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Reduced Prefrontal Cortical Gray Matter Volume in Young Adults Exposed to Harsh Corporal Punishment

Running title: Harsh Corporal Punishment

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ABSTRACT

Objective: Harsh corporal punishment (HCP) during childhood is a chronic, developmental stressor associated with depression, aggression and addictive behaviors. Exposure to traumatic stressors, such as sexual abuse, is associated with alteration in brain structure, but nothing is known about the potential neurobiological consequences of HCP. The aim of this study was to investigate whether HCP was associated with discernible alterations in gray matter volume (GMV) using voxel-based morphometry (VBM).

Methods: 1,455 young adults (18-25 years) were screened to identify 23 with exposure to HCP (minimum 3 years duration, 12 episodes per year, frequently involving objects) and 22 healthy controls. High-resolution T1-weighted MRI datasets were obtained using Siemens 3T trio scanner.

Results: GMV was reduced by 19.1% in the right medial frontal gyrus (medial prefrontal cortex; MPFC, BA10) ($P = 0.037$, corrected cluster level), by 14.5% in the left medial frontal gyrus (dorsolateral prefrontal cortex; DLPFC, BA 9) ($P = 0.015$, uncorrected cluster level) and by 16.9% in the right anterior cingulate gyrus (BA 24) ($P < 0.001$, uncorrected cluster level) of HCP subjects. There were significant correlations between GMV in these identified regions and performance IQ on the WAIS-III.

Conclusions: Exposing children to harsh HCP may have detrimental effects on trajectories of brain development. However, it is also conceivable that differences in prefrontal cortical development may increase risk of exposure to HCP.

Key Words: corporal punishment (CP), harsh corporal punishment (HCP), voxel-based morphometry (VBM), gray matter volume (GMV), medial prefrontal cortex (MPFC), dorsolateral prefrontal cortex (DLPFC), anterior cingulate gyrus (AC), MRPFC (medial rostral prefrontal cortex).

INTRODUCTION

Harsh physical discipline has been defined as "the use of physical force with the intention of causing a child to experience pain but not injury for the purpose of correction or control of the child's behavior" (Straus et al., 1997). However, such discipline (or its excessive use) has been considered as a type of child maltreatment and has been identified as having various negative psychological and physiological consequences. A history of exposure to severe corporal punishment (CP) is reportedly associated with aggression, delinquency (Gershoff, 2002), antisocial and violent behaviors (Ambati et al., 1998; Ohene et al., 2006; Slade and Wissow, 2004; Straus et al., 1997), depression (Banks, 2002; Straus and Kantor, 1994), suicidal behavior (Straus and Kantor, 1994), and other psychiatric disorders such as PTSD (Medina et al., 2001) and substance use disorders (Lau et al., 2005). Furthermore, CP is related to the intergenerational transmission of intimate partner and family violence (Deater-Deckard et al., 2003; Muller et al., 1995; Schwartz et al., 2006) and is associated with risk of being victim of physical abuse and risk of abusing own child or spouse, and decreased quality of family relationship and mental health (Gershoff, 2002). Moreover, a previous report on biological aspects has described significant alteration of the functioning of the hypothalamic-pituitary-adrenal axis in individuals exposed to harsh CP (HCP) (Bugental et al., 2003).

Exposure to various forms of childhood abuse, including physical abuse, sexual abuse and neglect have been associated with alterations in brain structure (e.g., (Andersen et al., 2008; Bremner et al., 1997; De Bellis et al., 1999; De Bellis et al., 2002; De Bellis and Kuchibhatla, 2006; Richert et al., 2006; Teicher et al., 2004; Teicher et al., 1997)). Diffusion tensor differences have also been observed in young adults with high-level exposure to parental verbal abuse (Choi et al., 2008).

Is exposure to parental HCP a sufficiently severe developmental stressor to be associated with discernible effects on brain morphometry? This study was designed to evaluate GMV using an unbiased, whole-brain, voxel-by-voxel approach in a non-clinical sample of late adolescents/young adults exposed to HCP during childhood. Our sample was screened to exclude extraneous factors (e.g., substance abuse, head injury, fetal drug exposure, exposure to physical, sexual or emotional abuse) that might have influenced brain development. Our hypothesis was that exposure to childhood HCP might alter the developmental trajectory of brain regions involved in regulating emotion, aggression, attention, and cognition.

PARTICIPANTS AND METHODS

1. Participants and procedure

The McLean Hospital Institutional Review Board approved all procedures. Participants in the study were recruited from the community through an advertisement entitled "Memories of Childhood". Screenings were conducted on 1,455 volunteers using a detailed online assessment instrument with 2342 entry fields that provided a vast array of information regarding childhood history, development, and symptomatology. The questionnaire also included demographic information, such as subjects' and parents' educational levels, annual household income, and race/ethnicity. In addition, a scale was included to assess subjects' perception of financial stress while they were growing up. Known as *'perceived financial sufficiency'* and based on a 5-point Likert scale, subjects rated their family's financial situation while growing up, which ranged from 1 (much less than enough money for our needs), to 5 (much more enough money for our needs). Subjects provided written informed consent prior to completing the online instrument, and again before interviews and imaging.

Eligible subjects were invited for two visits. The first visit constituted a face-to-face interview to elicit subjects' developmental history and history of psychiatric disorders using Structured Clinical Interviews for DSM-IV Axis I and II Disorders (SCID-I, II) (First et al., 1997). The second visit consisted of standardized psychometric testing such the Wechsler Adult Intelligence Scale III (WAIS-III) (Wechsler, 1997), the Woodcock-Johnson Test, and the Memory Assessment Scale (Golden et al., 1999). Finally, we recruited 45 individuals (23 subjects with CP and 22 controls) for MRI evaluation.

The CP group comprised 23 young adults (15 males, 8 females; mean age, 21.7 years, SD, 2.2 years) with a history of exposure to CP in early childhood (Table 1). The control group comprised 22 young adults (6 males, 16 females; mean age, 21.7 years; SD, 1.8 years) with neither a current nor past DSM-IV-TR Axis I disorder (based on the SCID-I) and with neither a history of abuse nor exposure to traumatic events or HCP. Excluded subjects were those who had any history of substance abuse, any recent substance use, head trauma with loss of consciousness, significant fetal exposure to alcohol or drugs, perinatal or neonatal complications, neurological disorders, or medical conditions that might adversely affect growth and development. All participants were right-handed and unmedicated. HCP and controls were matched as closely as possible for degree of alcohol and substance use.

2. Measure

2.1. Harsh Corporal punishment and other trauma

History of exposure to CP was obtained using the Life Experiences Questionnaire (LEQ) as part of the on-line assessment. The LEQ comprises 34 items that screen for exposure to traumatic events in general (e.g., witnessing gang violence, nearly drowning). Questions about parental CP are included in this questionnaire (e.g., "*Have you ever been punished with spankings from your parents' open hand*?" "*Have you ever been punished with spankings with a belt, paddle, or stick?*"). On interview, we were careful to exclude instances of physical abuse, emphasizing that CP had to occur specifically for discipline, with parents in emotional control, and not striking out in anger. All participants in the HCP group reported that CP began prior to their 12th birthday and lasted for a minimum of 3–5 years, with a frequency of about 12 episodes or more per year. Additionally, an object such as belt, strap, hairbrush, or paddle was used for punishment at least annually. HCP subjects must have experienced these punishments from a primary disciplinarian who was a custodial adult. Subjects in the control group were never struck with objects, and either had never received CP (64%) or had only moderate exposure.

History of exposure to no other forms of abuse were confirmed using the semi-structured Traumatic Antecedents Interview (Herman et al., 1989). Exposure to childhood verbal abuse was assessed with the Parental Verbal Aggression Scale (PVAS). Subjects with PVAS scores $\geq$

40, indicative of exposure to substantial and deleterious levels verbal abuse (Teicher et al., 2006), were excluded.

2.2. Psychiatric symptoms and well-being

Self-report ratings of dissociation, ‘limbic irritability’, depression, anxiety and anger-hostility were obtained using the Dissociative Experience Scale, (Bernstein and Putnam, 1986) limbic system checklist – 33 (LSCL-33) (Teicher et al., 1993), and Kellner’s Symptom Questionnaire (Kellner, 1987), respectively. Scores on these scales are elevated by exposure to other forms of childhood stress (Teicher et al., 2006), and have been found in previous studies to correlate with regional alterations in structure or function associated with maltreatment (Anderson et al., 2002; Choi et al., 2008). Hence, we used these ratings in an exploratory manner to delineate potential functional correlates of regions of reduced GMV.

3. MRI acquisition and analysis

Image analysis was performed on high-resolution T1-weighted MRI datasets, which were acquired on a Trio Scanner (3 T; Siemens AG). An inversion prepared 3D MPRAGE sequence was used with an eight-element phased-array RF reception coil (Siemens AG). The

GRAPPA acquisition and processing was used to reduce the scan time, with a GRAPPA factor of 2. Scan parameters were: the sagittal plane, TE/TR/TI/flip = 2.74 ms/2.1 s/1.1 s/12 deg; 3D matrix 256 x 256 x 128 on 256 x 256 x 170 mm field of view; bandwidth 48.6 kHz; scan time 4:56.

VBM was performed using SPM5 for imaging processing (MATLAB 6.5; The MathWorks Inc., Natick, MA, USA). As a fully automated whole-brain morphometric technique, VBM detects regional structural differences between groups on a voxel-by-voxel basis (Good et al., 2001a; Good et al., 2001b). Briefly, images were segmented into gray matter, white matter, cerebrospinal fluid, and skull/scalp compartments, then normalized to standard space and re-segmented. Any volume change that was induced by normalization was adjusted. The spatially normalized segments of gray and white matter were smoothed using a 12-mm full-width half-maximum isotropic Gaussian kernel. Statistical analysis of regional differences between groups was performed using a permutation test for decreased probability of a particular voxel containing gray or white matter. Potential confounding effects of age, gender, score on the PVAS, parental education, perceived financial sufficiency, and whole segment GMV were modeled. Variances attributable to them were excluded from analyses. The significance levels for statistics estimated by permutation tests were set at $P = 0.05$, corrected for multiple comparisons.

4. Statistical analysis

Significant sociodemographic differences between HCP and control group complicated the exploration of post-hoc functional correlates between VBM identified regions with significantly reduced GMV, and symptom ratings and IQ measures. Hence, multiple regression analysis was used to assess whether there were statistically significant associations (standardized beta weights and overall r-value) between GMV in identified regions and ratings, taking into account differences attributable to gender, parental education and perceived financial sufficiency. Multiple regression analysis was performed on the entire sample, as there were no significant group differences on most measures of interest. When a significant association was found, we also ascertained whether it was present in the HCP group alone, to help assure that the relationship was not an artifact of group differences. This approach reduced the number of cross-correlations examined by a factor of three. A multiple regression r value $\leq$ 0.01 was required for significance, to compensate for the number of tested associations. Statistical analyses were performed using SPSS statistical software (SPSS Inc., Chicago, IL).

RESULTS

HCP subjects reported mean duration of exposure to CP of 8.5 ± 3.5 years versus 1.8 ± 3.0 years for controls. Average age of onset and offset of CP in the HCP group was 3.9 ± 2.3 and 11.4 ± 2.5 years, respectively. HCP began almost concurrently with CP (4.2 ± 2.3 years). Subjects in the HCP group were predominantly male (65%), whereas controls were predominantly female (73%; Table I). Parents of HCP subjects had, on average, two years less education than parents of controls ($P = 0.004$), and HCP subjects experienced a somewhat greater degree of financial stress growing up ($P = 0.01$). HCP subjects were exposed to significantly higher levels of parental verbal aggression than controls ($P < 0.0001$), though no subjects were exposed to levels that we had previously defined as abusive (Choi et al., 2008; Teicher et al., 2006). Differences in gender ratio, parental education, perceived financial stress and exposure to parental verbal aggression were controlled for in subsequent analyses. HCP and control subjects did not differ in years of formal education. Control subjects had superior verbal IQ scores, which were about 10 points higher than in subjects with HCP ($P = 0.058$). There were no differences between groups in performance IQ (PIQ) or symptom ratings, except for 'contendedness' (5.8 ± 0.7 vs 5.0 ± 1.1; $F = 7.13$, df = 1,42, $P = 0.01$), which is a wellness item indicating freedom from depression and ability to experience happiness, joy and satisfaction.

The most prominent finding was a significant reduction in GMV in the right medial frontal gyrus (medial prefrontal cortex, MPFC) in individuals exposed to CP (BA 10; Talairach's coordinates x= 14, y= 47, z= 1, cluster size = 402, P = 0.037, corrected cluster level) (Fig. 1). A 19.1% lower average GMV was found in these regions of the CP subjects than in healthy controls.

Using lower criteria for statistical significance revealed 14.5% reduction in GMV in the left medial frontal gyrus (dorsolateral prefrontal cortex; DLPFC) (BA 9; Talairach's coordinates x= –10, y= 40, z= 20, cluster size = 283, P = 0.015, uncorrected cluster level) and 16.9% reduction in GMV in the right anterior cingulate gyrus (BA 24; Talairach's coordinates x= 10, y= 30, z= 15, cluster size = 124, $P < 0.001$, uncorrected voxel level). No other areas of reduction were found with a corrected cluster probability value that approached significance.

No significant correlations emerged between the GMV in those regions and symptom ratings (all $P > 0.10$). However, multiple regression analysis revealed that GMV in these identified regions was significantly correlated with PIQ on the WAIS-III (Table II). Overall, there was a 0.634 correlation between GMV and covariates of interest and PIQ for the entire group of subjects (n=45). There was also a significant correlation within the HCP (r = 0.754) group alone. As indicated in Table II, there were strong reciprocal correlations between GMV in right BA 10 region and left BA 9 and PIQ. Overall, there was a direct correlation between GMV in left BA9, and an inverse correlation between right BA10, and PIQ.

DISCUSSION

Results show that chronic exposure to childhood HCP was associated with a marked reduction in GMV in the right medial frontal gyrus (MPFC, BA10). There were also possible associations between HCP and reduced GMV in left medial frontal gyrus (DLPFC, BA 9) and the right anterior cingulate gyrus (BA 24). Other imaging studies have found those regions to be involved in aspects of addiction (Crockford et al., 2005; Drexler et al., 2000), suicidal behavior and/or depression (Bar et al., 2007; Liotti and Mayberg, 2001; Raust et al., 2007), post-traumatic stress disorder (PTSD) (Bremner, 2003; Fennema-Notestine et al., 2002; Geuze et al., 2007; Hou et al., 2007; Liberzon et al., 2003), dissociative disorders (Veltman et al., 2005), and depression (Fitzgerald et al., 2008). HCP may be an aversive and stressful event for human beings that potentially alters the developmental trajectory of some brain regions in which abnormalities have been associated with major forms of psychopathology.

The regions identified with reduced GMV are part of the medial rostral prefrontal cortex

(MRPFC). Recent studies have pointed to the MRPFC as a region of the human brain that plays a crucial role in social cognition as well as functional organization (Amodio and Frith, 2006; Gilbert et al., 2007). In particular, medial BA10 and BA32 appear to be involved with *self-knowledge, person perception and mentalizing* (Amodio and Frith, 2006). At its most basic level, *self-knowledge* involves the ability to differentiate the self from other objects and to recognize attributes and preferences related to oneself. The ability to represent another person's psychological perspective is referred to as *mentalizing*, and this capacity allows us to predict the behavior of others. *Person perception* involves judgments about the attributes and behaviors of others. BA24, in contrast appears to be involved in the internal monitoring of our actions to ensure that they are consistent with intentions and the current situational context (Amodio and Frith, 2006). The more posterior portion of the MRPFC (primarily BA 8 and 9) is activated by cognitive tasks, such as those designed to engage action monitoring and attention. For example, left BA9 is activated in young adults during working memory retrieval tasks (Sun et al., 2005).

It is interesting that individuals exposed to high levels of HCP had reduced GMV in right BA10 and possibly in right BA24. HCP is administered ostensibly to correct behavior. Children may increase their risk of exposure to CP, or HCP, if they have an inadequate ability to internally monitoring their own actions (BA 24), or if they have deficits in self-perception, person perception, or mentalizing (BA 10). Being able to predict how parents will react, and being able infer their parents' state of mind is probably quite adaptive. Hence, it is conceivable that differences observed in regional GMV were preexisting abnormalities that increased their risk of exposure to HCP. However, exposure to CP began at about 3.9 years of age, when prefrontal cortex is quite immature. BA10 has a particularly protracted pattern of dendritic development (Travis et al., 2005), and medial prefrontal cortex and other components of the 'social brain' undergo structural development, including synaptic reorganization, during adolescence (Blakemore, 2008). Nevertheless, this region of the brain is not quiescent during early development, as episodic memory and episodic future thinking (which requires involvement of medial prefrontal cortex) emerges at about 4 years of age (Weiler and Daum, 2008). It is perhaps most reasonable to assume that the use of CP or HCP for disciplining of young children is strongly dictated by parental experience and beliefs. However, continuing development of MRPFC regions may make it easier for a child to avoid exposure to physical punishment.

Conversely, exposure to HCP may have attenuated development of these regions. It is conceivable that exposure to HCP produced conflicts in perception and self-monitoring that were difficult to reconcile, and these conflicts attenuated or suppressed development. For example, it may be challenging to integrate perceptions of a parental figure as caring and loving on one hand, and critical and intentionally hurtful on the other. Similarly, there may be a disconnect between a child's self-monitored impression that he did not do much if anything wrong, versus a parental judgment that he needed to be severely punished for his mistakes. In short, HCP may create a mismatch between internal and external perceptions of one's actions or one's beliefs about others. In doing so, it may attenuate or arrest important components of social cognition.

It is interesting that left BA9 GMV was positively correlated with PIQ, while right BA10 was negatively correlated. GMV in BA9 and BA10 were found in a previous study to be two cortical regions most strongly associated with general intelligence (Haier et al., 2005). However, there were substantial gender differences in that study, with BA9 showing a greater correlation in males, and BA10 correlating more significantly in females. As seen in Table II, gender did not significantly affect associations in the present study. The observation that GMV in right BA10 was negatively correlated with PIQ was confusing, but understandable, as IQ may relate even more strongly to white matter volume (or gray/white matter ratio) in BA10 than to GMV alone (Haier et al., 2005).

VBM studies provided an unbiased, even-handed, assessment of regional alterations in GMV. However, these studies have a significant number of limitations. Care was taken to make sure that there were no issues with alignment. Subjects in the two groups were of almost identical age, and selected from a narrow age range to minimize any potential developmental differences in template registration. All subjects were scanned on the same machine over the same time-period. Unfortunately, there were significant differences between groups in gender ratio, parental education level and perceived financial stress, which can independently affect brain development. These factors were controlled for statistically, but these findings will need to be confirmed in samples that are better matched for gender and sociodemographic variables. Our primary concern in this study was to equate the two groups for degree of drug and alcohol use. Although no subject in the study had a history of drug or alcohol abuse, we found that subjects exposed to HCP used these substances to a much greater extent than controls recruited for other studies. The primary finding of reduced GMV in right MPFC was observed with corrected $P < 0.05$. Additional findings of reduced GMV in left DLPFC and right ACC were found to be highly significant at the uncorrected cluster level. There is no guarantee that these were not false-positive results or that all relevant brain areas were identified.

Neurobiological research on the effects of early stress has the potential to recast our thinking about the role of early experience in the development of psychopathology (e.g. (Teicher et al., 2002; Teicher et al., 2003)). HCP or excessive CP have been found to be associated with emergence of depression, addiction and aggressive behaviors (Ambati et al., 1998; Banks, 2002; Deater-Deckard et al., 2003; Gershoff, 2002; Lau et al., 2005; Muller et al., 1995; Ohene et al., 2006; Schwartz et al., 2006; Slade and Wissow, 2004; Straus and Kantor, 1994; Straus et al., 1997). These associations may be viewed in a new light, if it turns out to be true that HCP attenuates the development of brain regions crucial for self-knowledge, person perception, mentalizing, and internal monitoring of our actions. Results from this study raise the possibility that exposure to HCP acts as a chronic sub-traumatic stressor that alters the developmental trajectory of MRPFC. If so, it underscores efforts to prevent children from receiving CP or HCP from parents or other adults. It should be emphasized that CP received by these subjects was excessive. It involved more than open hand slaps to the buttocks, and in all cases persisted past their 6th birthday. How detrimental (or beneficial) spanking is depends a great deal on the age of the subject, frequency of administration, race, who administers the spanking, family context, and whether it is used as a primary means of discipline, or as a 'backup' strategy (Gunnoe and Mariner, 1997; Larzelere, 1996; Larzelere and Kuhn, 2005). These findings do not necessarily generalize to milder, less frequent, and less persistent episodes of spanking ending before age 6. Further, we must emphasize again the possibility that reduced GMV in the identified regions may have been a risk factor for persistence (or escalation) of CP, rather than a consequence of exposure. Prospective longitudinal studies will be required to validate and untangle the nature of the relationship.

FIGURE LEGENDS

Fig. 1. Significant differences between corporal punishment (CP) subjects and controls. Significantly lower gray-matter densities in CP subjects were measured in the right medial frontal gyrus (medial prefrontal cortex, BA10). Crosshairs placed at $x= 14$, $y= 47$, $z= 1$, the right medial prefrontal cortex. Color scale: 0–5 represent t-values.

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4. Table

Table I. Demographics and subject characteristics for VBM Comparisons

Measures	Healthy Controls	Harsh Corporal Punishment	ANOVA F-value	p-value
Subjects	22	23		
Male/Female	6M/16F	15M/8F	Fisher Exact	0.017
Age	21.68±1.84	21.74±2.22	0.009	0.925
Parental Education (yrs)	16.48±2.24	14.39±2.37	9.179	0.004
Financial Sufficiency	3.64±0.66	3.09±0.73	6.977	0.01
Parental Verbal Aggression	11.23±5.82	23.2±11.64	18.773	<0.0001
Education (yrs)[a]	13.89±1.60	14.23±1.53	0.965	0.323
Verbal IQ[b]	127.6±14.7	117.7±14.9	3.821	0.058
Performance IQ[b]	118.7±10.2	119.5±12.6	0.041	0.841

[a]ANCOVA with age and gender as covariates

Table II. Multiple regression analysis between prefrontal cortex gray matter volume and performance IQ scores.

	All Subjects		HCP Only		Controls Only	
Independent Variables	Beta	*P*-value	Beta	*P*-value	Beta	*P*-value
Right Medial PFC (BA 10)	-1.89	<0.001	-1.386	0.007	-2.054	0.026
Left dorsolateral PFC (BA 9)	1.745	0.002	1.277	0.018	0.779	NS
Right Anterior Cingulate (BA 24)	0.307	NS	0.453	NS	1.261	NS
Gender	0.03	NS	-0.023	NS	0.005	NS
Parental education	0.054	NS	-0.245	NS	0.227	NS
Financial sufficiency	-0.113	NS	0.262	NS	-0.507	NS
r value	0.634	0.006	0.752	0.04	0.65	NS

5. Figure
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