controversial (e.g., Maccoby and Jacklin, 1974; Kimura and Harshman, 1984; Harris, 1978; Juraska, 1986; Toran-Allerand, 1986; in particular see McGlone, 1980, and peer commentary). Most current opinion seems to favor the genetic position while recognizing the importance of culturally mediated social behavior in the maturation of the CNS. Indeed, Juraska and Kopcik (1988) have demonstrated that handling and hormonal mediation can affect both the size of the rat corpus callosum and the distribution of its fibers (see also Berrebi et al., 1988, and Deneberg et al., 1991, below).

Elsewhere, one of us (RLH) has speculated that there is an anatomical basis for sexual dimorphism in certain aspects of cognitive functioning, and this dimorphism is evolutionarily derived based on natural selection for complementary social behaviors in adults related to nurturance of dependent offspring (Holloway, 1983, 1990).[1] In essence, females devote more energy to social communication involving the inferior parietal and inferior temporal lobes, and thus use both cortices to a greater degree than males, whose dominant parietal lobe appears to be more specialized for visuospatial abilities. Furthermore, at least one of us (RLH) believes that the difference may be species specific (Holloway, 1986, 1990), as thus far sexual dimorphism in the relative sizes of the corpus callosum (CC) does not appear in the Anthropoidea, although the pongids have not been adequately studied thus far (Holloway and Heilbroner, 1992). In rats, Deneberg et al. (1991, 1992) have shown that the male rat has a larger CC than the female, and that the size differences are responsive to hormonal mediation, particularly in females.

The major structure responsible for the communication between the cerebral hemispheres is the corpus callosum (CC). Some 200 million fibers are believed to interconnect the two hemispheres through the CC (Tomasch, 1954). Recent work by Aboitiz et al. (1992) suggests no essential differences in fiber types and their distribution between human males and females.

RELATIVE AND ABSOLUTE SIZE OF THE CORPUS CALLOSUM

It remains our contention that there exists an important dimorphism between human males and females, such that the female corpus callosum is *relatively* larger than the male CC and that the difference is largest in the splenial or posterior portion of the CC, which mostly interconnects the inferior parietal, anterior occipital, and inferotemporal as well as primary visual cortex (de Lacoste-Utamsing and Holloway, 1982; Holloway and de Lacoste, 1986; de Lacoste et al., 1986). This is an important finding but one that is understandably controversial, as it provides the first evidence for anatomical differences in the human brain associated with the cerebral cortex, that is, above the level of the hypothalamus. The original findings by de Lacoste-Utamsing and Holloway (1982) describing a sexual dimorphism in the relative and absolute size of the CC favoring females appears to be the most controversial finding, particularly regarding absolute differences. While those results were basically confirmed and extended by Holloway and de Lacoste (1986, except with respect to posterior splenial one-fifth portion) and Holloway (1990), many reports claim not to have duplicated these findings (e.g., Clarke et al., 1989; Openheim et al., 1987; Witelson, 1985; Kertesz et al., 1987; Demeter et al., 1988; Byne et al., 1988; Weis et al., 1988; Weber and Weis 1986; Habib et al., 1991; Deneberg et al., 1992).

[1]The purpose of this paper is to provide a new data rather than speculate about the reason for the findings. Anonymous reviewers appear disappointed that such speculation isn't reported here. One of us (RLH) does believe that there exists sexual dimorphism (with overlap) in cognition and that both the cerebral cortex and its interconnecting bundle, the corpus callosum, contribute to that dimorphism as well as cultural programming. The evolutionary change from a hominoid with relatively shorter periods of infant and child dependence to hominids with greater degrees of such dependence represents a dramatic evolutionary option. Another of us (RLH) believes a complemental strategy, involving greater degrees of behavioral specialization among males and females, was useful for that important adaptation, which would provide the basis for human brain reorganization and size increase. RLH does believe females are more socially competent in communicative skills, that males are better at visuospatial tasks involving directionality and placement in complex space, and that these two basic moieties of cognitive adaptations made for a more successful hominid adaptation for survival, particularly for animals with offspring dependent on physical and social nurturance for longer postnatal periods and extended growth durations of the brain.

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On the other hand, Witelson (1989) has claimed some dimorphism as well as handedness effects for the so-called isthmus of the CC, which is where the posterior part of the body of the CC grades into the anterior splenial portion of the CC. The dimension appears to be larger in females, but it is not clear whether the difference is statistically significant. Elster et al. (1990) found some support for a limited but persistent dimorphism. A recent paper by Steinmetz et al. (1992) found a significant sex effect in the so-called isthmus but not one for handedness in their MRI study of 52 young adults. This finding is in contradiction to both Witelson (1985) and Deneberg et al., (1991) regarding handedness, a finding also supported by Nasrallah et al. (1986). More recently, Hines et al. (1992) have found some limited support for splenial dimorphism by studying the relationship between language and visuospatial cognition and the size of the splenium in a large female sample. However, males were not studied nor were their CCs measured.

As indicated in an earlier review (Holloway, 1990), many of these seemingly contradictory results were based on MRI studies where no control of brain size was provided, despite our initial insistence that it was the *relative* size of the CC which was dimorphic (deLacoste-Utamsing and Holloway, 1982). Indeed, as will become apparent (see also Appendix I), many of the statistical procedures published elsewhere have indicated near equality of CC size patterns between males and females in absolute terms. The issue of *relative size* of the CC, that is, relative to total brain size, is difficult to study as brain size is a measure with a high degree of sexual dimorphism in humans.

Only Peters (1988) tackled the problem of a lack of allometry in the size of the corpus callosum, realizing that the *relative* measures are larger for females. Both Deneberg et al. (1991) and Demeter et al. (1988) have claimed that since there is no correlation between the size of the CC and brain weight, brain size can thus be ignored. We believe this is highly unlikely, and this study shows a low but significant correlation between brain weight and most measures of the CC, except for dorsoventral splenial width, which appears to be highly dimorphic.

Papers supporting our earlier findings are rare and only partial support is given. Clarke et al. (1989) have found some limited support of our original observations regarding splenial bulbousness, but by and large their results demonstrate no significant differences in size of either the CC or its components between the sexes. While Allen et al. (1991) have also replicated some of our findings on the shape of the CC, that is, in the splenial region, they basically find little dimorphism in total measures. In addition, work by Hines et al. (1992) offers some support for a relationship between the splenium, handedness, and cognition, with different scores in these later measures between females with large splenial regions. The Allen et al. (1991) paper is of particular interest as they used much of the same methodology as found in our original paper (de Lacoste-Utamsing and Holloway 1982), and with larger sample sizes. Their discussion of the problems is very useful. The findings of Steinmetz et al. (1992) are clearly consistent with our previous findings, but significance levels are not provided.

We do not know the reasons for each of the inconsistencies in these various reports. Several (see below and Appendix I) can be explained partially as a failure of other workers to study the *relative* size patterns, relying on a lack of statistical significance in *absolute* values to claim disproval of the dimorphism hypothesis. As Allen et al. (1991) have suggested, it is important to use similar methods when attempting to replicate results, and indeed we do believe methodology as well as goals may help to explain some of the differences in reports (i.e., cadaver vs. living MRI patients, absolute vs. *relative* measures of the CC, and the variable of handedness and its interaction effects with sex).

In addition, sampling is likely to be an important factor in generating different results. The original studies by Holloway and de Lacoste relied on autopsied brains (not MRI) and were quite small in sample size. We believed then, and do now, that such samples were too small to show the high degree of overlapping that occurs when

large samples of each sex are compared, and in that sense our latest work is not totally consistent with the earliest studies by de LaCoste-Utamsing and Holloway (1982) and Holloway and de LaCoste (1986). In our experience, getting larger sample sizes has been difficult, given the preference for brain autopsy procedures to use coronal sectioning, and the current ease of acquiring MRI samples. We still regard autopsy studies as essential, however, because MRI analyses fail to provide a reliable control of brain size.

Three independent samples collected from 1985 through 1987 are reported here for the first time. The results of these three independent samples replicate our major findings. These results also show that there is considerable overlap in the size of these structures, both absolutely and relatively, and that the strength of the dimorphism may vary in different samples and populations. In addition, we will show that the patterns of sexual dimorphism in the brain for other neurological structures are very different from what appears to be the case for the CC. We believe that such a demonstration strengthens our arguments regarding the dimorphism of the CC, and lays the burden of explanation upon other workers to explain why only the corpus callosum follows such a pattern among major neurological structures.

In this paper, we are not primarily concerned with the functional sequelae of such dimorphic differences as may exist, or their ontogenetic, endocrinological, or behavioral relationships (including handedness). Many of the references cited in this report have excellent discussions of such relationships. Given the controversies surrounding relative and absolute measures as well as handedness, and the limited sample sizes of autopsied materials, we wish to confine our study to whether or not sexual dimorphism is present in our autopsy samples, and to explain as much of the controversial inconsistency as possible. (Comparative studies may be found in Holloway and Heilbroner, 1992; Heilbroner and Holloway, 1989; de Lacoste and Woodward, 1988. More speculative appraisals may be found in Holloway, 1983, 1990.)

MATERIAL AND METHODS

Three brain autopsy samples from adults were collected: (1) 47 brains (21 males, 26 females) were collected at Mt. Sinai Hospital, New York; (2) 43 brains (20 male, 23 female) were collected from Columbia University's College of Physicians and Surgeons, New York; (3) 29 brains (15 male, 14 female) were collected from Australian Aborigines in Perth, Australia. Both New York (NY) samples were multiethnic, but the large majority were Caucasian. Standard autopsy procedures were used in each institution with but minor variations. All brains were sectioned at the level of the medullocervical junction prior to weighing. Brains from Mt. Sinai were fixed by suspension in 10 percent saline/formalin, phosphate buffered to a pH of 7.2. At Columbia, brains were fixed in nonbuffered 10% formalin solution. Clinical records were examined by the pathologist at the time of autopsy to exclude cases with neurological and/or severe psychological disorders from the study, including alcohol and/or drug-related cases.

In the case of the Australian Aboriginal sample, some of the cases were accompanied by fresh brain weights and by the weight of the cerebral cortex in others. We use cerebral cortex weight in this sample for our brain size correction, as it provides the larger of the possible samples. We note that Witelson (1989) has also followed this procedure.

Brain dissections were performed after 14–28 days of fixation. Brains were weighed before dissection on a srping-loaded scale with an accuracy of $\pm$ 10 grams. A midsagittal section was then made, passing through the plane of the midline of the CC, third ventricle, cerebral aqueduct, interpeduncular fossa, mammillary bodies, and median raphe of the brainstem.

In the first two samples, color slides were taken of the midsagittal plane, with a metric ruler in the same plane, as described in de Lacoste-Utamsing and Holloway (1982). The Australian samples was also photographed, but on black-and-white film, with a rule in the same plane. The outline of the CC was then traced onto the photograph and measured directly. The NY slides were pro-

jected through an enlarger and thus measured at higher magnifications than the Australian sample. All measurements were taken by only one of us (RLH). In no instance was the sex, age, or brain weight of the brain known until after all measurements had been compiled. These data were provided separately from the slides/photographs after measuring was completed.

The slides and photographs were processed as described in detail elsewhere (Holloway and de Lacoste, 1986; deLacoste-Utamsing and Holloway, 1982), and the CC was measured for (1) total surface area in the midsagittal plane (CCAREA); (2) the dorsoventral width of the splenial portion of the CC (SPLNDV), which is a measurement taken at a right angle to the anterior-posterior axis of the body of the splenium at its widest point; the posterior one fifth of the area of the CC, which is almost always exclusively the splenium (POST5). The maximum width of the body at the mid anterior-posterior distance between the genu and tail of the splenium was also measured.

The following ratios were used to account for relative size differences: (1) RELCC is simply the area of the CC divided by the two-thirds power of brain weight × 100. The two-thirds power is used to approximate an areal dimension of brain volume. Ratio data using raw brain weight gave almost identical results. (2) POST5/CC area is the posterior one-fifth of the CC (splenium) area divided by the total area of the CC × 100; (3) RELSPLN is the maximum dorsoventral splenial width divided by the one-third power of brain size × 100. The power of one-third is used to approximate a linear derivative or single dimension of brain volume. (Dividing by raw brain or cerebrum weight does not alter the statistics resulting from a power relationship). (4) RATIO1 is POST 5/CC divided by the two-thirds power of brain weight × 100. Table 1 summarizes these measurements.

Each sample was analyzed statistically using univariate methods, and tested for sex and age effects by ANOVA. In the ANOVA procedure Type III least squares was used, with sex as the main factor and brain weight and age as covariates. In addition, to examine sexual dimorphism in other neural structures, three independent databases from the literature were used: (1) Klekamp et al. (1989) kindly provided their data of our analyses; (2) Wessely (1970); (3) Zilles (1972). These latter two databases were collected well before the controversy regarding sexual dimorphism of the CC and were examined to gain an appreciation of the variability in other human neural structures.

*TABLE 1. Absolute and relative measurements used in this study**

Measurement	Description
Absolute	
CCAREA	Total cross-sectional area (cm^2) of the corpus callosum in the midsagittal plane
SPLNDV	Maximum dorsoventral width (cm) of the splenium taken at a right angle to the longitudinal axis of the splenium
POST5	Area (cm^2) of the CC included in the posterior 1/5 segment of the A-P length of the CC
Relative, i.e., brain-size corrected	
RELCC	CCAREA/(brain weight$^{2/3}$)
POST5/CC	POST5 × 100/CCAREA
RELSPLN	SPLNDV × 100/(brain weight$^{1/3}$)
RATIO1	(POST5/CC) × 100/(brain weight$^{2/3}$)

*"Relative" in this context refers to ratio data where the absolute variates such as CCAREA are divided by the size of the brain or some derivative of that size, such as the one-third or two-thirds power of brain weight. Dividing by raw brain size does not change the t- or P values in any significant sense. In the case of Table 3, the Australian Aboriginal sample, the variates are divided by cerebral weight (one-third and two-thirds power) and not total brain weight.

RESULTS

Tables 2–4 provide the mean values of the various measures, both *absolute* and *relative*, for each of the three samples, and the results of Student's t-test for significant differences of the mean. None of the samples show significant sex differences with regard to the absolute values of CC variates, except in the Australian sample. In all samples, the brain weight and/or cerebrum weight for males is significantly larger than for females, while the values of CCAREA, POST5, and SPLNDV are essentially equal for males and females, or slightly larger for females. Both SPLNDV and POST5 area from the Columbia sample are absolutely larger in females. All three callosal variates in the Australian sample are larger for females, and nearly significantly so, with SPLNDV being truly larger in a statistically significant way. In all three samples, the

*TABLE 2. Sexual dimorphism in corpus callosum from Columbia sample**

Variable[2]	Sex	N	Mean	S.D.	Range	Student-t[1]	*P* (2-tailed)
CCAREA	M	20	6.11	1.36	3.46–9.27	0.17	.862
	F	23	6.05	1.08	3.87–8.21		
POST5	M	20	1.50	.30	0.91–2.12	−1.08	.288
	F	23	1.60	.32	1.16–2.14		
SPLNDV	M	20	1.07	.15	0.78–0.92	−1.44	.156
	F	23	1.14	.15	1.36–1.42		
Total	M	20	1357	166.4	1060–1560	2.55†	*.014*
brain	F	23	1245	119.7	1040–1520		
RELCC	M	20	5.00	.94	3.34–6.81	−0.90	.370
	F	23	5.25	.84	3.35–6.83		
RELSPLN	M	20	9.77	1.44	6.75–13.22	*−2.05†*	*.047*
	F	23	10.64	1.32	8.58–12.97		
RATIO1	M	20	0.206	.039	0.14–0.28	*−2.64†*	*.012*
	F	23	0.230	.019	0.20–0.27		
POST5/CC	M	20	24.75	3.10	18.62–29.94	*−2.07**	*.045*
	F	23	26.44	2.21	22.09–31.76		
Age (yrs)	M	20	58.3	18.1	20–83	−0.81	.42
	F	23	62.7	17.6	20–88		

[1] Negative values of *t* distinguish variates which appear to be larger in the female sample; dagger indicate $P < .05$.
[2] Areas in cm^2, weights in grams.
* In this and the succeeding two tables, the variables are those described in Table 1. Bold and underlined values are significant at the <.05 level. The ratio or relative data start with the RELCC variate.

*TABLE 3. Sexual dimorphism in corpus callosum from Mt. Sinai sample**

Variable	Sex	N	Mean	S.D.	Range	Student-t[1]	*P* (2-tailed)
CCAREA	M	21	6.64	.93	5.52–8.68	0.53	.599
	F	26	6.51	.73	5.84–9.14		
POST5	M	21	1.76	.24	1.43–2.51	0.07	.945
	F	26	1.75	.18	1.46–2.30		
SPLNDV	M	21	1.21	.13	0.94–1.44	−1.26	.215
	F	26	1.26	.16	0.95–1.59		
Total	M	21	1373	137	1110–1595	*5.79†*	*.000*
brain	F	26	1175	97	970–1335		
RELCC	M	21	5.41	.67	4.33–6.60	*−2.39†*	*.021*
	F	26	5.89	.70	4.94–7.89		
RELSPLN	M	21	10.93	1.17	8.35–12.60	*−2.70†*	*.009*
	F	26	12.02	1.51	8.81–14.77		
RATIO1	M	21	0.195	.026	0.174–0.271	*−4.43†*	*.000*
	F	26	0.232	.030	0.178–0.292		
POST5/CC	M	21	25.014	3.16	18.62–31.00	*−2.19†*	*.034*
	F	26	26.800	2.43	22.89–31.76		
Age (yrs)	M	21	67.2	11.6	35–89	0.16	.87
	F	26	66.6	14.5	30–91		

†$P < .05$.

range of values is extensive, as can be seen in Tables 2–4.

In contrast, the brain-corrected values are significantly larger in females from each of the three, although in the Columbia sample the RELCC area is larger for females, but not significantly so. POST5/CC and RATIO1 are significantly higher in the females from the NY samples, indicating that female brains show a CC which has a higher percentage of its area that is splenial. The relative values are mixed for females in the Australian sample, but do not attain statistical significance. The cerebral cortical weights are significantly different between males and females in this latter sample. Other samples of whole brain weights from Australian aborigines do indicate that the male brain is significantly larger than in females (Harper and Mina, 1981; Klekamp et al., 1989). Age differences are not significant in any sample, although the NY cases are clearly more aged, averaging 60–65 years.

The width of the body of the CC showed no

TABLE 4. Sexual dimorphism in corpus callosum from Australian Aboriginal sample (cerebrum corrected)

Variable	Sex	N	Mean	S.D.	Range	Student-t	*P* (2-tailed)
CCAREA	M	9	5.45	0.68	4.66–6.81	−2.06	.055
	F	10	6.35	0.12	4.12–8.15		
POST5	M	9	1.38	.10	1.24–1.54	−1.77	.095
	F	10	1.54	.27	1.07–1.87		
SPLNDV	M	9	1.03	.06	0.92–1.11	−2.13†	*.047*
	F	10	1.17	.19	0.92–1.55		
Total brain	M	9	1021	102.7	882–1160	2.20†	*.042*
	F	10	939	57.7	833–1064		
RELCC	M	9	5.44	.82	4.43–7.11	−2.64†	*.017*
	F	10	6.65	1.14	4.28–8.69		
RELSPLN	M	9	10.23	0.62	9.13–11.07	−2.57†	*.020*
	F	10	11.97	1.94	9.32–15.94		
RATIO1	M	9	0.53	.073	0.41–0.65	−0.72	.450
	F	10	0.56	.086	0.43–0.69		
POST5/CC	M	9	25.45	2.55	21.63–29.26	0.84	.409
	F	10	24.47	2.45	20.76–28.90		
Age (yrs)	M	9	47.9	18.2	14–79	1.608	.126
	F	10	35.4	15.6	18–63		

†$P < .05$.

significant difference between males and females in any of the samples in either absolute or relative values (the latter constructed by dividing body width by the one-third power of brain weight) and is not included in the tables for reasons of space.

The ANOVA results using sex as a main factor, and brain weight and age as covariates, indicated that both sex and brain weight could be important in producing significant F ratios. For CCAREA, the main effect (sex) gave a P of .08, and a $P = .0000$ for brain weight. (Age was not significant in any of the runs.) For POST5, the P for sex was .0074 and $P = .0000$ for brain weight. For SPLNDV, the P for brain weight was .15, whereas the P for sex was .021. In the case of the body of the splenium, there was no significant sex factor, while the P for brain weight was .02.

Given the slightly different procedures used to enlarge the Australian images of the CC, ANOVA was also performed on just the two NY samples. In these runs, the results were similar, but for CCAREA the sex effect had a $P = .097$, while the P (sex) for POST5 was .016. SPLNDV showed no significance for either the sex effect or brain weight. In general, then, the ANOVA results strongly suggest that both sex and brain weight are important considerations in looking at the size of the CC and some of its components.

*TABLE 5. Pearson correlations for CC variables, brain weight, and age**

	Brain	CCAREA	SPLNDV	POST5	Age
Brain	1.00	*.3482*	−.0516	*.2127*	−.1012
		(.0008)[1]	(.6291)	(.0442)	(.3428)
CCAREA		1.000	*.5322*	*.7979*	−.0866
			(.0000)	(.0000)	(.4172)
SPLNDV			1.000	*.8013*	.0950
				(.0000)	(.3731)
POST5				1.000	−.0502
					(.6382)

[1] Significance level in parentheses. Values < 0.05 in italics.
* N = 90, sexes combined from Columbia and Mt. Sinai.
In this and the succeeding two tables, the underlined values of the Pearson correlations are those significant at the <.05 level for the two NY samples combined, males only (Table 6) and females only (Table 7). Note the strong correlations between callosal variables but the weakness with total brain size. None of the age correlations are significant.

In addition, Table 5 shows the correlation coefficients between the combined NY samples, which number 90. (The Australian sample is not included as the method regarding data collection from photography was slightly different from the NY samples, as described under Materials and Methods.) Noteworthy are the low (but significant) correlations between brain size and the callosal measurements. SPLNDV is particularly weak and insignificant with regard to brain size, but strong with respect to CCAREA and POST5, other callosal measures. If sexual dimorphism were not strong between males and females, the correlations between

*TABLE 6. Pearson correlations for CC variables, brain weight, and age**

	Brain	CCAREA	SPLNDV	POST5	Age
Brain	1.00	*.5031*	.0374	*.3238*	.0525
		(*.0005*)[1]	(.8098)	(*.0320*)	(.7351)
CCAREA		1.000	*.5774*	*.8133*	−.0279
			(.0000)	(.0000)	(.8574)
SPLNDV			1.000	*.8103*	.0362
				(.0000)	(.8157)
POST5				1.000	−.0502
					(.6382)

[1] Significance level in parentheses. Values < 0.05 in italics.
*N = 44, males only, combined from Columbia and Mt. Sinai.

*TABLE 7. Pearson correlations for CC variables, brain weight, and age**

	Brain	CCAREA	SPLNDV	POST5	Age
Brain	1.00	.1638	.1189	*.2928*	−.2770
		(.2767)[1]	(.4313)	(.0483)	(.0624)
CCAREA		1.000	*.5530*	*.8042*	−.1581
			(.0001)	(.0000)	(.2941)
SPLNDV			1.000	*.8055*	.1286
				(.0000)	(.3943)
POST5				1.000	−.0284
					(.8512)

[1] Significance level in parentheses. Values < 0.05 in italics.
*N = 45, females only, combined from Columbia and Mt. Sinai.

SPLNDV and other measurements would be expected to be larger.

Tables 6 and 7 show the Pearson correlations and significance levels for each sex separately. In these cases, the correlations between SPLNDV and brain weight are somewhat higher but still low and insignificant. This also suggests that SPLNDV is a dimorphic variate. It is also noteworthy that the correlations between the variables and age are mostly negative, but not significantly so. These findings are at variance with the recent report by Witelson (1989) that males show a significantly higher loss in CC size than females. In our sample, it was the females who showed a higher negative correlation with age, although it was not significant in either sex. The correlations were essentially the same when run with the same data standardized to a mean of 0 and a S.D. of 1.0. We have no explanation for these discrepancies beyond sampling (see below).

Table 8 compares the values of the coefficient of variation (CV) and the standardized skewness (SKEW) for each of the measures in both males and females of each sample. In each sample, the CV can be high, that is, greater than 12%. In addition, the Mt. Sinai sample shows high skewness for both females and males in CC area. In general, the skewness coefficient is not high in the rest of the sample. We believe this sampling indicates samples that depart from a perfect normal (Gaussian) pattern. However, other tests such as Kruskal–Wallis, Kolmogorov–Smirnov, or Mann–Whitney unpaired tests provided basically the same results as the t tests reported in the tables: Raw values were not significant, except for brain weight, and ratio variables were significant.

T tests were run once again for each of the NY samples after arbitrarily removing both one male and female, each with the highest and lowest CCAREA values. The Mt. Sinai sample continued to show significant ratios in favor of female callosal values. In the Columbia sample similarly treated, the *P* values fell between 0.05 and 0.06 for the ratio variates.

Tables 9–11 clearly demonstrate that the sexual dimorphism for other neural structures, such as the thalamus, cerebellum, ventricles, etc., are significantly high, but that the ratios are not. In addition, Table 11 shows that the absolute value of the CC is not significantly different between males and females, but when the CC is corrected for brain weight, the ratio is significantly greater for females.

DISCUSSION

Three independent brain autopsy samples from different groups have been studied for sexual dimorphism in the corpus callosum, measuring both absolute and relative size of CC variates. In summary, these studies support earlier findings claiming sexual dimorphism in *relative* measures (e.g., de Lacoste-Utamsing and Holloway, 1982; Holloway and de Lacoste, 1986; Holloway, 1990). At the same time, these new studies also support other reports that there is often no statistically significant sexual dimorphism in absolute CC variates. Thus these studies do not entirely replicate our earlier results. We believe this is due to the much larger sample sizes tested in this study.

TABLE 8. Variation within samples as shown by coefficient of variation (CV) and skewness (SKEW)

	CCAREA		POST5		SPLNDV		Brain	
	CV	SKEW	CV	SKEW	CV	SKEW	CV	SKEW
Columbia								
Males (20)	22.2	1.12	19.7	.51	12.6	.21	12.8	.43
Females (23)	17.1	−.31	19.4	.37	13.6	.74	9.6	.41
Mt. Sinai								
Males (21)	14.1	1.75	13.9	2.57	10.7	−.50	10.0	−.32
Females (26)	11.3	4.38	10.6	1.64	12.4	.24	8.2	−.39
Australian								
Males (9)	12.5	1.1	7.6	.51	6.2	−.46	10.0	.35
Females (10)	17.6	−.35	17.3	−.34	16.3	.88	6.1	.73

TABLE 9. Sex differences in the brain based on Wessely (1970) data *

Structure	Male (N = 18)	Female (N = 13)	t-value	Probability
Brain	1379	1231	3.54	*.0014*
Cerebellum	148	135	2.51	*.0180*
Rhombencephalon	31.8	27.9	3.69	*.0009*
Ventricles	16.1	12.2	1.74	.0930
Ratio cerebel. (%)	11.10	11.27	0.61	.54
Ratio rhomb. (%)	2.38	2.34	0.49	.63
Ratio ventric. (%)	1.21	1.03	1.03	.313

* The brain weight is in grams, as are the other structures. The ratio data are derived by dividing the neural structure in question by the brain weight and multiplying by 100. These are reported as percentages. Unlike the corpus callosum, these show no significant sexual dimorphism. Values of $P < .05$ are highlighted to show the difference between absolute and relative values.

The three autopsy samples reported herein show the following: (1) There is considerable overlap in the size of the CC and its divisions among males and females; (2) the CC is larger in females than that for males when brain size is taken into consideration, and is usually significantly so; (3) the absolute sizes of the CC and its divisions tend to be the same for males and females, and not significantly larger for males, whatever their brain weights. This latter pattern is very different from most other parts of the CNS which have been volumetrically measured (see below). (4) There are significant but not large correlations between brain size and CC variables, except for SPLNDV (not significant), which probably is best explained by its high degree of sexual dimorphism.

Other neural structures and sexual dimorphism

As mentioned earlier, the patterning of the statistics for the CC is different from that for other CNS structures, aside from the hypothalamus (e.g., Swaab and Fliers, 1985). Consider the data presented by Wessely (1970) for the rhombencephalon, cerebellum, and brain weight. As in all samples encountered thus far, male brain size is significantly larger than female brain size (see Table 9) as are the volumes for the cerebellum, rhombencephalon, and ventricles. When expressed as a percentage of brain weight, however, the ratio of differences between males and females becomes insignificant.

Table 10, based on the data of Klekamp et al. (1987, 1989), shows that for very small and large structures the male brain is significantly larger than in females. When corrected for brain size, however, these values are not significantly different. In other words, the statistical patternings of male-female sexual dimorphism are different and opposite for the CC: The absolute values do not differ significantly, but the ratios do.

Another example of this statistical patterning can be seen from the study done by Zilles (1972), who published data for a large sample of human brains (35 males, 43 females) for brain weight, cortex weight, and corpus callosum cross-sectional area (Table 11). At the time that Zilles' paper was written, there was no controversy regarding sexual dimorphism of the corpus callosum, and Zilles' data show that, while the absolute value of the female CC area is greater than in males, it is not significantly so. Using Zilles' data we show that it is significantly greater in females than in males when corrected for brain weight. The absolute values for brain and cortex weight are much larger in males, with a very high degree of statisti-

*TABLE 10. Sex differences in the brain weights based on Klekamp et al. (1989) data for Australian Aborigines**

Structure	Male (N = 18)	Female (N = 16)	t-value	Probability
Brain	1276	1104	4.903	*0.00002*
Cerebellum	133.4	113.9	4.08	*0.0002*
Hippocampus	6.20	5.17	4.31	*0.0001*
Amygdaloid	2.74	2.36	2.39	*0.024*
Thalamus	13.01	11.89	2.20	*0.037*
Ratio cerebel. (%)	10.46	10.34	0.373	0.71
Ratio hipp. (%)	.0048	.0047	1.06	0.29
Ratio amygd. (%)	.00215	.00212	.25	0.804
Ratio thal. (%)	.010	.011	1.28	0.210

*The brain weight is in grams, as are the other structures. These figures were calculated after receiving the data courtesy of Drs. J. Klekamp and A. Riedel. These figures do not include Caucasian brains. The sexual dimorphism is statistically significant for all the absolute values of the brain structures, but nonsignificant when corrected for brain size, that is, made relative.

*TABLE 11. Sex differences in the human brain based on Zilles (1972) data**

Structure	Male	Female	t-value	Probability
Brain wt.	1308	1178	5.02	*0.0000*
Cortex	584	526	5.03	*0.0000*
CCAREA	6.18	6.28	0.481	0.63
Ratio cortex[1]	44.7	44.7	0.019	0.984
Ratio CCAREA[1]	5.42	5.90	2.74	*0.007*

[1]Ratio cortex = cortical weight divided by brain weight. Ratio CCAREA = corpus callosal area divided by brain weight.
*As in the other tables, brain weight and cortex are in grams, and CCAREA is in centimeters squared. The ratios are the structures in question divided by brain weight. Values of $P < .05$ are highlighted to show the differences between absolute and relative values.

cal significance (t values > 5.0) compared to either the CC area or relative measures.

Many of the studies cited earlier (Appendix I) which claim to find no significant CC size difference between males and females do not permit similar testing. For example, Clarke et al. (1989: Table 3, p. 226, show that in their MRI sample of brains (5 males, 7 females) the female CC area was 550 mm^2 while the male area was 540 mm^2, without any significant difference. This is consistent with our findings. But one would expect the brain size differences to be highly significant, and thus the relative size of the female CC might be significantly larger relative to the brain than in males. Their postmortem figures, however, show an extraordinary difference between males and females (male = 680 mm^2, females = 590 mm^2), which is significantly larger in males at the 0.005 level. This is a very unusual finding, as the remainder of their Table 3 demonstrates, since no other published studies show such a striking difference, and this is completely at odds with their M.R.I. sample.

Incidentally, Clarke et al. (1989: p. 226) confused the CC area values from the Byne et al. (1988) MRI study. The 602 and 583 mm^2 values for males and females in the Byne et al. study are only for those under 40 years of age. The 15 and 22 numbers refer to all ages, and the average CC area is 519 and 601 mm^2, respectively, once again showing females to be larger in absolute size. This is another example of consistency with our findings, even though the authors strongly disagree with our earlier conclusions. Without brain weights, the relative size cannot be known. Similarly, the posterior one-fifth area is given as 170 and 160 mm^2, respectively, for females and males by Byne et al. (1988), showing that females have a larger absolute splenial size, again consistent with our findings. These differences may not predict gender according to the methods used by Byne et al. (1988), but they are certainly different from what one finds in the rest of the brain when looking for sexual dimorphism.

Correspondingly, the relatively large MRI sample, reported by Habib et al. (1991) to show no significant differences in CC area or morphology between males and females, does not provide adequate brain size corrections. (Correcting for size by merely measuring A-P distance of the whole brain slice is not the same as weighing the brain, and

hardly a true correction for brain size,[2] considering the wide variation in cranial shape that exists in all populations.) The male sample is 35 cases, whereas the females number 18. As male brain sizes are usually significantly larger than females, might it not be possible that a larger sample of females would show a higher average value but with similar degrees of overlap? The 4.2% difference between male and female CC areas is much less than the usual 9–12% difference in brain size. Again, the differences between values between CC areas for males and females are much less than for the usual brain size differences.

Lastly, it is interesting to examine the Demeter et al. (1988) sample. Maximal splenial width was 11.8 mm for males and 11.6 for females, and thus nearly equal; the posterior one-fifth of the CC was 165 mm^2 for both males and females, yet total CC area was 627 and 582 mm^2 for males and females (hardly inconsistent with our findings). These authors did not test for relative values, however, even though they had measured brain weights. The differences between brain weight for males and females are extraordinarily large in this sample, with five (out of 21) of the males having brain weights greater than 1,500 grams (one value is greater than 1,700 g), while the highest female brain weight appears to be about 1,400 g, with at least four female values under 1,200 g. The mean brain weight is not reported for either sex, but the two means must differ at a very high level of statistical significance. The weak trend of a correlation between CC area and brain weight reported by the authors could be due to the relatively large size of the female CC or to the large sample difference of the mean brain weight between males and females. The brain weights in deLacoste-Utamsing and Holloway's (1982) study differed from that in the Holloway and de Lacoste (1986) study in that, in the second sample, female and male brain weights were almost equal (1,202–1,248 grams). In the first study the weights were 1,205 and 1,379 g, respectively.[3]

In sum, and as shown by Appendix I, almost every study that claimed no significant sexual dimorphism in the CC or its divisions has not studied the *relative* size of the callosum or the splenial portion. In fact, almost every study cited shows data that are consistent with our findings regarding a high degree of dimorphism in brain weight, but either equality or larger CC dimensions for the female corpus callosum, particularly in the splenial portion.

The question of absolute vs. relative size of the CC in human males and females will require far larger autopsy samples than have been published thus far, or where there are adequate brain size controls for a large sample of MRI data. In the meantime, the three new autopsy samples presented in this report indicate that there is a congruent pattern of statistical findings which show that in samples where the male brain is significantly larger than those of females, the CC area is either the same absolute size or slightly larger in females, and that relative to brain size, the female CC appears to be significantly larger than that of males. These findings were obtained even after reducing the samples by removing both the lowest and highest value of the CCAREA for one male and female each. As far as we can

[2]Habib et al. (1991) state: ". . . and each picture was magnified to a standard size. *In order to control for brain size,* magnification rates of MRI midsagittal sections were varied among individuals so as to reach a *standard brain anterior-posterior axis of 170 mm for each case.*" (p. 46, emphasis mine). This is not the same as controlling for brain size, given the high degree of variability in brain and cranial shapes in humans. This technique is essentially equating one measurement on a midsagittal section with brain size. No one can reliably predict brain weight with less than three dimensions. Most of the other MRI studies cited in this paper do not even use this weak method of controlling for size.

[3]One of us (RLH) would like to point out that neither deLacoste or myself were ever happy with the small samples that were reported in 1982 and 1986. Both of us regarded our findings as preliminary and thought that the absolute difference in splenial width would probably vanish with larger samples. Our values, as it turns out, are not typical. This sample, which was essentially completed in 1987, could not be reported until now due to illness of the senior author. We furthermore maintain that it is the *relative* size of the corpus callosum that is sexually dimorphic. All of the studies cited, except our own, have focused mostly on absolute differences, and not one has looked at ratio data by carefully examining brain size. ANOVA and ANCOVA techniques do not adequately test our basic hypothesis that the CC and some of its components are relatively larger in female human brains. Instead, they test the relative degree of variance explained by brain size and/or sex, depending on the investigators' goals.

determine, this trial was never attempted on the other studies. Small samples can be very sensitive to extreme values, as our trials indicated.

The posterior part of the CC (meaning the splenium as measured by the posterior fifth of CC area and dorsoventral splenial width), also shows strong size dimorphism, suggesting (but certainly not proving) that those areas of the cortex, such as the inferior and superior parietal lobules and the inferior temporal lobe, might have relatively more interconnections through the CC in females than in males. These apply only to averages, as the range of overlap is very great. Lastly, in this context we cite the studies of Hines et al. (1992), who appear to show results that tie together size differences in the splenial portion of the CC for females and a range of cognitive tests implicating the above cortical areas.

As interesting as the functional implications of these studies might be, it is important to stress the high degree of overlap of female and male values, and also to stress that larger sample sizes and studies which relate CC size variation to behavioral variation are necessary (which only Hines et al., 1992, have done). In addition, more microscopic analyses of fiber counts, diameters, and the ratio of myelinated to nonmyelinated fibers would be essential to better understand the nature and degree of the dimorphism (e.g., Aboitiz et al. 1992; Wium, 1984).

Comparative studies (e.g., de Lacoste and Woodward, 1988; Heilbroner and Holloway, 1989; Holloway and Heilbroner, 1992) suggest that the kind of dimorphism reported herein is absent in New and Old World monkeys. The deLacoste and Woodward (1988) study claims such a dimorphism for the pongids and strepsirhines; however, the data need amplification, as the number of species studied was large but the sample sizes within each were very small. Their study cannot rule out the possibility that human sexual dimorphism of the CC as reported here is species specific in the human, although dimorphism of the total size of the CC does exist in some rodents (see Deneberg et al., 1991). If the dimorphism is species specific, it raises the interesting question of how it got to be that way. Without a better understanding of the variation in the ultrastructure of the CC (meaning fiber components, myelinated and unmyelinated, diameters, etc.), we cannot answer that question. More quantitative study is clearly warranted and to be encouraged.

Finally, we note that these findings are in the main part consistent with earlier studies. We cannot explain each and every discrepancy, given the complexities of sample size and statistical analyses. MRI and cadaver-based studies are radically different methodologies, each with advantages and disadvantages. We emphasize the findings of *relative* (i.e., to the size of the brain) dimorphism favoring the CC splenial region in females. Most of the studies claiming to be at odds with our earliest findings focus either exclusively on *absolute* values or MRI samples where there are no adequate controls for brain size, and thus beg the question of *relative* size differences. Methodology, sample size, and perspective all play a role in these discrepancies. We can only note that when each sample is viewed in both absolute and relative terms (Appendix I), almost every one of them indicates near equality of the corpus callosum and its divisions between males and females, yet significantly higher brain weights in males. These facts are not contradictory to our findings, as has been claimed; rather, they are fully concordant with our observations and claims regarding *relative* sizes of the CC. We believe that the apparent inconsistencies are a function of failing to carefully control for brain size. As far as our earlier studies are concerned, we believe that the differences between this study and our earliest ones are best explained by sampling factors.

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APPENDIX I

A REVIEW AND SUMMARY OF ALL STUDIES AVAILABLE ON SEXUAL DIMORPHISM OF THE CORPUS CALLOSUM TO DATE.

Each study, arranged chronologically, provides a summary of whether the sample was from autopsy or magnetic resonance imaging, the sample sizes when available, whether statistically significant sexual dimorphism was reported, and the mean CC area for males and females. Where available, other measures such as the splenium are given, as well as information regarding the use of brain size as a control. Lastly, we comment on the possibility of the results being similar to ours.

1. ***de LaCoste-Utamsing and Holloway, 1982.*** Autopsy data, 9 males, 5 females. Dimorphism significant: mean C areas = 704 (M), 708 (F). Relative CC measures reported. Both splenial thickness and posterior one-fifth dimensions higher in females, which have not been replicated. Given small sample size, the results for absolute differences have not been duplicated.

2. ****Wium, 1984.*** Autopsy data, but not given. Reported in the abstract that females had absolutely larger splenia than males, while males had more fibers in the splenial portion. Cannot be certain without the data, but the direction of splenial size is consistent with our findings.

3. ***Bell and Variend, 1985.*** Autopsy data, 40 children. Dimorphism not significant. Brain weight not studied. Children aged from birth to 14 years, giving very small sample sizes within age groups. Not truly relevant to our studies.

4.****Witelson, 1985.*** Autopsy data, 12 males, 30 females. Dimorphism not significant. Mean CC area, 672 (M), 654 (F). Relative measures were not given. Neither consistent right-handers (CRH) or mixed-handers (nCRH) showed any sexually dimorphic differences, except in brain size. Ratio data (not in study) using published averages show females have proportionately

larger CC areas than males, as well as larger posterior fifths (splenium). Male brain weights were much larger than those of the females. This study could be consistent with our observations regarding the relative size of the CC.

5. ***Bleier et al., 1986.*** Magnetic resonance imaging. Dimorphism reported as not significant. Data not provided. No attempt was made to ascertain the relative size of the CC or its component parts.

6. ****Holloway and deLacoste, 1986.*** Autopsy data, 8 males, 8 females; dimorphism significant. Mean CC area 618 (M), 744 (F). Brain size studied and relative CC sizes reported. Splenial width was 10.3 in males and 13.3 in females. Posterior one-fifth was not reported. Brain weight was not significant between males and females. Sample sizes very small, suggestive of outlying values for female CC area and maximum splenial width.

7. ****Weber and Weis, 1986.*** Autopsy data, 18 males, 18 females; dimorphism not significant. Mean CC area was 639.5 (M), 613 (F). Brain size was studied, averaging 1,029 in males and 890 in females, a significant dimorphism, but with unusually low weights. (Average age was 74.7, which is high.) The splenial posterior one-fifth area was 164.5 in males and 162.4 in females. The CC area was marginally higher in males, but S.D.s were in the vicinity of 105.3. Relative figures not provided. These results are consistent with our observations, given the near equality of CC area and splenial portion between the sexes.

8. ****Yoshii et al., 1986.*** Magnetic resonance imaging, 14 males, 19 females; dimorphism not significant. Data not provided. No significant differences were reported in the abstract, and brain weights were not studied. A "blinded rating" revealed the female splenium to be more bulbous ($P = .025$). No significant handedness effect. Possibly consistent with our findings.

9. ****Kertesz et al., 1987.*** Magnetic resonance imaging, 51 males, 53 females; dimorphism not significant. Mean CC area was 724 (M), 716 (F). Axial brain size correction (horizontal) shows female ratio is significantly larger than male ratio. Sagittal section size correction larger in females but not significantly so. Splenium to genu size ratios were larger in 85 cases for females and 78 cases for males. Chi-square showed no significant difference. Possibly consistent with our observations on relative CC size.

10. ****Oppenheim et al., 1987.*** Magnetic resonance imaging, 40 males, 40 females; dimorphism not significant. Data not given. Mean splenial area was reported as a percent of total CC area, and was higher in females (31.2% females, 30.4% males). Splenial width was 23.7% in males and 24.1% in females. Brain size was not studied. Total CC areas not given. The percentage figure may not be statistically significant, but the direction clearly favors females and is consistent with our views regarding relative size.

11. ****Byne et al., 1988.*** Magnetic resonance imaging, 15 males, 22 females; dimorphism reported not significant. Mean CC area was 519 (M), 601 (F). Brain size was not studied. Both the CCAREA and posterior one-fifth (splenium) were absolutely larger in females. The splenium was 160 mm^2 for men and 168 mm^2 for women in the age > 40 sample. In the total sample, posterior one-fifth was 170 in females and 160 in males. Given these findings, and the usual dimorphism of brain size being larger in males, these results are fully consistent with our findings.

12. ****Demeter et al., 1988.*** Autopsy data, 22 males, 12 females; dimorphism not significant. Mean CC area was 627 (M), 582 (F). Relative measures not given. Posterior one-fifth area (splenium) was 165 mm^2 in both males and in females. Splenial width was 11.8 mm in males and 11.6 mm in females. Brain weights for males cluster between 1,300 and 1,700 cc. Female brain weights cluster between 1,050 and 1,200 cc, and do not overlap male values. Six male values are above 1,500 cc. With these large brain size differences but relatively minor differences in callosal sizes, these results could well be consistent with our observations.

13. ***O'Kusky et al., 1988.*** Magnetic resonance imaging, 26 males, 24 females. No significant dimorphism. Brain size was not controlled nor measured. Values of total CC area or thicknesses and regions of the CC not given for males and females, respec-

tively. The averages are mixed sexes comparing epileptic patients and normal controls for different handedness groups. No significant differences reported. Without sex values, no comparisons can be made.

14. ***Weis et al., 1988.*** Magnetic resonance imaging, 20 males, 26 females; dimorphism not significant. Mean CC area was 669.9 (M), 665.2 (F). Total CC areas are almost equal for males and females. The splenial (posterior one-fifth area) was 191.5 for males, but 199.9 for females. Brain size was not considered. This study could be consistent with our findings, particularly if brain size was dimorphic.

15. ***Clarke et al., 1989.*** Both autopsy and magnetic resonance imaging data collected. Mean CC area was 680 (M), 590 (F). Relative measures not reported. In autopsied sample, males had significantly larger CC areas than females (680 mm^2 vs. 590 mm^2). In the MRI sample, females had a slightly larger CC area (females = 550 mm^2 and males = 540 mm^2; not significant). Posterior one-fifth (splenium) larger in MRI women (152–148), but in autopsied sample the male mean was larger (173–165). In both samples the females had a higher relative area of the posterior one-fifth splenial region. Maximum splenial widths only slightly larger in males in both samples (11.1 vs. 10.7; 10.8 vs. 10.3 in autopsy and MRI samples, respectively). Bulbosity index significantly higher in females for autopsy group, but larger in males for MRI sample. The MRI samples were small (N = 5, males, N = 7, females). Since brain weights are not reported, it is impossible to ascertain whether the relative sizes were different between the sexes. This study offers mixed results, some of which are consistent with our study, for example, in the splenial region.

16. ***Witelson, 1989.*** Autopsy data. Dimorphism reported as significant. Mean CC area was 674.5 (M), 650.4 (F). Patients were terminal cancer victims. Brain weights available, but only cerebrum weight was used. Relative data not provided. Report shows that regions were "corrected" for cerebrum weight by using two-factor (hand and sex) ANCOVA methods exclusively. The total CC area was larger in males and "proportional to overall brain size" (p. 825). The female sample was almost three times as large as the male sample for CRH. The isthmus was larger in females in both handedness groups. These results are mixed, but essentially provide evidence for some sexual dimorphism in the presplenial section, the so-called isthmus. Witelson's characterization of other studies is faulty in that no relative studies were done. These results are thus only partially consistent with our study regarding shape and relative size.

17. ***Elster et al., 1990.*** Magnetic resonance imaging, 60 males, 60 females. Dimorphism mixed. Mean CC area was 719 (M), 692 (F). Cerebral area in midsagittal plane was used as brain size control. Ratio data show some significant differences favoring females as in splenial width/CC length and CC area/cerebral area. Most areal and linear measures were not significantly larger in males. These results do tend to show a small but persistent dimorphism favoring the female, and thus support some of our results.

18. ***Going and Dixson, 1990.*** Autopsy data, 17 males, 16 females; dimorphism not significant. Mean CC area was 656 (M), 621 (F). Cerebrum weight was available, but not used directly for ratios. Posterior one-fifth area was 192 mm^2 in males and 170 mm^2 in females. "Correcting" for cerebral size gave males a CC area of 631 mm^2 and females 646 mm^2. None of the authors' statistics showed any significant dimorphism between males and females. The method of size control is faulty when an average correction is used for all brains rather than individually, and the averages resulting from dividing CC area by cerebral weight show females with a ratio of 1.305 and males with an average of 1.224. The average age of females was 82 years, that of males was 74.4 years. These are very high, and given the loss of neurons with advancing age, makes the female sample particularly suspect. The S.D.s of the CC areas are about 20%. Maximum width of the splenium was reported to have been measured but no figures are provided. This study claims not to be in support of our results, but the methods do not permit a true comparison. Some of the averages still favor the females, whether significant or not.

19. ***Holloway, 1990.*** Autopsy data, 13 males, 9 females; dimorphism significant; mean CC area was 705 (M), 765 (F). Cortical area, but not brain weight, were studied. Relative measures were significantly larger in females, as was maximum dorsoventral splenial width. Total cortical area not significantly different between males and females.

20. ***Prokop et al., 1990.*** Autopsy and magnetic resonance imaging. We have been able to secure only an abstract of this paper. Not certain of ages, nor whether any ratio data were studied. The abstract claims there were no significant differences or sexual dimorphism.

21. ***Allen et al., 1991.*** Magnetic resonance imaging, adult and children (122 age-matched adults, 24 age-matched children). Dimorphism was not significant in absolute measures. Mean CC area was 6.87 cm^2 in males and 6.80 in females. Brain size was controlled by measuring the area of the cerebral cortex in midsagittal section, and was significantly higher in males (92.96 vs. 88.57 in females). The maximum splenial width was 1.27 in males and 1.35 in females, the latter being significant at the .035 level. A "bulbosity index" was clearly higher in females and significantly so. CC sizes are almost equal between the sexes, while the splenial width is larger in females. At the same time, the area of cerebral cortex is significantly higher in males. These results, while mixed, are basically consistent with our study.

22. ***Deneberg et al., 1991.*** Magnetic resonance imaging, 51 males, 53 females; dimorphism not significant. Mean cc area was 731 (M), 722 (F). Brain size was an area calculated from one horizontal section as per Kertesz et al. (1987), and thus not a strict control of brain size. Factor analysis was performed on 99 width measures to extract a smaller set of measurements. In the region where maximum splenial width occurs, the female width (right-handed) was 11.59 mm, the male was 11.625 mm. For left-handers, the female sample mean was 11.4 and 11.53 for males. Sex effects varied depending where the width measures occurred, being larger for females in some cases and smaller in others. In no case were ratio data tested, nor does the paper provide any discussion of the supposed brain size control, that is, one horizontal brain area. Without this latter measure we cannot assess the dimorphism in approximate brain size, or relative sizes of the CC components. We cannot be certain whether these results are or are not consistent with our observations.

23. ***Habib et al., 1991.*** Magnetic resonance imaging, 35 males, 18 females; dimorphism not significant. Mean CC area was 809 (M), 775 (F). Authors claim that brain size was controlled by adjusting CC length to a standard sagittal length of 170 mm. This cannot truly control for brain size. Posterior subregions are all absolutely higher in males but not significantly so. (P1 88.8 M, 86.9 F; P2 86.01 M, 83.7 F; P3 219.9 M, 201.4 F) Males and female values are quite close, but without true brain size, the relative size of the CC components cannot be ascertained. These results are not truly consistent with our study. However, when handedness is examined, consistent right-handed (CRH) males had a total CC area of 746.5 mm^2 and females were 770.6. The P1 and P2 subregions were also larger in females: P1 101.4 (F) to 81.8 (M); P2 92.2 (F) to 77.06 (M). P3 larger in males for either handedness group. For nonconsistent right-handers, males were larger than females in all CC measures. These results are thus mixed, partly consistent with our observations and partly not.

24. ***Witelson and Goldsmith, 1991.*** Autopsy data, 8 males, only. Nonconsistent right-handers (nNCRH) had larger CC areas and isthmus region than CRH males. Brain weight was studied, but relative values not reported. These values are consistent with Witelson's earlier reports.

25. ***Steinmetz et al., 1992.*** Magnetic resonance imaging, 26 males, 26 females; the statistical significance of dimorphism was mixed, but not in mean CC area. Mean CC area was 678 (F), 673 (M). Brain size not controlled. No significant differences in most CC regions, except for 2 out of 3 posterior regions, which were absolutely larger in females than in men. The percentages of these posterior areas to the total CC area were significantly larger in females in two posterior regions. The differences held for

sex but not handedness. These results are clearly consistent with our observations.

SUMMARY

Sixteen out of 25 studies (not including this or our earlier studies) that claim to show no significant sexual morphism of the corpus callosum have some results that are consistent with our findings when the relative size of the corpus callosum is considered. Such studies are prefixed by an asterisk (*) to suggest that more data, particularly of a relative nature, might corroborate some of our findings regarding shape and relative size.

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Sexual Dimorphism of the Human Corpus Callosum From Three Independent Samples: Relative Size of the Corpus Callosum

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ABSTRACT Three independent autopsy samples of brains without apparent neuropathology were studied to ascertain whether there was sexual dimorphism in the human corpus callosum (CC). Using planimetric measurements on midsagittal brain sections, several morphometric features of the CC were studied: total callosal area, maximum dorsoventral splenial width, the posterior one fifth of the total area of the CC (mostly splenium), and brain weight. Ratio data correcting for brain size were also studied. In all samples, absolute brain size was larger in males, and significantly so. Measurements of splenial dorsoventral width were higher in females than males, but not significantly, except in the Australian sample. Total callosal area was absolutely higher in the Australian female sample than in males, and almost equal in the two American samples, without statistically significant differences. The posterior one-fifth area (splenium) was larger for females in each of the samples. The variables which were corrected for brain size were usually significantly larger in females, although this pattern varied in each sample. The statistical pattern of sexual dimorphism for the human CC differs from that found in most other neural structures, such as the amygdaloid nucleus, cerebellum, hippocampus, and thalamus. The absolute sizes of these structures are always significantly larger in males. When corrected for brain size, the relative sizes are not significantly larger. The CC is the only structure to show a larger set of relative measures in females.

Aside from absolute and relative brain weights (e.g., Holloway, 1980), sexual dimorphism in the human CNS has not been well documented except for the hypothalamus (Swaab and Fliers, 1985; Hines et al., 1992; see Breedlove, 1992, for a general review on vertebrate CNS dimorphism). Midline structure dimorphism was suggested by Papez (1937) while he was studying the brain of Helen Gardner, but the original measurements were not published, precluding statistical analysis. Bean (1906) suggested both sexual and ethnic differences in the corpus callosum as well as the rest of the brain, but a later study by Mall (1909) found little of substance, except brain size as being truly dimorphic. Many references regarding cerebral hemispheric dominance organization for language and spatial abilities strongly suggest some sexual dimorphism (e.g., Kimura, 1987, 1992; Hines et al., 1992), but the question of whether the differences are inborn or culturally acquired is

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