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Journal of Psychiatric Research 42 (2008) 167–183

JOURNAL OF PSYCHIATRIC RESEARCH

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Cerebral white matter deficiencies in pedophilic men

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Received 19 April 2007; received in revised form 24 October 2007; accepted 26 October 2007

Abstract

The present investigation sought to identify which brain regions distinguish pedophilic from nonpedophilic men, using unbiased, automated analyses of the whole brain. T1-weighted magnetic resonance images (MRIs) were acquired from men who demonstrated illegal or clinically significant sexual behaviors or interests ($n = 65$) and from men who had histories of nonsexual offenses but no sexual offenses ($n = 62$). Sexual interest in children was assessed by participants' admissions of pedophilic interest, histories of committing sexual offenses against children, and psychophysiological responses in the laboratory to erotic stimuli depicting children or adults. Automated parcellation of the MRIs revealed significant negative associations between pedophilia and white matter volumes of the temporal and parietal lobes bilaterally. Voxel-based morphometry corroborated the associations and indicated that the regions of lower white matter volumes followed, and were limited to, two major fiber bundles: the superior fronto-occipital fasciculus and the right arcuate fasciculus. No significant differences were found in grey matter or in cerebrospinal fluid (CSF). Because the superior fronto-occipital and arcuate fasciculi connect the cortical regions that respond to sexual cues, these results suggest (1) that those cortical regions operate as a network for recognizing sexually relevant stimuli and (2) that pedophilia results from a partial disconnection within that network.

Keywords: Arcuate fasciculus; Magnetic resonance imaging; Pedophilia; Sex offenders; Sexual abuse; Superior fronto-occipital fasciculus

1. Introduction

Pedophilia refers to sexual interest in children (Krafft-Ebing, 1886/1965),[1] and *teleiophilia*, in adults (Blanchard et al., 2000). Although etiological investigations of pedophilia have primarily addressed experiential causes (e.g., Araji and Finkelhor, 1985; Quinsey, 1986), neuropsychological findings suggest that pedophilic and nonpedophilic men may differ more fundamentally in brain function and, potentially, in brain structure: Pedophilic men show lower IQs (Cantor et al., 2004, 2005a), poorer visuospatial and verbal memory scores (Cantor et al., 2004), higher rates of non-right-handedness (Cantor et al., 2004, 2005b), elevated rates of having suffered childhood head injuries resulting in unconsciousness (Blanchard et al.,

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[1] Some writers differentiate between *pedophilia*, an exclusive interest in prepubescent children, and *pedohebephilia*, an erotic interest in prepubescent and pubescent children (Freund et al., 1972). In this article, we use the term *pedophilia* to refer to both variants.

0022-3956/$ - see front matter
doi:10.1016/j.jpsychires.2007.10.013

2002, 2003), and elevated rates of having failed school grades or having required placement in special education programs (Cantor et al., 2006).

Although imaging technologies have provided the potential opportunity to uncover more direct evidence of a neuroanatomic component to pedophilia for nearly two decades, the application of those technologies to pedophilia has lagged behind that for other psychopathologies. This is likely attributable, at least in part, to the large number of potential brain regions to investigate and to the dearth of well-supported theories of pedophilia for guiding researchers in selecting which brain regions to examine. To manage Type I error rates while testing the numerous components of the brain, researchers must choose either to limit the brain regions examined to those indicated by a particular theory (thus requiring less stringent statistical correction) or to examine the entire brain, applying more stringent correction. The disadvantage to analyzing the entire brain is that larger samples are necessary to compensate for the lower power otherwise available per comparison. The disadvantage to limiting examination to regions predicted by specific theories of pedophilia is that neuroanatomic differences, should they lay in other regions, would be overlooked. This is particularly problematic for studies of pedophilia; the existing neuroanatomic theories of pedophilia have thus far been largely unsuccessful in predicting neuropsychological or neuroanatomical findings (Blanchard et al., 2006). In the present investigation, we employed the whole-brain exploratory approach, using relatively large samples and unbiased, automated analyses. This permitted the evaluation of the differences predicted by existing theories as well as the exploration of differences unanticipated by those theories.

The predominant neuroanatomic theories of pedophilia fall into two broad categories: *Frontal-Dysexecutive Theories* associate sexual offending with dysfunction of frontal cortex and behavioral disinhibition (e.g., Graber et al., 1982). Proponents cite studies showing that heterogeneous groups of sexual offenders perform poorly on purported tests of executive functioning, including Controlled Oral Word Association, Delay of Gratification, Porteus Mazes, Stroop, Trail-Making, and Wisconsin Card Sort (Bowden, 1987; Dolan et al., 2002; Flor-Henry, 1987; Langevin et al., 1989a; Ponseti et al., 2001; Stone and Thompson, 2001; Valliant et al., 2000). *Temporal-Limbic Theories* implicate either the regulation of sexual behavior by deep temporal lobe structures (e.g., Hucker et al., 1986) or the role of such structures in behavioral disinhibition (e.g., Graber et al., 1982). Temporal-limbic theorists cite the associations between temporal lobe epilepsy and paraphilia (e.g., Kolárský et al., 1967) and between temporal lobe lesions and the hypersexuality exhibited in Klüver-Bucy Syndrome (e.g., Lilly et al., 1983). More recently, *Dual Dysfunction Theories* have been offered, in which pedophilic men suffer from dysfunction both in temporal regions (disturbing sexual urges) and in frontal regions (causing behavioral disinhibition; e.g., Cohen et al., 2002).

Despite the intuitiveness of those theories, the predictions based on them have received little empirical support. Although some investigators reported finding specific dysfunctions, closer examination of those studies suggests that such claims are overstated. For example, Stone and Thompson (2001) set out to test the frontal-dysexecutive theory by administering frontal lobe tests to sexual offenders and reported that their sample scored significantly below published norms. Although those authors interpreted their results to confirm frontal dysfunction, their battery consisted of only frontal lobe tests; had tests sensitive to temporal or parietal lobe functions been included, temporal and parietal dysfunction also might have been apparent. Moreover, a comprehensive review of neuropsychological studies suggested that the purported evidence of specific dysfunctions may instead be a methodological artefact (Blanchard et al., 2006): The studies that identified group differences had larger samples (and, therefore, more statistical power) than the studies that identified no group differences. It is possible that this population suffers from nonspecific cognitive deficits and that statistically powerful studies would find group differences on any neuropsychological tests, whereas studies with insufficient power would find none.

Prior imaging studies have also yielded little support for those theories: Although one CT study reported that pedophilic men have deficits in ‘‘left and bilateral temporal’’ regions (Hucker et al., 1986), subsequent CT studies found no such differences, including studies from the same researchers (Hendricks et al., 1988; Langevin et al., 1988, 1989b). Notably, these studies tended to examine only the anatomy suggested by the temporal-limbic theory of pedophilia, leaving other regions unexplored.

In the first published MRI study of pedophilia, Schiffer et al. (2007) tested the frontal-dysexecutive theory, hypothesizing that pedophiles suffer the same inability to inhibit repetitive behaviors as do persons with obsessive–compulsive disorder (OCD) and that pedophiles would therefore show abnormalities in the same neuroanatomy. Consistent with that hypothesis, analyses of the brain regions hypothesized to distinguish pedophilic from nonpedophilic subjects received ‘‘small volume correction,’’ whereas the analyses of the rest of the brain were subjected to more stringent statistical correction. Those investigators reported that the pedophiles had less grey matter volume in frontostriatal circuits, as they hypothesized.

Some of the inconsistency in this literature is likely attributable to the difficulties in assessing pedophilia. Although the DSM criteria for pedophilia rely on ‘‘sexual urges’’ involving children, such urges are internal, and few pedophilic men acknowledge that they experience them. Much more often, those interests are inferred from patients' penile (phallometric) responses in the laboratory to erotic stimuli depicting children or from patients' histories of committing sexual offenses against children. Unfortunately, none of those three indicators of pedophilic urges is entirely satisfactory (see Seto, 2008).

Phallometry entails the measurement of a sexually mature male's penile responses to erotic stimuli depicting children or adults; the relative magnitude of a patient's responses to the stimulus categories indicates his relative interest in persons of those categories (Blanchard et al., 2001). Meta-analysis of 61 sexual offender follow-up studies found that phallometric response to children was the single most effective predictor of committing new sexual offenses (Hanson and Bussière, 1998). Unfortunately, phallometric data are not always available; for example, some men fail to produce sufficient responses in the laboratory to any class of stimuli (Blanchard et al., 2001).

Patients' offense histories are diagnostically informative because men who have offended against children are more likely to show a pedophilic pattern on phallometric testing than are men without such offenses (Blanchard et al., 2001; Freund and Watson, 1991b). It also is only an imperfect indicator, however; not all men who offend against children are pedophilic (Freund and Watson, 1991a), and there are pedophilic men who have never offended directly against a child (such as possessors of child pornography; Seto et al., 2006). To maximize the diagnostic accuracy in the present study, we employed all three indicators: open acknowledgement of pedophilic urges, phallometric test results, and sexual offense histories.

Because the aforementioned methods of assessing pedophilia do not always produce the same diagnostic conclusion, two sets of analyses were conducted: one using offense history and admission of being pedophilic and one using phallometric responses. Thus, the following results contain four parts: parcellated volumes by offense-based diagnosis, voxel-wise comparisons by offense-based diagnosis, correlations of parcellated volumes with phallometric responses, and voxel-wise correlations with phallometric responses. The frontal-dysexecutive theory of pedophilia predicts that group differences will exist in the grey matter volumes of prefrontal and orbitofrontal cortex. The temporal-limbic theory predicts that such differences will exist in the grey matter of the limbic system. The dual dysfunction theory predicts that grey matter differences will occur in both regions.

2. Materials and methods

2.1. Participants

Sexual offender participants were recruited from the Kurt Freund Laboratory of the Centre for Addiction and Mental Health (CAMH; Toronto, Canada), which provides evaluation services to male patients referred as a result of illegal or clinically significant sexual behaviors or interests. The primary source of referrals to the facility is parole and probation officers, with physicians and lawyers providing others.

A patient was deemed eligible for this study if he acknowledged pedophilia during structured interview. A non-admitter was deemed eligible if he showed a phallometric response to any category of children (i.e., either pubescent or prepubescent; either male or female) that was greater than his responses to both categories of adults (i.e., men and women). Finally, a patient lacking usable phallometric results (such as those producing an insufficient response to any stimulus category) was deemed eligible if he had committed one or more sexual offenses against children age 14 years or younger but no sexual offenses against any person age 17 or older. Charges and admission to child pornography possession were each treated as offenses against children 14 or younger.

At the outset of this study, we intended also to include a group of teleiophilic sexual offenders. Although too few such men participated in the study to form an independent group, they could nonetheless be included in correlational analyses. These participants were selected according to the following inclusion criteria. Patients who admitted experiencing sexual interest in sadistic or violent sexual behaviors (with an adult of either sex) were deemed eligible. A non-admitter was deemed eligible if he committed one or more sexual offenses against a person age 17 or older, committed no sexual offenses against any person age 14 or younger, had no charges for possessing child pornography, and admitted to no such possession.

As in prior neuropsychological and neuroanatomic studies of sexual offenders (e.g., Dolan et al., 2002; Gillespie and Mckenzie, 2000; Hucker et al., 1986; Langevin et al., 1989b), the control group for the present study was composed of men who had been convicted of one or more nonsexual offenses but no sexual offenses (*nonsexual offenders*). The use of nonsexual offenders is intended to control for neuroanatomical findings potentially attributable to incarceration-related stress or general criminality. Chronic stress is consistently associated with neuroanatomic changes both in humans and in non-human animals (e.g., Bremner and Narayan, 1998; Karl et al., 2006; McEwen, 2001). Although criminality per se has never been studied neuroanatomically, brain volumetric differences have been reported in samples of men with antisocial personality disorder or psychopathy relative to healthy controls (Laakso et al., 2001; Raine et al., 2000, 2003; Yang et al., 2005). The use of a nonsexual offender comparison group is the most straightforward way to control for potential effects of both stress and of general criminality.

The nonsexual offenders were recruited from federal and provincial parole and probation offices in and around Toronto. Because the federal and provincial systems differ in their policies regarding research recruitment, different methods were used to verify the status of these men as nonsexual offenders. Federal recruits were pre-screened by federal system employees; only men with nonsexual and no sexual offenses were referred to the investigators. Provincial recruits referred themselves to the study by responding to brochures deposited in provincial probation/parole offices; when these men arrived to participate in the study, they provided written consent for the researchers to obtain their criminal records to verify their status subsequently. Their convictions ranged in severity from fraud to homicide, but primarily consisted of property offenses.

A potential participant was excluded if he reported: being under age 18, weighing more than 300 lbs, ever having been employed grinding metal, a medical history that counterindicated MRI (such as metal in the eye), any diagnoses of schizophrenia, or having suffered a traumatic brain injury.

This study was approved by the research ethics boards of the Centre for Addiction and Mental Health (Toronto, Canada), the University Health Network (Toronto, Canada), and the Ministry of Community Safety and Correctional Services (North Bay, Ontario, Canada).

2.2. Sexological measures

The phallometric procedure is detailed by Blanchard et al. (2007). Briefly, a computer records an examinee's penile blood volume while he is exposed to a standardized set of stimuli that depict a variety of activities and persons of potential erotic interest. Change in penile blood volume (i.e., degree of penile erection) indicates his relative erotic interest in each class of stimuli. The stimuli were audiotaped narratives presented through headphones and accompanied by slides. There were seven categories of narratives. They described sexual interactions with either female children, female pubescents, female adults, male children, male pubescents, or male adults or erotically neutral (i.e., solitary, nonsexual) activities. The accompanying slides depicted nude models corresponding in age and sex to the topic of the narrative (or landscapes, for the neutral narratives). The data reduction process yields seven category scores, one to reflect each of the six combinations of the age group and sex of the stimuli, plus the neutral category.

To produce a single score summarizing each patient's relative erotic interest in children, a *Phallometric Pedophilia Index* was calculated as the arithmetic sum of the patient's responses to stimuli depicting children minus the arithmetic sum of his responses to stimuli depicting adults $(\text{response}_{\text{male children}} + \text{response}_{\text{female children}} + \text{response}_{\text{male pubescents}} + \text{response}_{\text{female pubescents}}) - (\text{response}_{\text{male adults}} + \text{response}_{\text{female adults}})$. Thus, greater values on this index represented greater erotic interest in children.

A standardized form was used to record patients' sexual offense histories. This information included patients' numbers of victims ages $\leqslant 11$, victims ages 12–14, victims ages 15–16, and victims ages 17+. The information came primarily from documents that accompanied the patients' referrals, such as police, probation, or parole officer reports. Some patients provided additional information regarding offenses that were not included in their files and for which they had not been charged. During structured interviews, patients were asked to rate their own erotic interests in females of six age ranges ($\leqslant$5 years, 6–10, 11, 12–14, 15–16, and 17+ years) and in males in the same ranges.

2.3. Cognitive measures

Participants underwent a brief neuropsychological battery that included a six subtest short-form of the WAIS-R (Wechsler, 1981), a modified version of the Edinburgh Handedness Inventory (Oldfield, 1971; Williams, 1986), and the CAGE Alcohol Interview Schedule (Mayfield et al., 1974).

2.4. MR image acquisition

Images were acquired with a 1.5T MRI system (G.E., Milwaukee, WI) at the Toronto General Hospital (Toronto, Canada). A three-dimensional, inversion-prepped, radio-frequency fast spoiled-gradient recalled-echo (IR-FSPGR) sequence was used (TI = 300 ms, TR = 12 ms, TE = 5 ms, flip angle = 20°, FOV = 20 cm, matrix = 256 × 256 pixels), yielding 124 contiguous 1.5 mm thick coronal sections.

2.5. Image processing

Intensity non-uniformity was corrected with the Sled and Pike (1998) algorithm. To correct for differences in head size and to enable the automation of the tissue classification process, images were normalized to MNI-Talairach space, using the Collins et al. (1994) methods and resampled to 1.0 mm isotropic voxels. Tissue classification into grey matter, white matter, or cerebrospinal fluid (CSF) was accomplished using an artificial neural network that was trained with a back-propagation algorithm (see Zijdenbos et al., 1998). Non-brain tissue, such as skull, was removed by an iterative deformation of a preset approximation of the cortex to identify the CSF-parenchyma boundary (MacDonald et al., 1994). The resultant images were checked manually, and any remaining skull or scalp tissue was removed. Parcellation of the grey matter, white matter, and CSF images was conducted with ANIMAL (Automated, Nonlinear, Image Matching and Anatomical Labeling; Collins et al., 1995). The reference brain used by ANIMAL was manually delineated into 39 non-overlapping regions by a neuroanatomist (NK).

2.6. Voxel-based morphometry (VBM)

VBM analyses were conducted on SPM2 (Statistical Parametric Mapping, http://www.fil.ion.ucl.ac.uk/spm) running under MATLAB 6.5.1. Nonlinear registration was performed separately on subjects' grey matter, white matter, and CSF maps using Ashburner and Friston's (1999) algorithm and using the custom templates formed by averaging all participants' maps of that tissue type (Good et al., 2001). Each voxel's intensity was then modulated such that voxel intensity subsequently represented the volume of the pre-registered tissue. Finally, each image was smoothed with a 10 mm full-width-half-maximum, Gaussian blurring kernel to increase the normality of the distributions (Ashburner and Friston, 1999).

2.7. Statistical procedures

The statistical approach for detecting group differences in the parcellated brain regions proceeded as follows. The 39 regions were treated as four sets of tissue: cortical grey matter (12 regions), subcortical grey matter (11 regions), white matter (11 regions), and CSF (five regions). Each set was tested by multiple analysis of variance (MANOVA); significant MANOVAs ($\alpha = .05$) were followed-up by independent groups' t-tests, to ascertain which specific regions contributed significantly ($\alpha = .05$) to the overall group difference. This procedure maintains α levels while providing greater statistical power than does the Bonferroni approach (Stevens, 2002, p. 182). The analogous procedure was used for testing the correlations of the parcellated brain volumes with phallometric responses: The aforementioned sets of tissue were tested by multiple regression, and significant regressions ($\alpha = .05$) were followed-up by Pearson r's ($\alpha = .05$). This constitutes the correlational adaptation of Fisher's protected t-tests (Cohen and Cohen, 1983). Two voxel-wise analyses were conducted, using general linear models that paralleled the analyses of the parcellated volumes: one model tested for group differences at each voxel, and one tested the correlation at each voxel with the Phallometric Pedophilia Index. The alpha levels applied to each voxel were adjusted to produce false discovery rates (FDR) of 10%, 5%, and 1%, as specified in the following.

3. Results

3.1. Final sample

A total of 65 sexual offender patients met the inclusion/exclusion criteria and underwent MRI, and a total of 62 control participants contacted the investigators, met the inclusion/exclusion criteria, and underwent MRI. Not included in these numbers are one patient whose imaging data were lost due to a technical difficulty and one control participant who was excluded because of a brain injury and coma he did not disclose during his initial screening. Table 1 provides the groups' demographic, socioeconomic, and neuropsychological characteristics; they differed significantly only in alcohol use, with the control group exhibiting more problematic alcohol use.

3.2. Differences in brain region volumes by offense history and admission of pedophilic urges

Of the 65 sexual offenders, 44 were classifiable as pedophilic on the basis of their offense histories; the remainder had committed a sexual offense against a person age 15 or older (such as the men who were initially recruited as teleiophilic sexual offenders). Patients who admitted to pedophilia during interview were retained regardless of offense history. Of these pedophilic men, 90.9% had offenses against females, and 31.8% had offenses against males. (The sum of these numbers exceeds 100% due to persons having offenses against both girls and boys.) Of the 62 controls, 53 were classifiable as nonpedophilic nonsexual offenders on the basis of their offense histories; the remaining cases were excluded either because their criminal records (reviewed after their assessment appointments) revealed a sexual offense (despite their self-report that their records included only nonsexual offenses) or because they reported pedophilia upon interview. Thus, the following independent groups comparisons included a total of 97 cases.

MANOVA indicated that the pedophilic group differed significantly from the nonsexual offenders in the set of white matter regions (Wilks' $\Lambda = .68$, $F(11, 85) = 3.72$, $p = .0002$), but no significant omnibus differences were detected in cortical grey matter (Wilks' $\Lambda = .87$, $F(12, 84) = 1.08$, $p = .38$), subcortical grey matter (Wilks' $\Lambda = .89$, $F(11, 85) = 0.99$, $p = .46$), or CSF (Wilks'

Table 1
Demographic, socioeconomic, and neuropsychological characteristics of the patient group and the nonsexual offender control group

Characteristic	Patient group ($n = 65$)	Control group ($n = 62$)	Comparison	P (two-tailed)
Years of age (mean ± SD)	36.4 ± 13.5	36.9 ± 9.4	$t(125) = -0.23$	.82
IQ[a] (mean ± SD)	96.2 ± 15.3	96.3 ± 11.5	$t(125) = -0.03$	.98
Non-right-handed (percent)	23.1%	14.5%	$\chi^2(1, n = 127) = 1.52$	.22
Employment[b] (mode)	Laborer	Laborer	$\chi^2(3, n = 127) = 3.13$	.37
Subjects' years of education (mean ± SD)	12.2 ± 3.0	12.1 ± 2.8	$t(125) = 0.20$	.84
Father's educational level[c] (median)	High school graduation	High school graduation	$\gamma(n = 105) = .146$	.27
Mother's educational level[c] (median)	High school graduation	High school graduation	$\gamma(n = 113) = .083$	.51
CAGE alcoholism screening score (mean ± SD)	1.1 ± 1.4	2.1 ± 1.6	$t(125) = -3.8$	.0003

[a] Estimated from six subtests of the WAIS-R (Information, Similarities, Digit Span, Arithmetic, Picture Completion, and Block Design).

[b] Employment was coded according to the categories provided in the WAIS-R and then grouped as: 1 = farmer, farm laborer, laborer, operative; 2 = professional/technical worker, service worker, craftsman/foreman; 3 = clerical/sales worker, manager, official, proprietor; 4 = student, no employment history.

[c] Education level was coded as: 1 = less than grade 8, 2 = grade 8, 3 = grade 9–11, 4 = high school graduation, 5 = trade school, 6 = community college, 7 = university, 8 = graduate/professional school.

$\Lambda = .91$, $F(5,91) = 1.83$, $p = .12$). Table 2 shows the follow-up t-tests comparing the groups on each brain region. Significantly distinguishing the pedophilic and nonsexual offender groups were the volumes of the temporal lobe white matter bilaterally, parietal lobe white matter (right, and only marginally left), and corpus callosum. Table 2 suggests that the pedophilic group also had significantly greater volumes in both lateral ventricles and the fourth ventricle; however, as already noted, the omnibus test of the CSF regions was not significant.

As indicated already, the control group exhibited a greater propensity to engage in problematic alcohol use than did the pedophilic men. In order to evaluate the counterintuitive possibility that the difference in white matter volumes was caused by greater alcohol use among the controls, the analyses of the brain volumetric data were repeated, this time including CAGE alcohol interview schedule scores as a covariate. Omnibus testing of the set of white matter regions by MANCOVA yielded the same result as before (Wilks' $\Lambda = .704$, $F(11,84) = 3.22$, $p = .001$). Follow-up ANCOVAs of the five white matter regions that were previously significant remained significant (right temporal lobe, $F(1,94) = 9.37$, $p = .003$, partial $\eta^2 = .091$; left temporal lobe, $F(1,94) = 5.65$, $p = .019$, partial $\eta^2 = .057$; right parietal lobe, $F(1,94) = 9.56$, $p = .003$, partial $\eta^2 = .092$; left parietal lobe, $F(1,94) = 4.06$, $p = .047$, partial $\eta^2 = .041$; corpus callosum, $F(1,94) = 5.29$, $p = .024$, partial $\eta^2 = .053$).

Table 2
Mean ± SD brain tissue and CSF volumes by participants' classification by offence history and admission to experiencing pedophilia

Brain region	Mean ± SD volume (cm^3)		Effect size (d)	t(95)	P (two-tailed)
	Pedophilic men ($n = 44$)	Nonsexual offender controls ($n = 53$)			
Grey matter, cortical					
Right frontal lobe	154.9 ± 16.2	151.7 ± 14.1	0.21	1.02	.31
Left frontal lobe	157.9 ± 15.2	156.3 ± 12.2	0.12	0.60	.55
Right temporal lobe	122.9 ± 14.9	122.1 ± 14.1	0.05	0.25	.80
Left temporal lobe	122.3 ± 14.7	122.7 ± 12.5	−0.03	−0.17	.87
Right parietal lobe	85.7 ± 10.8	84.8 ± 8.6	0.10	0.49	.63
Left parietal lobe	83.4 ± 8.7	82.9 ± 8.7	0.06	0.30	.77
Right occipital lobe	46.0 ± 6.2	48.1 ± 5.3	−0.38	−1.83	.07
Left occipital lobe	50.7 ± 6.5	51.6 ± 5.6	−0.16	−0.76	.45
Right insula	12.0 ± 1.4	12.0 ± 1.0	0.02	0.09	.93
Left insula	12.4 ± 1.3	12.3 ± 1.1	0.07	0.35	.73
Right cingulate region	22.8 ± 2.7	22.8 ± 2.3	−0.02	−0.11	.92
Left cingulate region	20.9 ± 2.8	21.2 ± 2.0	−0.15	−0.72	.48
Grey matter, subcortical					
Right caudate nucleus	6.6 ± 0.8	6.6 ± 0.5	0.10	0.49	.62
Left caudate nucleus	6.7 ± 0.8	6.6 ± 0.5	0.19	0.91	.37
Right putamen	8.9 ± 1.1	9.1 ± 0.8	−0.19	−0.92	.36
Left putamen	8.4 ± 1.1	8.7 ± 0.9	−0.35	−1.70	.09
Right globus pallidus	1.5 ± 0.3	1.5 ± 0.2	0.02	0.09	.93
Left globus pallidus	1.6 ± 0.3	1.5 ± 0.2	0.17	0.81	.42
Right thalamus	10.5 ± 0.6	10.5 ± 0.6	0.03	0.14	.89
Left thalamus	10.8 ± 0.7	10.8 ± 0.7	0.05	0.26	.79
Right subthalamic nucleus	0.1 ± 0.0	0.1 ± 0.0	−0.20	−1.00	.32
Left subthalamic nucleus	0.1 ± 0.0	0.1 ± 0.0	−0.10	−0.47	.64
Brain stem and cerebellum	211.3 ± 19.2	210.4 ± 20.4	0.04	0.22	.83
White matter					
Right frontal lobe	88.4 ± 9.6	90.0 ± 10.0	−0.16	−0.79	.43
Left frontal lobe	92.6 ± 9.2	95.5 ± 10.2	−0.30	−1.46	.15
Right temporal lobe	50.7 ± 5.8	54.0 ± 4.9	−0.63	−3.08	.003
Left temporal lobe	48.9 ± 5.3	51.6 ± 5.2	−0.52	−2.54	.01
Right parietal lobe	47.0 ± 6.9	50.8 ± 6.1	−0.59	−2.86	.005
Left parietal lobe	44.9 ± 6.8	47.4 ± 5.8	−0.39	−1.89	.06
Right occipital lobe	18.5 ± 4.5	19.4 ± 3.2	−0.23	−1.10	.27
Left occipital lobe	16.2 ± 4.3	15.0 ± 3.3	0.31	1.53	.13
Right fornix	0.9 ± 0.2	0.9 ± 0.2	−0.20	−0.96	.34
Left fornix	0.9 ± 0.2	0.9 ± 0.1	0.05	0.25	.80
Corpus callosum	15.7 ± 2.8	17.1 ± 2.8	−0.53	−2.57	.01
CSF					
Right lateral ventricle	12.3 ± 8.4	9.2 ± 5.8	0.44	2.14	.04
Left lateral ventricle	13.3 ± 10.2	9.8 ± 6.6	0.43	2.08	.04
Third ventricle	2.5 ± 0.9	2.2 ± 0.9	0.25	1.22	.23
Fourth ventricle	4.0 ± 1.6	3.4 ± 1.1	0.44	2.15	.03
Subarachnoid space	830.0 ± 115.3	819.3 ± 105.3	0.10	0.48	.64

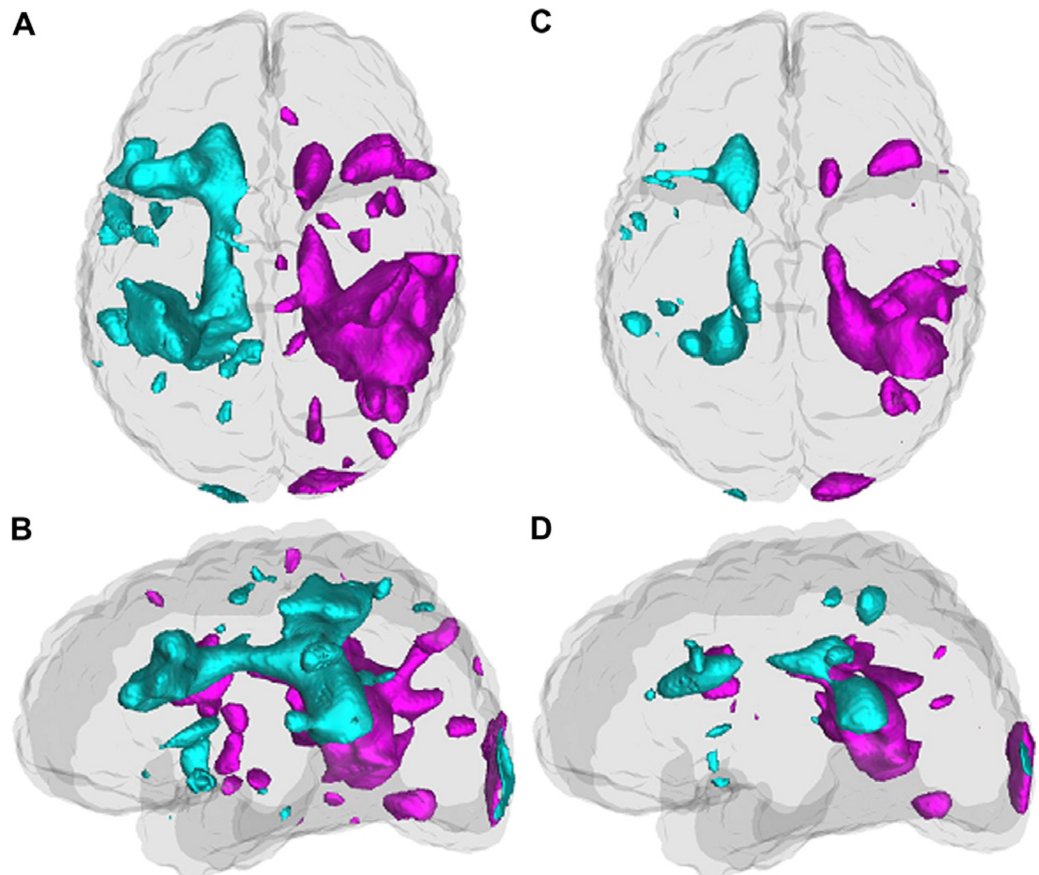

Fig. 1. 3D renderings of all voxels representing significantly lower white matter volumes in pedophilic men ($n = 44$) relative to control men with histories of nonsexual offenses ($n = 53$). Panels A and B show the significant voxels thresholded at $t(95) \leqslant -2.56$ for a false discovery rate of .10. Panels C and D show the significant voxels thresholded at $t(95) \leqslant -3.15$ for a false discovery rate of .05. Voxels in the left hemisphere appear in cyan; voxels in the right hemisphere appear in magenta.

3.3. Voxel-wise comparison of pedophilic men with nonsexual offenders

This analysis entailed the voxel-wise comparisons of the same 97 cases in the same two groups as the previous analysis. Consistent with the parcellation analyses, significant clusters of voxels representing decreased white matter volumes (but not greater white matter volumes) were detected, whereas none of the voxel cluster peaks representing grey matter or CSF was significant after FDR correction. The white matter voxels that were lower among pedophiles were wide-spread (Fig. 1), and they appeared to be intrahemispheric: No cluster spanned across hemispheres or appeared to connect a cortical region with the brain stem or spinal cord.

The fibers distinguishing the two groups appeared to consist of two regions. The larger region followed the superior fronto-occipital fasciculus;[2] it ran along the dorsal border of the caudate nucleus, extending posteriorly toward the occipital pole and extending anteriorly to terminate primarily in the middle frontal gyrus (Fig. 2, Panels A and C) (Heimer, 1983). The anterior extension appeared also to terminate in two other, weaker clusters, one in the frontal operculum and one in the opercular part of the inferior frontal gyrus (Fig. 2, Panel D). Much of the extent of the superior fronto-occipital fasciculus runs alongside that of the longitudinal fasciculus. The identity of the significant structure was indicated by its position medial to the internal capsule, whereas the superior longitudinal fasciculus runs lateral to the internal capsule. The second region occurred only in the right hemisphere, following the arcuate fasciculus from the parietal opercular region to the temporal opercula, wrapping around the posterior extension of the Sylvian fissure (Fig. 2, Panel B) and descending to the inferior temporal and fusiform gyri (Fig. 3).

3.4. Correlations of brain regional volumes with Phallometric Pedophilia Index

As already noted, correct diagnoses cannot always be assigned according to self-reports and offense histories. Therefore, analyses were repeated using the correlations

[2] The structure we call here the superior fronto-occipital fasciculus has also been called the *superior occipitofrontal fasciculus* and the *subcallosal fasciculus*, and, because there has been some question regarding whether there exists an inferior occipitofrontal fasciculus, some authors exclude the word "superior" from the name (Schmahmann and Pandya, 2006).

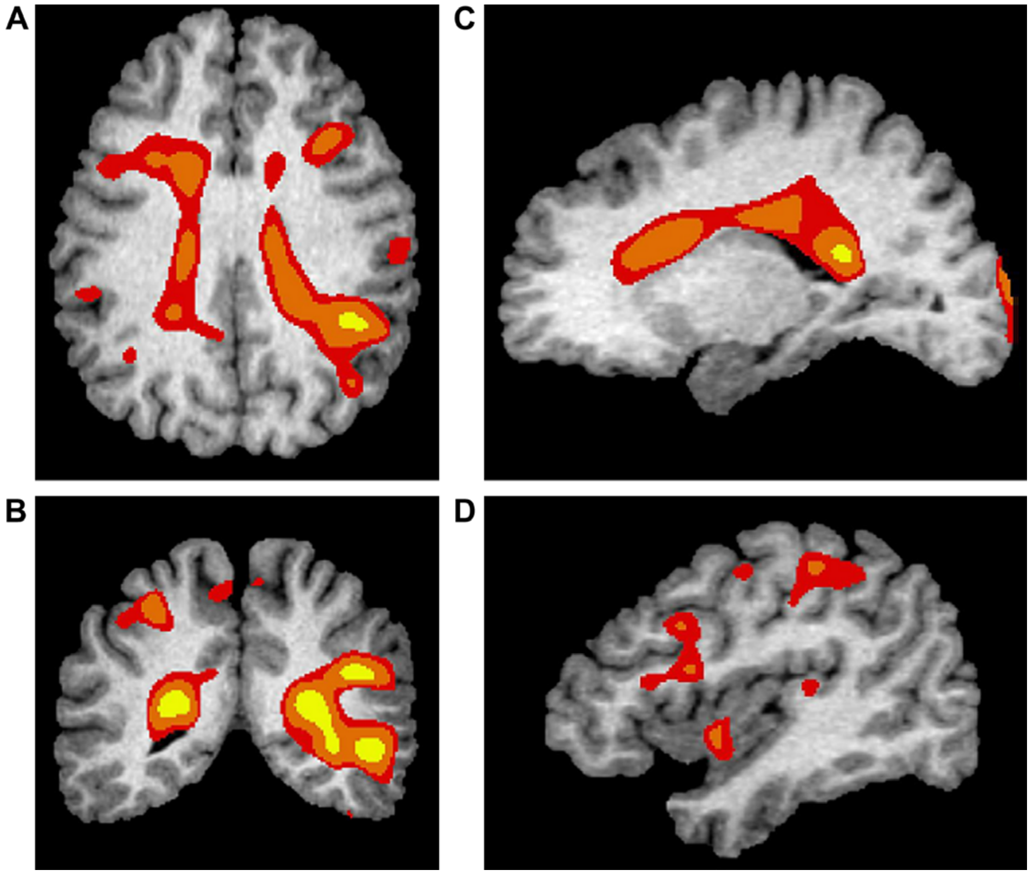

Fig. 2. Regions of low white matter volumes in pedophilic men ($n = 44$) relative to control men with histories of nonsexual offenses ($n = 53$), superimposed on axial (Panel A, $z = 28$), coronal (Panel B, $y = -48$), and two sagittal (Panel C, $x = -19$; Panel D, $x = -43$) sections. Red represents regions of significantly lower white matter volumes in pedophilic men thresholded at $t(95) \leqslant -2.56$ for a false discovery rate of .10; orange, thresholded at $t(95) \leqslant -3.15$ for a false discovery rate of .05; and yellow, thresholded at $t(95) \leqslant -4.2$ for a false discovery rate of .01.

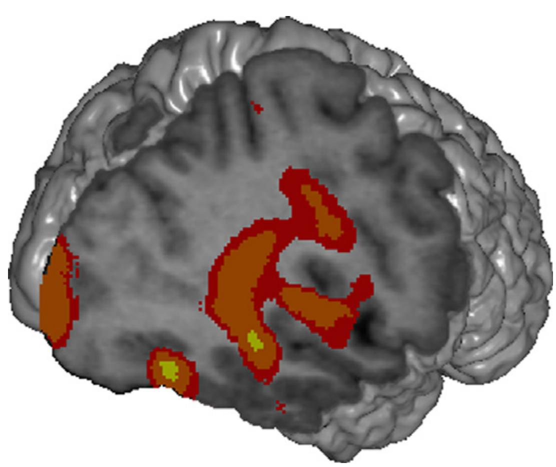

Fig. 3. Regions of low white matter volumes in pedophilic men ($n = 44$) relative to control men with histories of nonsexual offenses ($n = 53$), superimposed on an oblique section. Red represents regions of significantly lower white matter volumes in pedophilic men thresholded at $t(95) \leqslant -2.56$ for a false discovery rate of .10; orange, thresholded at $t(95) \leqslant -3.15$ for a false discovery rate of .05; and yellow, thresholded at $t(95) \leqslant -4.2$ for a false discovery rate of .01.

of parcellated volumes with phallometric responses. Because Phallometric Pedophilia Index scores are continuous rather than dichotomous, there is no need to classify participants; instead, higher scores represent a greater severity (or probability) of pedophilia, whereas lower scores represent the reverse. This strategy has several advantages: The prior strategy required that sexual offenders with histories of offending against adults be excluded, so that only pedophilic offenders were represented. Analyzing the MRI data by Phallometric Pedophilia Index, however, allows these cases to be retained; the pedophilic men would tend to score higher on the index, whereas the nonpedophilic sexual offenders would tend to score lower. Similarly, the prior analysis required that nonsexual offenders who admitted to experiencing pedophilia be excluded, but they could be retained for correlational analyses; again, men who experience pedophilic interests would tend to score high on the index while the majority would tend to score low. Finally, analyses using continuous variables are typically more powerful statistically than analyses using dichotomous variables.

Of the 65 patients who participated in the study, 61 completed the phallometric assessment; of those, 59 produced usable phallometric results. Of the 62 control participants, 50 completed the phallometric assessment; of those, 49 produced usable phallometric results. Thus, the following correlations included the 108 participants who produced usable results and represent a somewhat different subset of subjects than those used in the between-groups analyses.

Phallometric Pedophilia Index scores related significantly to the white matter volumes ($R = .473$, $F(11, 96) = 2.51$, $p = .008$), but not to cortical grey matter ($R = .260$, $F(12, 95) = 0.58$, $p = .86$), subcortical grey matter ($R = .263$, $F(11, 96) = .65$, $p = .79$), or CSF volumes ($R = .274$, $F(5, 102) = 1.66$, $p = .15$). Table 3 shows the correlations between the Phallometric Pedophilia Index and the individual regions. The regional volumes most strongly associated with pedophilia index scores were again in temporal and parietal white matter, bilaterally, and the corpus callosum. Although the correlations suggested that greater pedophilia index scores related to larger volumes of both lateral ventricles, the omnibus test of CSF regions was not significant.

Table 3
Mean ± SD grey matter, white matter, and CSF volumes and their correlations with genital (phallometric) responses to stimuli depicting children versus adults

Brain region	Mean ± SD volume (cm^3)	Correlation with Phallometric Pedophilia Index
Grey matter, cortical		
Right frontal lobe	152.5 ± 15.1	.07
Left frontal lobe	156.1 ± 13.8	.08
Right temporal lobe	123.5 ± 14.9	−.03
Left temporal lobe	123.5 ± 14.4	−.02
Right parietal lobe	84.9 ± 9.6	.00
Left parietal lobe	82.4 ± 8.5	.01
Right occipital lobe	46.9 ± 5.8	−.05
Left occipital lobe	50.9 ± 5.9	−.09
Right insula	12.0 ± 1.2	−.06
Left insula	12.4 ± 1.2	−.02
Right cingulate region	22.5 ± 2.6	−.02
Left cingulate region	20.9 ± 2.3	−.07
Grey matter, subcortical		
Right caudate nucleus	6.6 ± 0.6	−.05
Left caudate nucleus	6.7 ± 0.6	−.04
Right putamen	9.0 ± 1.0	−.06
Left putamen	8.6 ± 1.1	−.11
Right globus pallidus	1.5 ± 0.3	.06
Left globus pallidus	1.6 ± 0.3	.03
Right thalamus	10.6 ± 0.7	−.03
Left thalamus	10.9 ± 0.8	.05
Right subthalamic nucleus	0.1 ± 0.0	−.09
Left subthalamic nucleus	0.1 ± 0.0	−.06
Brain stem and cerebellum	214.1 ± 20.0	.06
White matter		
Right frontal lobe	89.0 ± 10.4	−.16
Left frontal lobe	93.8 ± 10.3	−.17
Right temporal lobe	52.3 ± 5.6	−.31**
Left temporal lobe	50.2 ± 5.5	−.25*
Right parietal lobe	49.2 ± 6.8	−.32**
Left parietal lobe	46.3 ± 6.4	−.33***
Right occipital lobe	19.2 ± 4.0	−.08
Left occipital lobe	15.8 ± 4.0	.02
Right fornix	0.9 ± 0.2	−.06
Left fornix	0.9 ± 0.2	.04
Corpus callosum	16.4 ± 2.8	−.19*
CSF		
Right lateral ventricle	11.3 ± 7.5	.19*
Left lateral ventricle	11.8 ± 8.2	.22*
Third ventricle	2.4 ± 0.9	.10
Fourth ventricle	3.6 ± 1.3	.08
Subarachnoid space	805.4 ± 126.2	.08

Note. $N = 108$. Greater values on the Phallometric Pedophilia Index represent greater penile responses to stimuli depicting children; thus, positive correlations indicate that greater volume of that region of the brain is associated with greater severity (or probability) of pedophilia.

* $p < .05$ (two-tailed).

** $p < .005$ (two-tailed).

*** $p < .0005$ (two-tailed).

In order to ascertain whether these findings were affected by alcohol use, the correlations between the pedophilia index scores and the brain volumes were recalculated as partial correlations, partialling out CAGE alcohol interview schedule scores. All the associations changed very little and remained significant (right temporal lobe partial $r(105) = -.30$, $p = .001$; left temporal lobe partial $r(105) = -.24$, $p = .013$; right parietal lobe partial $r(105) = -.31$, $p = .001$; left parietal lobe partial $r(105) = -.33$, $p = .001$; corpus callosum partial $r(105) = -.19$, $p = .046$).

3.5. Voxel-wise correlations with the Phallometric Pedophilia Index

This analysis used the same 108 cases as the previous analysis and used FDR correction of Type I error rates. Like the prior VBM analysis, the clusters of significant voxels occurred only for lesser volume of white matter, and the regions consisted of cortico-cortical tissue (Fig. 4). The regions included the same anatomical structures as before, but encompassed much more of the tissue branching out from both the superior fronto-occipital and arcuate fasciculi (Fig. 5). Individual structures are difficult to identify in those figures because of the very large number of significant voxels and because the voxels are graphically represented dichotomously as significant or not-significant. Fig. 6 instead shows *t*-maps from the VBM analyses from both the correlational analysis and from the earlier, group-based comparison. Although the left panels (the group analyses) implicate the same structures as the right panels (the correlational analyses), they differ in emphasizing the main trunks of those structures rather than the major branches of those structures.

3.6. Associations of white matter with other volumes

In analyses of normalized volumes, lesser volumes of one tissue type imply increased volumes of another. The total of the white matter region volumes correlated significantly with that of the CSF regions ($r(125) = -.40$, $p < .0001$) but not with that of the cortical or subcortical grey matter regions ($r(125) = .07$, $p = .43$; $r(125) = -.11$, $p = .24$).

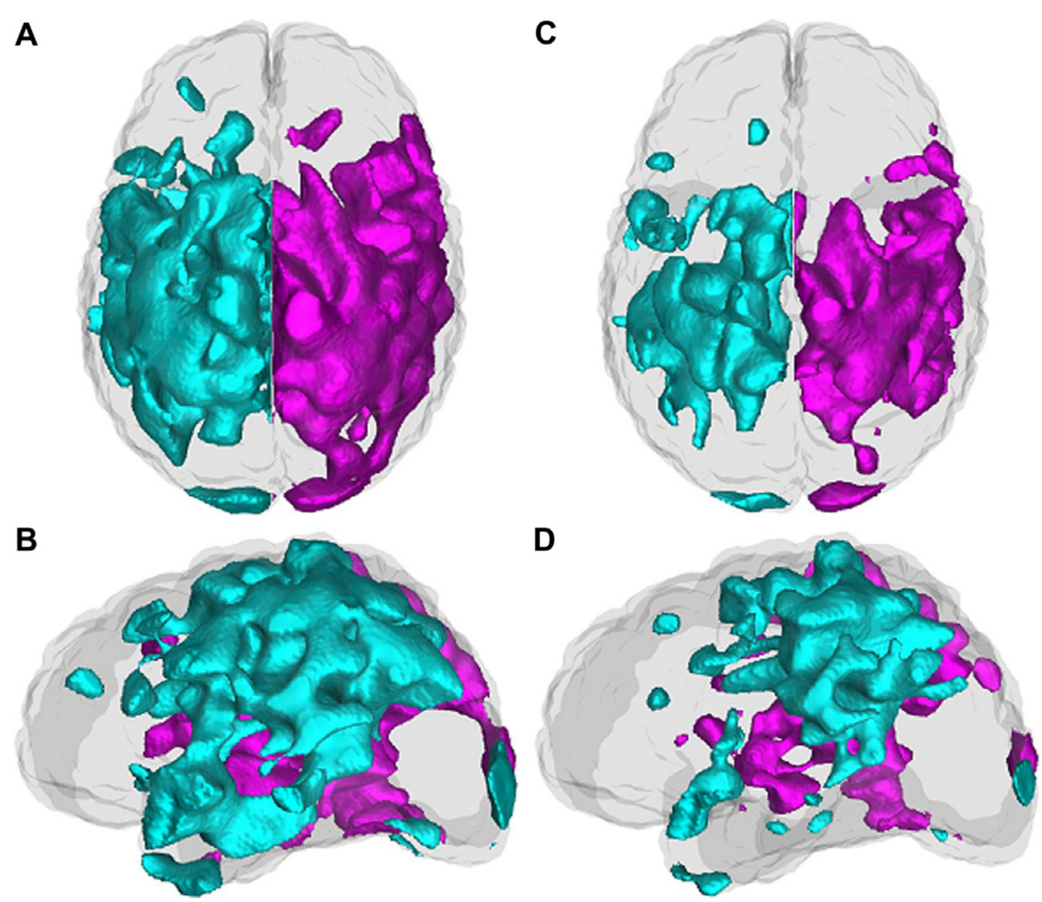

Fig. 4. 3D renderings of all voxels representing significantly negative correlations between participants' white matter volumes and their genital responses in the laboratory to stimuli depicting children versus adults (*Phallometric Pedophilia Index*; $n = 108$). Panels A and B show the significant voxels thresholded at $r(106) \leqslant -.19$, or $t(106) \leqslant -2.03$, for a false discovery rate of .10. Panels C and D show the significant voxels thresholded at $r(106) \leqslant -.25$, or $t(106) \leqslant -2.63$, for a false discovery rate of .05. Voxels in the left hemisphere appear in cyan; voxels in the right hemisphere appear in magenta.

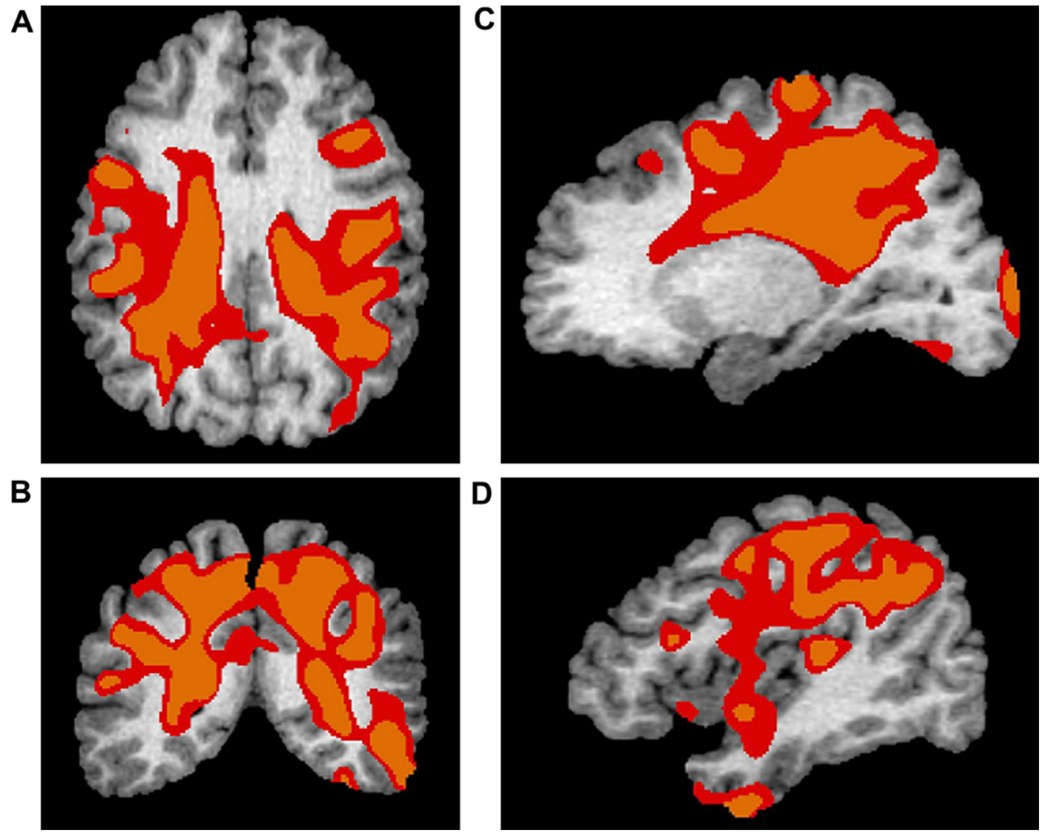

Fig. 5. Regions of negative correlation between participants' white matter volume and their genital responses in the laboratory to stimuli depicting children versus adults (*Phallometric Pedophilia Index*; $n = 108$), superimposed on axial (Panel A, $z = 28$), coronal (Panel B, $y = -48$), and two sagittal (Panel C, $x = -19$; Panel D, $x = -43$) sections. Red represents regions of significantly negative correlations thresholded at $r(106) \leqslant -.19$, or $t(106) \leqslant -2.03$, for a false discovery rate of .10; orange, thresholded at $r(106) \leqslant -.25$, or $t(106) \leqslant 2.63$, for a false discovery rate of .05.

4. Discussion

4.1. Summary of results

The present results revealed large regions of significantly lower white matter volumes among the pedophilic men, but no regions with significantly greater white matter volume nor any regions with any significant differences in grey matter or CSF volumes in either direction. These results emerged regardless of whether pedophilia was represented by dichotomous classification on the basis of offense history (and admissions of pedophilia) or was represented by phallometric responses, and regardless of whether brain structure was assessed by automated parcellation or assessed by VBM.

The parcellated data (both in the group analyses and correlational analyses) found significantly less white matter in the temporal and parietal lobes, and the VBM analyses indicated the significant region to be the superior fronto-occipital fasciculus and the right arcuate fasciculus. Figs. 1 and 4 show that the large, contiguous regions demarcated by VBM include some occipital and frontal territory, although those regions were not significant in the parcellated analyses (Tables 2 and 3). Such a discrepancy can occur from the varying proportions of each lobe's white matter residing within the significant region. That is, comparatively large proportions of the parietal lobe and temporal lobe white matter were contained by the significant region, whereas comparatively small proportions of the frontal and occipital lobe white matter were. The automated parcellation and the VBM analysis also differed in that the parcellation data suggested an association with the corpus callosum. Because the superior fronto-occipital fasciculus runs immediately ventral to lateral portions of the corpus callosum, the region labeled as corpus callosum in the reference brain used to parcellate images may have included adjacent, non-callosal white matter.

The large size of the region of low white matter volumes invites one to expect that pedophilic men would exhibit additional symptoms of poor brain functioning beyond their sexual abnormality. That expectation does indeed appear to be the case: Relative to controls, samples of pedophilic men show lower IQs, poorer visuospatial and poorer verbal memory scores, threefold higher rates of non-right-handedness, elevated rates of having suffered childhood head injuries resulting in unconsciousness, and elevated rates of having failed school grades or having required placement in special education programs (Blanchard et al., 2002, 2003; Cantor et al., 2004, 2005a,b, 2006). It has also been reported recently that pedophilic

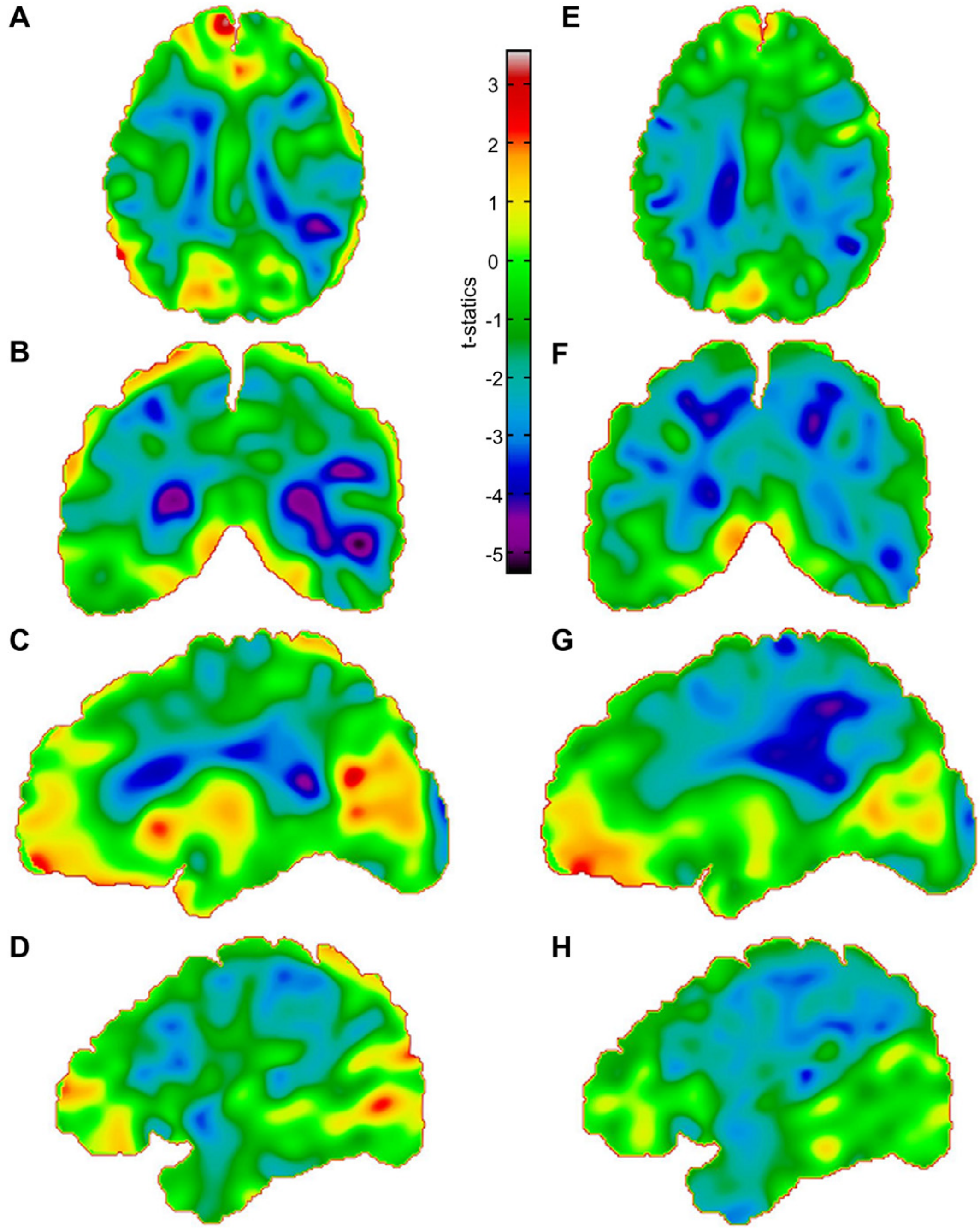

Fig. 6. Panels A–D show the axial ($z = 28$), coronal ($y = -48$), and two sagittal ($x = -19$, $x = -43$) t-maps of the white matter volumes of the pedophilic men ($n = 44$) relative to those of nonsexual offender control men ($n = 53$). Panels E–H show the corresponding t-maps of correlations of participants' white matter volumes with their genital responses in the laboratory to stimuli depicting children versus adults (*Phallometric Pedophilia Index*; $n = 108$). In all panels, color scale represents t-scores, with the most negative values appearing in violet/blue and the most positive values, in orange/red.

men are physically shorter than nonpedophilic controls (Cantor et al., in press), suggesting that the poor white matter volumes detected here may be one component of generally poor physical development.

4.2. Differences from prior findings

Schiffer et al. (2007) and the present investigation both compared structural MRIs of pedophilic men with those of controls; however, the present investigation identified an association between pedophilia and white matter, whereas Schiffer et al. (2007) identified an association between pedophilia and grey matter. The most obvious explanation for why the present study found an association between pedophilia and white matter—and Schiffer et al. (2007) did not—is that the present study had a larger sample and, therefore, greater statistical power. Schiffer et al. (2007) applied their less stringent small volume corrections only to the brain regions hypothesized by their frontal-dysexecutive theory; white matter regions were subjected to more stringent statistical correction. The reason Schiffer et al. (2007) found an association between pedophilia and some grey matter regions—and the present study did not—may be because the present study contrasted pedophiles with nonsexual offenders, whereas Schiffer et al. (2007) contrasted the pedophiles with men who had no (known) criminal history. Thus, the group differences in grey matter reported by Schiffer et al. (2007) might reflect factors other than pedophilia, such as general criminality or histories of chronic stress.

4.3. Possible models of the association of white matter with pedophilia

More than one explanation can be produced to explain the association observed here between pedophilia and white matter volumes: (a) Pedophilia, or some characteristic more common among pedophilic than nonpedophilic men, causes low white matter volumes. (b) An as-yet unidentified third variable causes (or merely correlates with) both the low white matter volumes and causes pedophilia, thereby establishing a non-causal correlation between pedophilia and white matter volume. (c) Low white matter volumes cause pedophilia directly. We consider these possibilities in turn.

4.3.1. Pedophilia causes low white matter

Although low white matter causing pedophilia is the most dramatic interpretation of these data, a correlation between pedophilia and low white matter volume could emerge from already pedophilic men being more likely to engage in some behavior or to possess some characteristic that causes white matter volumes to decrease.

Although no study can ever rule out all possible influences on white matter volumes, the present study does allow us to exclude some possibilities. Alcohol use, for example, can reduce white matter volumes (e.g., Bjork et al., 2003), but it was the control subjects here who had the greater propensity for problematic alcohol use. Normal aging is associated with changes in white matter volumes (e.g., Allen et al., 2005), and, in samples of sexual offenders, those who offended against children are typically older than those who offended against adults (e.g., Gebhard et al., 1965). The groups used here, however, matched in age, and the finding of low white matter volume emerged nonetheless.

Also limiting the plausibility of this interpretation is the accumulating evidence that pedophilic men neuroanatomically differ from nonpedophilic men early in life: For example, handedness preferences are exhibited *in utero* (Hepper et al., 1991, 2005), and the odds of non-right-handedness are three times higher in pedophilic than in nonpedophilic men (Cantor et al., 2004, 2005b). Although one might hypothesize behaviors of adulthood that could plausibly reduce white matter volumes in the noted fiber bundles, it is more difficult (although still possible) to hypothesize what behaviors that a pre-pedophilic infant or fetus might exhibit that would do so.

4.3.2. "Third variable" explanations and potential confounds

A correlation between pedophilia and white matter volume could also emerge from some variable that causes pedophilia and independently causes low white matter volume. For example, it is plausible that pedophilic men were exposed *in utero* to some teratogenic substance or pathogen that interfered with the development of white matter and interfered with the development of sexual interests (but that neither of these two sequelae caused the other). If such a scenario is correct, then pedophilia would be caused by differences in brain structure other than those that were found here, or pedophilia would not be caused by differences in brain structure at all.

The other third-variable explanation of these data is that the pedophilic and nonpedophilic subjects differed on one or more confounding characteristics and that the low white matter volume is associated with that confound rather than with pedophilia itself. As already mentioned, some potential confounds can be ruled out: Age, IQ, handedness, education, and socioeconomic variables were all equivalent between the patients and the controls in this study, and, in the case of alcohol, it was the control group that consumed more. Because the control sample in this study was composed of men who had committed nonsexual crimes (instead of healthy men without any criminal history), the results are not easily attributable to histories of chronic stress or to general criminality.

Also arguing against stress and general criminality as an explanation of these results is that none of the brain areas thus far reported to relate to those characteristics emerged in the present data. Meta-analytic reviews have shown chronic stress to be reflected in smaller volumes of the hippocampus, frontal lobe grey matter, and the corpus callosum (Bremner and Narayan, 1998; Karl et al., 2006; McEwen, 2001), but no effects were observed in those areas, despite that the present samples were larger than the samples used in those studies. Although no neuroanatomical differences have been reported among general criminals, such as those in the control group used here, men with antisocial personality disorder or psychopathy have been reported to have less grey matter volume in prefrontal regions (Raine et al., 2000; Yang et al., 2005) and in the hippocampus (Laakso et al., 2001) and greater white matter volume in the corpus callosum (Raine et al., 2003). It is not known whether it is merely coincidental that the neuroanatomic differences associated with chronic stress pertain to the same brain regions as the neuroanatomic differences associated with antisociality or whether there is a more important association among them. Although none of these areas associated with stress or antisociality appeared relevant to the present results, these factors could be more conclusively excluded as an explanation by future studies of pedophilic men that use multiple control groups: a nonsexual offender control group (like the one used here) and a group of healthy men with no criminal history.

Because this study is necessarily correlational in nature, there may yet exist some variable, still unaccounted for, that could explain the group differences in white matter volume. Such a confound would exist if (1) the subjects systematically differed in some remaining characteristic and if (2) that characteristic were significantly related to white matter volume deficits in large brain regions. Although one can postulate many characteristics that could differ between these groups or could relate to wide ranging deficits in white matter volume, it is more difficult to imagine one that could do both; nonetheless, this always remains a possibility in studies in which it is not possible to randomly assign cases.

4.3.3. Low white matter causes pedophilia

The most straightforward explanation of the present results is that low white matter volumes increase the risk of developing pedophilia. We have previously hypothesized that pedophilia results from some perturbation of early neurodevelopment that causes a constellation of symptoms that includes pedophilia and aforementioned neuropsychological characteristics (Blanchard et al., 2002), such as low IQ and elevated rates of non-right-handedness (e.g., Cantor et al., 2004). Although this is the most parsimonious interpretation, it invites one to ask how low volumes of the superior fronto-occipital fasciculus and right arcuate fasciculus might alter sexual interests.

As mentioned in Section 1, prior hypotheses regarding neuroanatomic substrates of pedophilia—the Frontal-Dysexecutive Theories, Temporal-Limbic Theories, and Dual Dysfunction Theories—all pertained to dysfunction of grey matter structures. These theories each presume that some individual cluster of neuronal cell bodies is damaged or underdeveloped and thus unable to produce signals sufficient to cause normal sexual interests (or to suppress abnormal sexual interests). The present white matter findings, however, suggest that the neuroanatomic component to pedophilia may instead be an insufficiency of connectivity among a set of topographically disparate brain regions. This would suggest for pedophilia what has previously been suggested for schizophrenia and mood disorders: "It is becoming increasingly evident that a lesion model is inappropriate and that a more relevant characterisation will be found in terms of disorders of functional interconnections between brain regions" (Frith and Dolan, 1998, p. 259).

Functional imaging studies of healthy (nonpedophilic) men have repeatedly identified a set of grey matter regions that consistently respond to sexual stimuli; of these, the cortical regions include (a) medial and middle frontal cortex (Ferretti et al., 2005; Garavan et al., 2000; Gizewski et al., 2006; Karama et al., 2002; Montorsi et al., 2003; Rauch et al., 1999), (b) insula (Garavan et al., 2000; Gizewski et al., 2006; Karama et al., 2002; Moulier et al., 2006; Park et al., 2001; Stoléru et al., 1999), (c) superior and inferior parietal lobules (Beauregard et al., 2001; Bocher et al., 2001; Ferretti et al., 2005; Moulier et al., 2006; Mouras et al., 2003; Ponseti et al., 2006; Rauch et al., 1999; Redouté et al., 2000; Stoléru et al., 2003), (d) visual cortex (Beauregard et al., 2001; Bocher et al., 2001; Moulier et al., 2006; Mouras et al., 2003; Park et al., 2001; Ponseti et al., 2006), (e) inferior temporal cortex (Beauregard et al., 2001; Ferretti et al., 2005; Karama et al., 2002; Montorsi et al., 2003; Moulier et al., 2006; Park et al., 2001; Stoléru et al., 1999, 2003; Yang, 2004), and (f) the fusiform gyrus (Bocher et al., 2001; Ferretti et al., 2005; Gizewski et al., 2006; Karama et al., 2002; Moulier et al., 2006; Rauch et al., 1999; Stoléru et al., 2003). The grey matter regions identified by those functional imaging studies are all connected through the two white matter regions identified here: The superior fronto-occipital fasciculus runs posteriorly from frontal cortex, extending to the insula where it bifurcates to the parietal lobules and to visual cortex (Catani et al., 2002; Jellison et al., 2004; Wakana et al., 2004), and the second white matter region we identified extended from the fusiform and inferior temporal gyri following the arcuate fasciculus to the parietal operculum. Thus, the present white matter findings would support the notion that the cortical regions that respond to visual sexual stimuli operate together to appraise environmental stimuli as sexually relevant (Stoléru et al., 1999, 2003; Redouté et al., 2000).[3] That is, the superior fronto-occipital and arcuate fasciculi may be the pathways through which the cortical regions coordinate their responses. If true, then the lower volumes of those fiber bundles suggest that pedophilia may result from disconnection (or insufficient connection) among the components of this hypothesized sexual recognition system.

The preceding discussion referred to neuropathology as a simple cause of pedophilia; however, it is also possible that the neuroanatomic features seen here instead produce a susceptibility to developing pedophilia, possibly interacting with other factors. Such an other factor could be childhood sexual abuse. In long-term follow-up studies, victims of childhood sexual abuse are at an elevated likelihood to commit sexual offenses in adulthood, but only a small proportion of them does (e.g., Salter et al., 2003; Widom and Ames, 1994). It is feasible that among victims of childhood sexual abuse, the ones who are most likely to develop sexual interests in children are those who also have deficiencies of white matter volume.

Regardless of whether white matter deficiencies produce pedophilia or a susceptibility to it, the present results suggest the need to pursue what causes the white matter deficiencies. If the problem is a controllable factor, such as a

[3] It is likely premature to make any final list of which cortical regions compose this hypothesized sexual recognition system. For example, although Stoléru et al. (in press) included orbitofrontal cortex in that system, the more recently available imaging studies have more frequently implicated middle frontal cortex (Ferretti et al., 2005; Garavan et al., 2000; Gizewski et al., 2006; Montorsi et al., 2003).

teratogenic substance in the environment, then there may exist a method of preventing that factor and, thereby, reducing the occurrence of pedophilia. It is also possible, however, that the neuroanatomic factors identified here are the result, not of a pathological process, but of expectable variation. That is, one would expect that, within any healthy population, some individuals would have greater white matter volumes than other individuals; pedophilic men may have undergone normal neurodevelopment but fallen at the low end of the distribution, increasing their risk of developing pedophilia. Thus, the associations observed here might have emerged because men with naturally occurring low white matter volume were more likely to have developed pedophilia and been recruited into this study.

4.4. Suggestions for future research

These findings invite one to ask how these structural differences might affect brain function: It is possible that pedophilic brains respond the same way as do nonpedophilic brains—but when exposed to depictions of children instead of adults—and it is possible that different structures (or a partially different set of structures) respond. Walter et al. (2007) exposed 13 pedophilic men and 14 healthy men to photographs of adult women (but not to photographs of children), finding that the pedophiles responded less strongly than controls did in three regions: the dorsolateral prefrontal cortex, hypothalamus, and dorsal midbrain/periaquaductal grey. To ascertain whether the same structures respond in pedophilic and nonpedophilic brains, future investigators will need to employ designs in which each patient type is exposed to each stimulus type.

White matter abnormalities have already been implicated in several psychiatric disorders, including bipolar disorder, obsessive–compulsive disorder, and schizophrenia (e.g., Bruno et al., 2004; Pol et al., 2004; Szeszko et al., 2005). Thus, the present results suggest that pedophilia may be one of many behavioral disorders characterized by aberrant connectivity. The present results therefore suggest the need for studies using imaging technologies that are well-suited to capturing features particular to white matter tissue. Diffusion tensor imaging of the white matter regions would verify our identification of the relevant fiber tracts and the cortical regions to which they project. An fMRI study of the effective connectivity of the relevant grey matter regions would clarify which regions constitute the hypothesized sexual appraisal system. The hypothesis we offered here—that pedophilia results from inadequate connectivity among those components—predicts that the levels of activity in those regions would intercorrelate less strongly among pedophilic than among control men. Finally, the patient group studied here was pedophilic; because pedophilia is one of several paraphilias, it remains possible that our findings pertain to the more general category. Future studies that include both men with pedophilia and men with nonpedophilic paraphilias (such as fetishism) might serve to elucidate to which entity the present results apply.

Conflict of interest

None of the authors has any actual or potential conflict of interest, any financial or personal relationships with any organization or person that could inappropriately influence or be perceived to influence their work.

Contributors

Authors Cantor and Christensen initiated and designed the study. Authors Cantor and Blanchard wrote the introduction and results sections of the manuscript. Authors Dickey, Klassen, and Barbaree contributed to the literature searches and discussion sections of the manuscript. Authors Kuban and Blak contributed to the methods sections pertaining to phallometric and sexological data collection. Authors Richards and Hanratty conducted the voxel-based morphometry analyses, produced the figures, and contributed to the methods sections of the manuscript pertaining to preprocessing and VBM. Author Mikulis developed the imaging protocols. Author Kabani conducted the anatomical identifications and contributed to the future directions portion of the discussion. All authors have approved the final manuscript.

Acknowledgement

This research was funded by grant 94205 from the Canadian Institutes for Health Research (CIHR) awarded to Ray Blanchard. CIHR had no further role in this study's design; in the collection, analysis, or interpretation of data; in the writing of this article; nor in the decision to submit this article for publication.

Portions of these results have been presented at the International Academy of Sex Research, Amsterdam, Netherlands (July 2006) and the Association for the Treatment of Sexual Abusers, Chicago (September 2006).

We are indebted to Gregory P. Brown, Elias Constantatos, Nanci Lipstein, Robert Small, and Hien Tran for their assistance in conducting this research.

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