asians had larger adjusted mean cranial capacities than did Europeans, who had larger capacities than Africans.

8.2. K&O critique

K&O argued that the International Labour Office used such rough approximations of head size that they were of little value for scientific racial comparisons. The studies sometimes rounded head measurements to the nearest 5 mm and sometimes only deduced them from stature using an expected ratio between stature and head dimensions. K&O were able to locate

only 165 of the 337 references cited in the source book because many were in difficult-to-obtain journals from Bulgaria, Poland, and Japan, while others were from the technical report literature and unpublished data. Only 37 of the 165 references K&O obtained actually contained data on head measurements. Many of the samples had allegedly been misclassified. For example, Samoans, Japanese, Chinese, Filipinos, and Hawaiians resident in Hawaii were categorized as "Australia (European population)," while Romanians were classified as "South-eastern Africa." K&O also argued that body size presented a problem. Since body size varies with age, the International Labour Office compilation claimed to control for it by restricting its data to the age group 25–45 years. However, K&O found that a source cited for Central Europe contained data only for the age group 60–89 years, and another cited for South-eastern Europe contained data only for ages 3–18 years. Taken together, K&O argued these errors and inconsistencies, along with the imprecise estimation techniques, rendered the International Labour Office data useless for comparison of cranial capacities across racial groups.

K&O also claimed that using the Ainu Eqs. (5) and (6) again produced different results from the German equations used by Rushton (Eqs. (3) and (4)). For males, use of the Ainu equation shows Africans and Europeans each have capacities of 1397 cm^3, while East Asians trail with 1371 cm^3. For females, the European and East Asian estimates from the Ainu are very close (1216 and 1213 cm^3), while Africans are only 1141 cm^3. Taken at face value, K&O point out, these data would suggest a large race × sex interaction.

8.3. R&A reply

The fact that the data from the International Labour Office were gathered independently of the purpose of testing for race differences in cranial capacity is a virtue, not a fault. It means that the data were collected free from the "bias" with which researchers on this topic are so often charged (e.g. by Gould, 1996; Kamin, 1974; Lewontin, Rose & Kamin, 1984). As to the inconsistencies and errors of classification cited by K&O (European samples misclassified as "African" and Asian samples misclassified as "European"), their effect is to blur the population categories, making Africans more similar to Europeans and Europeans more similar to Asians, and thus work to underestimate race differences. Similarly, adding younger and older aged samples serves only to increase uncontrolled error and so again minimizes race differences, rather than falsely exaggerating them as K&O invite their readers to believe. Since the Asian > European > African differences emerged despite the sources of idiosyncratic error K&O identified, the racial differences appear to be more robust, not less so.

K&O's independent analyses of the International Labour Office data is a further exercise in obfuscation. After using the Ainu Eqs. (5) and (6), they claimed to have found yet another "race × sex interaction." What they failed to mention, however, is that contrary to what they reported in Sections 2.5, 4.2, and 7.2, it is now the Black women who average the smallest cranial capacity, exactly the *opposite* of what they claimed earlier. Nor did K&O statistically analyse their data to see whether the interaction was significant (it was) or whether it remained after controlling for body size (it did). Nor did they note that pooling across sex showed that Africans averaged significantly smaller cranial capacities (1269 cm^3) than Asians (1292 cm^3) or Europeans (1307 cm^3), a relationship not altered after controlling for body size.

Revealingly, K&O did not analyze the data on head circumference, although they were

available to them and they had made much of this variable (see Sections 4.2, 6.2, and 7.2). Perhaps this was because when we calculated the averages, we found that White males = 569 cm, Black males = 560 cm, White females = 544 cm, and Black females = 520 cm. The main effects of race and sex, as well as the race × sex interaction were all significant.

9. Head shape and cranial capacity: new analyses

K&O somewhat nihilistically concluded (p. 125) that: "The most illuminating summary of these data is also the simplest: whites and blacks have differently shaped heads, and the shape difference varies between the sexes." In fact, it has long been reported that the races differ in head shape with Blacks averaging heads that are proportionately longer, narrower (especially in the front), and flatter than those of Whites and Asians, and that Asians in turn have more spherically-shaped heads than do Whites (Beals et al., 1984; Broca, 1861; McShane, 1983). Thus, Howells (1989) collected and analyzed 57 measures taken from 2504 individual crania from 18 modern populations gathered worldwide and compared these with several earlier hominids including Neanderthal and *Homo erectus* populations. Howells concluded that in overall shape, sub-Saharan Africans fell at the opposite end of a continuum from Far Easterners, with Europeans intermediate. Nonetheless, Howells found that modern Africans, Europeans, and East Asians were, on average, all more similar to each other than any of them was to Neanderthals.

Beals et al. (1984) analyzed up to 20,000 male and female skulls for 122 populations from around the world. They found that skulls from hot climates like Africa were dolichocephalic (long relative to wide), but those from colder climates like Europe, and especially East Asia, were brachycephalic (wide relative to long). Wider skulls had greater cranial capacity than did longer skulls (independently measured by filling the skull with mustard seed). Beals et al. proposed a thermoregulatory model to explain the evolution of these differences: it was easier to keep a smaller, elongated head cool in a hot climate and a larger, more spherical head warm in a cold climate. Beals et al. found an average increase of 2.5 cm^3 in cranial capacity for every 1° increase in latitude. They also reported (pp. 305–306) that the average cranial volume for modern humans is 1350 cm^3 for males and females combined, somewhat less than the frequently cited figure of 1400 cm^3, historically derived from considering Europeans or males as representative.

One problem with Beals et al.'s (1984) thermoregulatory model (elaborated on by Armstrong, 1990) is that the brain is a metabolically very expensive organ. Although the human brain represents about 2% of total body mass, the brain's energy demand is equal to about 20% of the body's basal metabolic rate. It is impossible that such a metabolically expensive organ would enlarge simply from selection for brachycephalization or, especially, for thermoregulation. It is possible, however, that thermoregulation was a force selecting against increased brain size in sub-Saharan Blacks (and in other tropical populations). Regardless, Beals et al. (1984, p. 305) noted that increasing encephalization leads to a more spherical shape. They cite the almost forgotten work of Thomson (1903), who demonstrated the structural relation between encephalization and brachycephalization experimentally by

removing the brain case and replacing the brain with a rubber bladder into which air could be pumped. Endocranial volume, then, is itself partly the result of cranial shape.

Here we examine more systematically how the races differ in cranial shape and size using data from the stratified random sample of 6000 US Army personnel previously analyzed by Rushton (1992; see Section 7), with replications made separately for males and females to examine the general reliability of the results. The representativeness and validity of these data, based on measures of the outside of the head (and including Asians, Whites, and Blacks, men and women), can be gauged by the overall average cranial capacity found of 1375 cm^3. This is remarkably similar to the 1350 cm^3 found in Beals et al.'s worldwide study, estimated from filling the skull with mustard seed. (Possible explanations for it being 25 cm^3 larger is that Americans of all racial groups are larger in body size than are their counterparts elsewhere, and the US Army excludes those with IQs less than 85.)

The US Army data are noteworthy in another way. Whereas the two previous large-scale studies of population differences in cranial shape (Beals et al., 1984; Howells, 1989), examined samples differing widely across geographic distance, cultural circumstance, and even centuries of time, the present investigation holds these and other factors constant including age, health status, and occupation of individuals.

9.1. Methods

The raw data were collected in the 1988 anthropometric survey of a stratified random sample of over 6000 US Army personnel. Head and body size measures were provided by Dr. Bruce Bradtmiller of Anthropology Research Project, Inc., the commercial firm commissioned by the US Army to conduct the survey. (All original measurements for this study are filed at the Anthropology Research Project, Yellow Springs, OH 45387; a report of summary statistics is also available in Gordon et al., 1989.)

Data were categorized by sex (male or female) and race (Asian, White, or Black), with head length, width, and height treated as dependent variables. Since our interest was in head shape, we did not correct for body size when doing analyses. All statistical analyses were performed using the Statistical Analysis System (SAS Institute Inc., 1985). Two-way ANOVAs were used to evaluate the effect of sex and race on each variable. Canonical discriminant analysis was performed to determine if and how the races and sexes differed with respect to head morphology. Discriminant analysis was performed first on the whole data set, and then on subsets of 300 of each sex from each race. Means, variances, and covariances were calculated for each race × sex combination on the first three canonical axes.

9.2. Results

The two-way ANOVAs for race and sex on morphological features revealed that variation due to sex was greater than that due to race for all variables. We then pooled the data across sex for additional analyses. The first three canonical axes generated by canonical discriminant analysis described 78, 18, and 4% of the among-group variation in the sample, respectively.

Total canonical structure coefficients for the first canonical axis (CAN 1) revealed a pure size component (i.e., increases in all three head size variables: head height, head length, and head

width). The second canonical axis (CAN 2) described increased head breadth and head height relative to head length. The third canonical axis (CAN 3) indicated increased head height relative to head breadth. Canonical discriminant analysis revealed clear separation of the races along the three canonical axes (Wilk's $\lambda = 0.3964$; $P < 0.001$). We plotted the mean values for each race–sex combination on CAN 1 and CAN 2 to illustrate the first two of these relationships (Fig. 3). Discriminant analysis showed that the model was very successful at assigning individuals to races, irrespective of sex. When the model was recreated based on a randomly selected portion of the data, and then retested with the remaining portion, we observed a similar success rate.

CAN 1 distinguished the two sexes (Fig. 3). Males, regardless of race, have significantly larger crania than do females. CAN 2 distinguished the races, with Asian Americans having significantly greater head breadth and head height, relative to head length, than did European Americans, who had relatively greater head breadth and head height than did African Americans. CAN 3 showed that, relative to head breadth, head height of European Americans was higher than that of Asian and African Americans.

9.3. *Evolutionary considerations*

Across species, bigger brains evolved via natural selection for increased intelligence (Jerison,

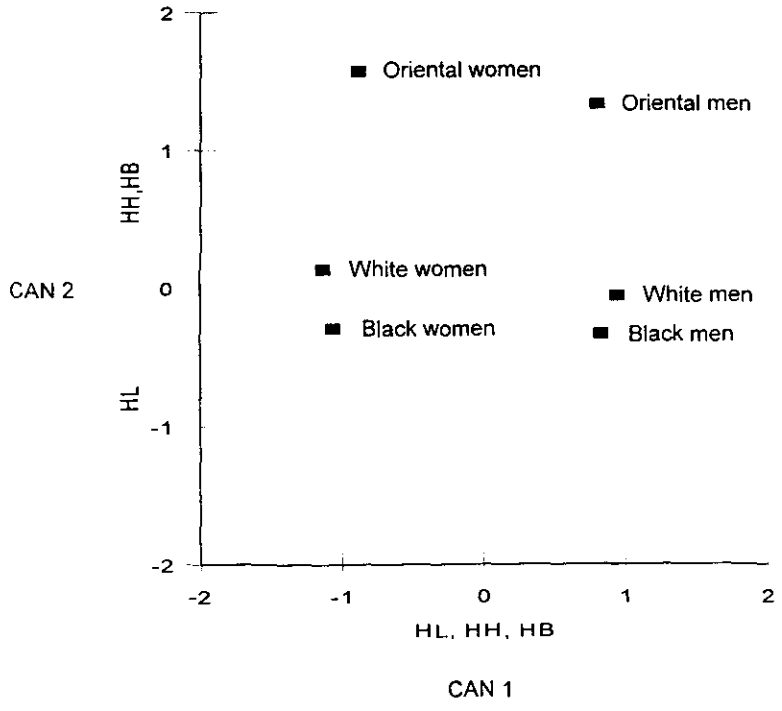

Fig. 3. Means of each race × sex group on the first two canonical axes. Variables important in defining the axes (according to standardized coefficients) are shown above the arrows: HH, head height; HW, head width; HL, head length.

1973). Across human races, Beals et al. (1984) proposed an evolutionary theory based on climate and the body's heat-loss mechanisms to explain differences in cranial shape and size. Based on this data, Howells (1989) argued against the Multi-Regional Continuity model of human origins, but was otherwise agnostic about their evolutionary implications. Lynn (1991) proposed a theory of brain size evolution for human races based on selection for intelligence. Rushton (1995) formulated a hypothesis based on the selection of life history traits (including brain size and intelligence), consistent with the Out-of-Africa model of human origins summarized below.

Three million years ago, Australopithecines averaged a cranial capacity of less than 500 cm^3 (about the size of a chimpanzee brain); two million years ago, *Homo erectus* averaged a capacity of about 1000 cm^3; and 0.25 million years ago, *Homo sapiens* averaged a capacity of about 1200 cm^3. According to the "African Eve" theory of human origins (Stringer & McKie, 1996), modern humans emerged in Africa some 200,000 years ago, with an African/non-African split about 110,000 years ago, and with an European/East Asian split about 41,000 years ago. The further north the populations migrated, out of Africa, the more they encountered the cognitively demanding problems of gathering and storing food, acquiring shelter, making clothes, and raising children successfully during prolonged winters. As the populations that migrated from Africa evolved into present-day Caucasoids (current cranial capacity, 1347 cm^3) and Mongoloids (current cranial capacity, 1364 cm^3), they did so in the direction of larger and more spherical brains, whereas cranial capacity and head shape of populations that remained in Africa changed very little (current cranial capacity, 1276 cm^3) (see Fig. 4). Thus, the evolutionary sequence fits with and explains how and why the races differ both in head size and in head shape.

Selection for increased brain size led to changes in skull morphology and in the musculo-skeletal system; the geographic clustering of these traits also support the Out-of-Africa theory. For example, Stringer, Dean and Humphrey (1999) showed that racial differences exist in various mandibular traits (jaws and teeth) including the bichondylar breadth of the mandible (i.e., the distance between the two surfaces at the back of the jaw that attach to the base of the cranium). In Asians this is wide, in Africans it is narrow, and Europeans are in between. Widening brain cases led to widening bichondylar breadths.

Another critical factor influencing cranial shape is skull musculature. For example, *Homo habilis* had greater post-orbital constriction (indentation of the skull behind the eye socket) and larger temporal fossae (the opening through which muscles pass from head to jaw) than did *H. erectus*, which had greater post-orbital constriction and larger temporal fossae than did *H. sapiens* (Fleagle, 1999). Within *H. sapiens*, Blacks have greater post-orbital constriction and larger temporal fossae than do Whites, who have greater post-orbital constriction and larger temporal fossae than do Asians (Brues, 1990). This is because as brain tissue expanded in the temporal and parietal lobes, it did so at the expense of the temporalis muscles, which run through the temporal fossa in each zygomatic arch, and serve to close the jaw. Since smaller temporalis muscles cannot close as large a jaw, jaw size was reduced. Consequently, there is less room for teeth, resulting in smaller teeth, shorter roots, and fewer teeth. (Asians and Europeans have smaller jaws, fewer and smaller teeth, and shorter roots than do Africans; Brues, 1990). The decrease in jaw size (orthognathism replacing prognathism) in turn led to decreased size of neck muscles and the bony protuberances where they attach (nuchal crests,

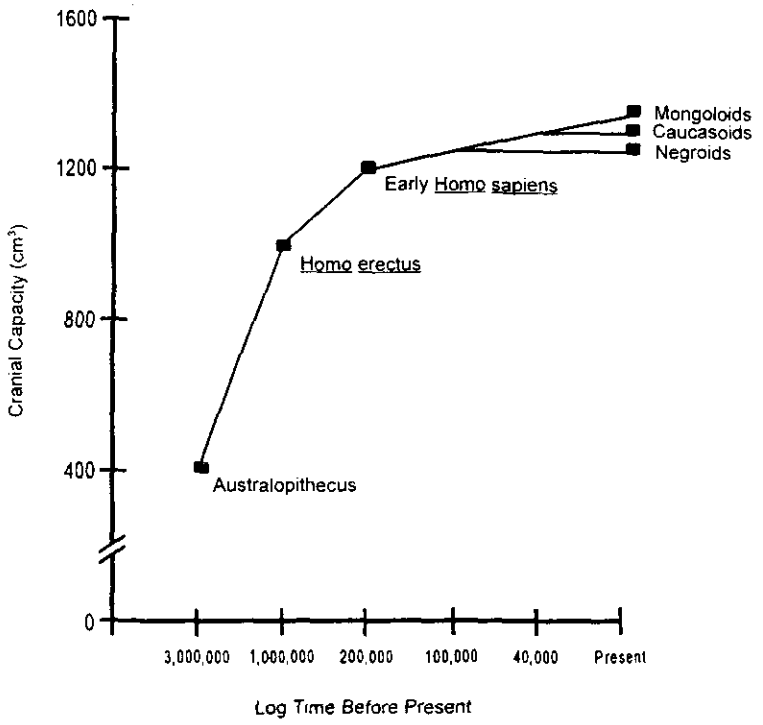

Fig. 4. Increasing cranial capacity over evolutionary time.

cervical spinous process), which are no longer required for supporting heavy prognathic faces. (Asians and Europeans have reduced neck muscles and smaller spinous processes and less prognathic faces than do Africans: Binkley, 1989). As brain tissue in the frontal lobes expanded, it took up the space previously occupied by bony super-orbital rims, thereby causing a decrease in glabellas. (Asians and Europeans have less pronounced glabellas than do Africans; Krogman & Ýpcan, 1986). Further down the postcranial skeleton, increased encephalization required a wider pelvic opening, formed by the pubic and ischial bones, rather than just by the iliac bone, in order to allow birth of larger-brained infants. (Asians and Europeans have wider pelvises than do Africans; Krogman & Ýpcan, 1986). There is no explanation for these changes in the musculo-skeletal system other than for accommodating increased brain size.

Finally, because larger brains require more time to develop, the maturation rate is also affected. Gestational age approximates 33 weeks in chimpanzees and 38 weeks in modern humans. Puberty is reached around 8 years in chimpanzees and 13 years in humans. Life span averages 30 years in chimpanzees and around 75 years in humans in contemporary economically developed nations. These trends are also found across human groups. Asians and Europeans give birth at later gestational ages than do Africans, and their children reach puberty later and live longer. Thus, changes in brain size have cascading effects on other traits (Rushton, 1995). Since the "life-history" variables associated with brain size correlate highly

both across species and across the human sub-species they require a general theory to explain their co-evolution of the kind advanced in Rushton (1995).

10. General discussion

It is always useful in science to have real errors pointed out, and this is not peculiar to research on race, head size, and IQ. But how many errors did K&O actually claim to find, how many did they really find, and how much, if at all, do they matter? We identified only three real errors claimed by K&O, each of which we were able to verify (two in articles by Lynn, 1990, 1993; one in Rushton & Osborne, 1995). Correcting for the two Lynn errors reduced the Black–White difference, one to a null relation; correcting the one by Rushton and Osborne increased the sex difference by about 40 cm^3 (in favor of males) and also slightly (3 cm^3) reduced the White–Black difference for females. None changed the overall picture.

K&O's "alternative" findings and interpretations, based on race × sex interactions, head circumference measures, and the Ainu Eqs. (5) and (6) produced inconsistent results. The race × sex interactions K&O drew attention to in the data on children and adolescents (Sections 2.5 and 4.2) and in one sample of adults (Section 7.2) with some samples of Black females averaging larger head size on some measures that White females, disappears on other measures or in other adult samples, or even reverses, with Black females now averaging disproportionately *smaller* craniums than their White female counterparts (Section 8.3). K&O's head circumference analyses found Blacks having smaller or equal cranial size to Whites during childhood, significantly larger cranial size during adolescence, and either non-significantly larger cranial size in adulthood or significantly smaller cranial size in adulthood. In short, their corrected results wandered all over the place. K&O, of course, could argue that this is what you would expect when there's no signal, just noise. But Lynn's, Jensen's and Rushton's studies instead show consistent, replicable results, which are found again in our reanalysis of the US Army data.

Taken together, K&O's inconsistent results, their selective reporting of those items that support their position while ignoring items that did not, and attempts to refute aggregated data show that their critique is an exercise in obfuscation. It is not prudent to put faith in the results of any one study, any one critique, or any isolated event or finding. It is wiser to employ the principle of aggregation and average the data across the numerous exemplars. The sum of a set of multiple measurements is a more stable and unbiased estimator than any single measurement selected from the set because aggregation causes specificity and error variance to cancel out, leaving only true score variance to remain. Apparently, this straightforward principle, known since the 19th century, requires continual repetition (Rushton, Brainerd & Pressley, 1983).

While focusing on the small inconsistencies in the general picture is a mainstay of advocacy, what matters in science is whether a similar pattern emerges from the results of many different studies using different methodologies. Consistencies are more important because science, in its continuing battle against ad hoc explanations, advances only through the discovery of such consistencies (or consistent inconsistencies) across various studies and lines of evidence.

Whereas the results reported by Jensen, Lynn, and Rushton produced consistent and cumulative results, the re-analyses reported by K&O did not.

Further, K&O introduced several errors of their own into the cranial size/IQ literature. They erred in attributing the Black–White differences in head size found in the National Collaborative Perinatal Project's study of 35,000 children to arithmetic error and uncontrolled differences in sex ratio. The real reason young Black girls sometimes average cranial capacities equal to or greater than their White counterparts is because young Black girls mature faster and this finding is important because it is consistent with other findings on race differences (Rushton, 1995). Different formulas for calculating head size can produce different results because Blacks average proportionately longer heads whereas Whites and Asians average proportionately wider and higher heads. Even this limiting statement must not be overinterpreted because in most samples Blacks also averaged absolutely smaller in all head size measurements.

Unlike K&O, we consider overall cranial volume more important than shape. Our new analyses based on large data sets confirm that the races differ both in head shape and in average cranial capacity. When viewed in this context, race differences in brain size and intelligence make evolutionary sense. K&O's attempted refutation of the race/brain-size/IQ relationship then is not only an attempt to obfuscate findings in a controversial area of behavioral science, but to decouple the study of racial differences from our understanding of them in terms of human evolutionary origins.

References

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

Armstrong, E. (1990). Brains, bodies and metabolism. *Brain, Behavior, and Evolution, 36*, 166–176.

Baker, J. R. (1974). *Race*. Oxford: Oxford University Press.

Beals, K. L., Smith, C. L., & Dodd, S. M. (1984). Brain size, cranial morphology, climate, and time machines. *Current Anthropology, 25*, 301–330.

Binkley, K. M. (1989). *Racial traits of American Blacks*. Springfield, IL: Charles C. Thomas.

Boas, F. (1894). Human faculty as determined by race. In G. W. Stocking Jr, *A Franz Boas reader*. Chicago: University of Chicago Press.

Broca, P. (1861). Sur le volume et la forme du cerveau suivant les individus et suivant les races. *Bulletin Société d'Anthropologie Paris, 2*, 139–446.

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

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

Brues, A. M. (1990). *People and races*. Prospect Heights, IL: Waveland Press.

Clauser, C., Tebbetts, I., Bradtmiller, B., McConville, J., & Gordon, C. C. (1988). *Measurer's handbook: US Army anthropometric survey 1987–1988 [com](Tech. Rep. No. NATICK/TR-88/043, AD-A202 721)*. Natick, MA: US Army Natick Research, Development and Engineering Center.

Darwin, C. (1871). *The descent of man*. London: Murray.

Davenport, C. B., & Love, A. G. (1921). *The medical department of United States Army in the world war* (Vol. XV), Statistics, Part 1. Army Anthropology. Washington, DC (Cited in M. J. Herskovits *The anthropometry of the American Negro*, New York: Columbia University Press, 1930).

Eveleth, P. B., & Tanner, J. M. (1990). *Worldwide variation in human growth* (2nd ed.). London: Cambridge University Press.

Flashman, L. A., Andreasen, N. C., Flaum, M., & Swayze II, V. W. (1998). Intelligence and regional brain volumes in normal controls. *Intelligence, 25*, 149–160.

Fleagle, J. (1999). *Primate adaptation and evolution* (2nd ed.). New York: Academic Press.

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., McConville, J. T., Tebbetts, I., & Walker, R. A. (1989). *1988 anthropometric survey of US Army personnel: Summary statistics interim report (Tech. Rep. No. NATICK/TR-89/027, Ad-A209 600)*. Natick, MA: US Army Natick Research, Development and Engineering Center.

Gould, S. J. (1996). *The mismeasure of man* (2nd ed.). New York: Norton.

Gur, R. C., Turetsky, B. I., Matsui, M., Yan, M., Bilker, W., Hughett, P., & Gur, R. E. (1999). Sex differences in brain gray and white matter in healthy young adults: Correlations with cognitive performance. *Journal of Neuroscience, 19*, 4065–4072.

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.

Herman-Giddens, M. E., Slora, E. J., Wasserman, R. C., Bourdony, C. J., Bhapkar, M. V., Koch, G. G., & Hasemeier, C. M. (1997). Secondary sexual characteristics and menses in young girls seen in the office practice: A study from the Pediatric Research in Office Settings Network. *Pediatrics, 99*, 505–512.

Herskovits, M. J. (1930). *The anthropometry of the American Negro*. New York: Columbia University Press.

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

Howells, W. W. (1989). *Skull shapes and the map (Papers of the Peabody Museum of Archaeology and Ethnology), Vol. 67*. Cambridge, MA: Harvard University Press.

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

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

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

Jerison, H. J. (1973). *Evolution of the brain and intelligence*. New York: Academic.

Jurgens, H. W., Aune, I. A., & Pieper, U. (1990). *International data on anthropometry*. Geneva, Switzerland: International Labour Office.

Kamin, L. J. (1974). *The science and politics of IQ*. Hillsdale, NJ: Erlbaum.

Kamin, L., & Omari, S. (1998). Race, head size, and intelligence. *South African Journal of Psychology, 28*, 119–128.

Krogman, W. M. (1970). Growth of head, face, trunk and limbs in Philadelphia White and Negro children of elementary and high school age. *Monographs of the Society for Research in Child Development, 35*(3, No. 136).

Krogman, W. M., & Ýpcan, M. Y. (1986). *The human skeleton in forensic medicine* (2nd ed.). Springfield, IL: Charles C. Thomas.

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, 196*, 225–264.

Lewontin, R. C., Rose, S., & Kamin, L. J. (1984). *Not in our genes*. New York: Pantheon.

Lynn, R. (1990). New evidence on brain size and intelligence: A comment on Rushton and Cain and Vanderwolf. *Personality and Individual Differences, 11*, 795–797.

Lynn, R. (1991). The evolution of racial differences in intelligence (with commentaries and author's response). *Mankind Quarterly, 32*, 99–173.

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. (1997). Geographical variation in intelligence. In H. Nyborg, *The scientific study of human nature: Essays in honor of H. J. Eysenck*. New York: Pergamon.

McShane, D. (1983). Neurocranial form: Differentiating four ethnic populations using a simple CT scan measure. *International Journal of Neuroscience, 21*, 137–144.

Murdoch, J., & Sullivan, L. R. (1923). A contribution to the study of mental and physical measurements in normal school children. *American Physical Education Review, 28*, 209–330.

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

Osborne, R. T. (1980). *Twins: Black and White*. Athens, GA: Foundation for Human Understanding.
Osborne, R. T. (1992). Cranial capacity and IQ. *Mankind Quarterly, 32*, 275–280.
Passingham, R. E. (1979). Brain size and intelligence in man. *Brain, Behavior, and Evolution, 16*, 253–270.
Paterson, D. G. (1930). *Physique and intellect*. New York: Century.
Reed, T. E., & Jensen, A. R. (1993). Cranial capacity: New Caucasian data and comments on Rushton's claimed Mongoloid–Caucasoid brain size differences. *Intelligence, 17*, 423–431.
Rushton, J. P. (1990). Race, brain size and intelligence: A rejoinder to Cain and Vanderwolf. *Personality and Individual Differences, 11*, 785–794.
Rushton, J. P. (1991a). Mongoloid–Caucasoid differences in brain size from military samples. *Intelligence, 15*, 351–359.
Rushton, J. P. (1991b). Reply to Willerman on Mongoloid–Caucasoid differences in brain size. *Intelligence, 15*, 365–367.
Rushton, J. P. (1992). Cranial capacity related to sex, rank, and race in a stratified random sample of 6325 US military personnel. *Intelligence, 16*, 401–413.
Rushton, J. P. (1993). Corrections to a paper on race and sex differences in brain size and intelligence. *Personality and Individual Differences, 15*, 229–231.
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*. New Brunswick, NJ: Transaction.
Rushton, J. P. (1997). Cranial size and IQ in Asian Americans from birth to age seven. *Intelligence, 25*, 7–20.
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., Brainerd, C. J., & Pressley, M. (1983). Behavioral development and construct validity: The principle of aggregation. *Psychological Bulletin, 94*, 18–38.
Rushton, J. P., & Osborne, R. T. (1995). Genetic and environmental contributions to cranial capacity in black and white adolescents. *Intelligence, 20*, 1–13.
SAS Institute Inc (1985). *SAS user's guide: Statistics, version 5 edition*. Cary, NC: SAS Institute Inc.
Spearman, C. (1927). *The abilities of man: Their nature and measurement*. New York: Macmillan.
Stringer, C. B., Dean, M. C., & Humphrey, L. T. (1999). Regional variation in human mandibular morphology. *American Journal of Physical Anthropology*, Suppl. 28 (Abstract).
Stringer, C., & McKie, R. (1996). *African exodus*. London: Cape.
Tan, U., Tan, M., Polat, P., Ceylan, Y., Suma, S., & Okur, A. (1999). Magnetic resonance imaging brain size/IQ relations in Turkish university students. *Intelligence, 27*, 83–92.
Thomson, A. (1903). A consideration of some of the more important factors concerned in the production of man's cranial form. *Journal of the Royal Anthropological Institute, 33*, 135–166.
Todd, T. W. (1923). Cranial capacity and linear dimensions, in white and Negro. *American Journal of Physical Anthropology, 6*, 97–194.
United States National Aeronautics and Space Administration (1978). *Anthropometric source book: Vol. 2. A handbook of anthropometric data (NASA Reference Publication No. 1024)*. Washington, DC: NASA.
Wickett, J. C., Vernon, P. A., & Lee, D. H. (in press). The relationships between the factors of intelligence and brain volume. *Personality and Individual Differences*.
Willerman, L. (1991). Commentary on Rushton's Mongoloid–Caucasoid differences in brain size. *Intelligence, 15*, 361–364.