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Patterns of Cortical Thinning in Relation to Event-Based Prospective Memory Performance Three Months after Moderate to Severe Traumatic Brain Injury in Children

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Abstract

While event-based prospective memory (EB-PM) tasks are a familiar part of daily life for children, currently no data exists concerning the relation between EB-PM performance and brain volumetrics after traumatic brain injury (TBI). This study investigated EB-PM in children (7 to 17 years) with moderate to severe TBI or orthopedic injuries. Participants performed an EB-PM task and concurrently underwent neuroimaging at three months postinjury. Surface reconstruction and cortical thickness analysis were performed using FreeSurfer software. Cortical thickness was

significantly correlated with EB-PM (adjusting for age). Significant thinning in the left (dorsolateral and inferior prefrontal cortex, anterior and posterior cingulate, temporal lobe, fusiform and parahippocampal gyri), and right hemispheres (dorsolateral, inferior, and medial prefrontal cortex, cingulate, and temporal lobe) correlated positively and significantly with EB-PM performance; findings are comparable to those of functional neuroimaging and lesion studies of EB-PM.

Keywords

Event-based prospective memory; Traumatic brain injury; FreeSurfer; Volumetrics; Cortical thinning; Pediatrics

Prospective memory (PM) is the ability to form an intention to perform a specific action and to remember later to perform this action. For effective PM performance, one must (in response to an external cue) activate self-initiated processes directed toward recognizing the cue, retrieve the associated delayed intention, and successfully execute it in a timely manner. Examples of PM tasks include giving a school permission slip or report card to a parent to sign, or passing a note to a friend or teacher the next time he/she is seen (Herrmann, Brubaker, Yoder, Sheets, & Tio, 1999). These are everyday examples of event-based PM (EB-PM) tasks in which one remembers to perform an intended action in response to a certain target event (Einstein & McDaniel, 1990, 1996). A child's day is replete with tasks they have to remember to fulfill and, similarly for adults, PM is considered a fundamental ability to effectively handle challenges of daily life (Harris, 1984; Meacham & Dumitru, 1976; Meacham & Leiman, 1982; Wilkins & Baddeley, 1978; Winograd, 1988).

In stark contrast to the number of studies of the effects of traumatic brain injury (TBI) on PM in adults (Cockburn, 1995; Fortin, Godbout, & Braun, 2002; Groot, Wilson, Evans, & Watson, 2002; Hannon, Adams, Harrington, Fries-Dias, & Gipson, 1995; Henry, et al., 2007; Kinsella, et al., 1996; Kliegel, Eschen, & Thöne-Otto, 2004; Knight, Harnett, & Titov, 2005; Knight, Titov, & Crawford, 2006; Louda, Loseva, & Mielke, 2007; Mathias & Mansfield, 2005; Roche, Fleming, & Shum, 2002; Roche, Moody, Szabo, Fleming, & Shum, 2007; Shum, Valentine, & Cutmore, 1999), few have been conducted involving children with TBI (McCauley & Levin, 2004; McCauley, McDaniel, Pedroza, Chapman, & Levin, 2009; Ward, Shum, Dick, McKinlay, & Baker-Tweney, 2004; Ward, Shum, McKinlay, Baker, & Wallace, 2007). Of these studies, three used experimental procedures involving EB-PM tasks (forming and carrying out an intention to make a specific response to an external cue) analogous to what one would encounter in everyday life revealing that children with TBI demonstrated impaired PM functioning relative to orthopedically-injured controls (McCauley & Levin, 2004; McCauley, McDaniel, Pedroza, Chapman, & Levin, 2009) and typically-developing children (Ward, Shum, McKinlay, Baker, & Wallace, 2007). McCauley and colleagues (2009) have recently reported that children 1-15 years following severe TBI performed more poorly on a naturalistic measure of EB-PM task than children with orthopedic injuries, and that the use of monetary incentives significantly improved EB-PM performance in these children irrespective of injury severity. Although brain-behavior relations are well-known in terms of episodic memory in children with TBI (Anderson & Catroppa, 2007; Catroppa & Anderson, 2002; Catroppa, Anderson, Ditchfield, & Coleman, 2008; Di Stefano, et al., 2000; Donders, 1993; Donders & Hoffman, 2002; Lowther & Mayfield, 2004; Roman, et al., 1998; Salorio, et al., 2005), no corresponding neuroimaging data currently exists with regard to PM functioning in these children.

Neuroimaging Findings

Investigations of the neural substrates of PM in healthy adults have been conducted in a number of different experimental paradigms and imaging modalities including positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). Additionally, studies of clinical populations correlating lesion analyses with PM performance have provided insight into the neuropsychology of PM. Results from these studies elucidating the functional neuroanatomy of PM will be briefly reviewed and consolidated.

Positron Emission Tomography

Okuda and colleagues (1998) were one of the first to describe the distributed neural networks underlying PM using PET scans of participants who were required to tap their left hand when reading aloud PM target words while performing an ongoing task of orally recalling a previously-presented set of words. Analyses of regional cerebral blood flow (rCBF) increases (PM task - ongoing task) indicated significant activations in the right dorsolateral prefrontal cortex, right ventrolateral prefrontal cortex, left frontal pole, left anterior cingulate gyrus, medial frontal lobes, and left parahippocampal gyrus. Given that the areas of activation resulted from the contrast of PM versus the ongoing encoding and recall of words (word repetition task), these areas were primarily involved in the maintenance of the future intention, but were also related to increased demands of working memory (dorsolateral prefrontal cortex), maintenance of an intention (frontal pole and right ventrolateral inferior frontal), attentional control (medial frontal), and novelty detection (left parahippocampal gyrus). Burgess et al. (2001) found that increased activations in the bilateral frontal poles, right dorsolateral prefrontal and inferior parietal/precuneus, and decreased activations in the left frontotemporal regions were associated with PM performance. The significance of activations in the right dorsolateral prefrontal cortex and parietal/precuneus region were considered responses to anticipatory processes and visual maintenance of the PM response, respectively. Burgess and his colleagues (2003) later reported that the functions of the medial and lateral frontal pole differ as medial aspects demonstrated decreased activation while lateral aspects demonstrated increased activation during the execution of a PM task; they speculated that the medial area suppresses internally-generated thought while the lateral area maintains it. Finally, Okuda et al. (2007) found that activations in the bilateral frontal poles, left lingual gyrus, right rectus and anterior cingulate gyri were significantly related to PM task performance in rCBF contrasts with the ongoing task.

Functional Magnetic Resonance Imaging

To date, only three studies using fMRI in PM have been reported. In 2006, Simons et al. attempted to determine whether or not neural systems involved in PM cue identification and intention retrieval were substantially overlapping. Their findings supported those of Burgess (2003) suggesting a medial versus lateral functional specificity in the frontal poles; however, in contrast to the Burgess et al. study, Simons found that the functional dichotomy was accentuated under high intention retrieval demand. Brain regions associated with PM cue identification included bilateral (frontal poles, inferior frontal gyri, insula cortex) and right hemisphere areas (parietal/precuneus and the angular gyrus). Intention retrieval was associated with activations in bilateral (frontal poles, precentral gyri, insula, inferior parietal cortex) and right (medial, middle, and superior frontal gyri, precuneus) hemisphere. Eschen et al. (2007) studied the question as to whether or not motor brain regions are involved in PM functioning. They contrasted verbal encoding for to-be-enacted versus to-be-recalled action phrases and found that areas involved in preparatory motor movements (all in the left hemisphere: dorsal and ventral premotor cortices including the supplementary motor cortex,

postcentral gyrus, precuneus/inferior parietal, and posterior middle temporal regions) were activated. Finally, in a recent study to determine the relative contributions of sustained (occurring throughout the PM task, e.g. strategic monitoring and active maintenance of working memory) and transient (occurring in response to PM cues, e.g., intention retrieval) processes in PM (Reynolds, West, & Braver, 2009), areas of activation related to sustained response to the EB-PM task included bilateral medial superior frontal cortex, lateral parietal cortex, anterior cingulate, and left dorsolateral prefrontal cortex (e.g., middle frontal gyrus). Interestingly, areas producing transient increases specifically to the PM cue were found in the right middle temporal lobe which could not be attributable to other low-frequency events (e.g., oddball task targets).

Lesion Studies

Although some studies have been conducted evaluating the relation between brain lesions and time-based PM (remembering to perform an action at a certain time or after a specific period of time has elapsed), the focus here will be limited to those relating to EB-PM specifically. Further, studies investigating PM functioning in groups defined only by etiology without regard to specific brain regions (e.g., patients with TBI, parkinsonism, dementia) were not reviewed. In a consecutive series of patients of mixed etiology (mostly tumors, but also including stroke and TBI), a series of tasks involved in multitasking were administered; Burgess et al. (2000) reported that PM was impaired in patients having circumscribed lesions in the posterior cingulate and superior frontal cortex and frontal pole. In a comparison of patients following either left anterior temporal lobectomy (LATL) or anterior communicating artery aneurysm (ACoA) repair, patients with LATL were impaired on measures of both retrospective memory (RM) and PM while ACoA patients were impaired on PM functioning only (Palmer & McDonald, 2000). These results highlight the role of medial prefrontal structures in PM as separate from RM processes. Patients with dorsolateral prefrontal lesions (of mixed etiologies) were found to be impaired on naturalistic PM tasks compared to normal controls, but not at a level significantly different from patients with mixed-etiology posterior brain lesions (Daum & Mayes, 2000). Cheng and colleagues (Cheng, Wang, Xi, Niu, & Fu, 2008) found in their sample of patients with prefrontal lesions of mixed etiology that patients performed poorly on measures of EB-PM compared to controls, did not differ from controls on measures of RM, and finally that there were no EB-PM performance differences when patients were compared based on lesion laterality. A case report (Daum & Ackermann, 1994) of ischemic damage in the right anterior thalamus resulted in symptoms of poor visual RM and PM which raises the possibility of subcortical-frontal connections playing a role in PM functioning.

In summary, previous neuroimaging studies have found structures including right middle and inferior prefrontal, parietal/precuneus, bilateral frontal poles and cingulate, left middle and inferior prefrontal, and middle temporal and parahippocampal gyri to be important areas subserving PM functioning. Lesion studies, although less specific in terms of implicating discrete brain regions or specific etiologies, have supported the view that damage to the medial prefrontal, temporal cortex, and even the thalamus (Burgess, et al., 2003; Daum & Ackermann, 1994) impairs PM functioning. In spite of a considerable knowledge base regarding interconnected neural networks involved in PM in healthy individuals, no studies to date have explored the relation between PM performance and neuropathological changes following TBI in children. To address this gap, we have investigated EB-PM in children and adolescents with moderate to severe TBI and concurrent magnetic resonance imaging (MRI) at three months postinjury in a *prospective* cohort using the same experimental methodology as that of McCauley et al. (2009). We had four main hypotheses: 1) the EB-PM performance of children with moderate to severe TBI will be significantly below that of children with orthopedic injuries (OI); 2) consistent with the neuropathology of TBI, significant cortical

thinning will be evident in the frontal and temporal lobes of children with TBI; 3) these areas of cortical thinning will be related significantly to EB-PM performance; and 4) the pattern of significant brain-behavior findings will be consistent with that of previous functional neuroimaging and lesion studies.

Method

Participants

Informed consent was obtained from the parent/guardian through a procedure and consent form approved by the Institutional Review Boards of Baylor College of Medicine, the University of Texas at Dallas, the University of Texas Southwestern Medical Center, and the University of Miami School of Medicine. Child assent was obtained in accordance with federal regulations (45 CFR 46.404). Participants were prospectively recruited from level-1 trauma centers in Houston, Dallas, and Miami as part of a longitudinal study of neurobehavioral outcome following TBI.

TBI severity was determined through the lowest postresuscitation Glasgow Coma Scale (GCS) score (Teasdale & Jennett, 1974) in the first 24 hours postinjury. This sample included children and adolescents ranging in age (at injury) from 7 to 17 years: 40 children with moderate to severe TBI (post-resuscitation GCS ≤ 12 irrespective of computed tomography [CT] results or post-resuscitation GCS 13-15 with trauma-related intracranial abnormalities on CT scan of the head at hospital admission (Williams, Levin, & Eisenberg, 1990), and 41 children who sustained orthopedic injuries (OI) not involving the head (e.g., broken bones, fractures, etc.) requiring emergency room treatment. The OI participants had mild to moderate injuries as defined by the Abbreviated Injury Scale (Committee on Injury Scaling, 1990). Children with OI were specifically included in this study to control for risk factors predisposing children to traumatic injury and to equate for nonspecific factors associated with trauma and hospitalization. All participants were fluent in English, full-term births (i.e., ≥ 37 weeks of gestation and > 2500 g), had no preexisting major neuropsychiatric disorder (e.g., schizophrenia, bipolar disorder), and no previous hospitalization for head injury. As part of the design of the larger longitudinal study, children were assessed through neuropsychological evaluation and concurrent neuroimaging at three months postinjury. The neuropsychological battery included measures not related to EB-PM functioning (e.g., episodic memory, attention, etc.), and the same test administration order was maintained for all participants during the EB-PM testing blocks to control for level of effort.

Materials and Task

Socioeconomic Composite Index—The SCI provides a measure of a family's socioeconomic status and has been shown to moderate the effects of severe TBI on long-term outcomes (Yeates, et al., 1997). The index is derived by computing z-scores based on the combined distributions of the OI and TBI groups for three variables including: 1) an 8-point scale rating family income, 2) a 7-point scale of parent/guardian education, and 3) rating of occupational prestige using the Total Socioeconomic Index (TSEI; Hauser & Warren, 1999). The z-scores for these variables were then summed and standardized (mean = 0, SD = 1) based on the aggregate sample of participants (OI and TBI groups) to form the SCI score.

Event-Based Prospective Memory—Details of the EB-PM task have been previously presented (McCauley, et al., 2009), but will be described briefly. The study was a crossover design with two motivation conditions (order randomized across participants) and two periods with no wash-out interval. While performing a research neuropsychological battery

(standard order to control for ongoing task difficulty), children were asked to respond “Please give me three points” each time the examiner said the EB-PM cue “Let’s try something different.” This cue was presented every 20 minutes with three PM cue presentations in each of the motivation conditions. Dollars or pennies were exchanged for accurate performance in the high versus low motivation conditions, respectively. Two points were awarded for realizing the delayed intention (PM component) and two points were also awarded for recalling the correct phrase (*retrospective* memory component or RM). Correct responses were awarded four points and responses with incorrect RM content (e.g., “Please give me *some* points”) were awarded two points; a maximum of 12 points was available in each condition. For the purposes of this study, scores under both conditions were summed for a total EB-PM score (range 0-24).

Magnetic Resonance Imaging—T₁-weighted 3D sagittal acquisition series were performed on Philips Intera 1.5T whole body scanners (Philips, Cleveland, OH). Parameters included 1.0-mm-thick slices, 0mm slice gaps, TE = 4.6ms/TR = 15ms, FOV = 256/RFOV = 100%, and a reconstructed voxel size M/P/S (mm) = 1.0/1.0/1.0.

MRI Post-processing and FreeSurfer Analyses—Cortical reconstruction and segmentation were performed with the FreeSurfer image analysis suite (Athinoula A. Martinos Center for Biomedical Imaging, 2005). Details of the procedures are described in prior publications (Dale, Fischl, & Sereno, 1999; Dale & Sereno, 1993; Fischl & Dale, 2000; Fischl, Liu, & Dale, 2001; Fischl, et al., 2002; Fischl, Salat, et al., 2004; Fischl, Sereno, B., & Dale, 1999; Fischl, Sereno, & Dale, 1999; Fischl, van der Kouwe, et al., 2004; Han, et al., 2006; Jovicich, et al., 2006; Segonne, et al., 2004). Briefly, this processing includes the removal of non-brain tissue using a hybrid watershed/surface deformation procedure (Segonne, et al., 2004), automated Talairach transformation, segmentation of the subcortical white matter and deep gray matter volumetric structures (Fischl, et al., 2002; Fischl, Salat, et al., 2004), intensity normalization (Sled, Zijdenbos, & Evans, 1998) tessellation of the gray matter-white matter boundary, automated topology correction (Fischl, et al., 2001; Segonne, Pacheco, & Fischl, 2007), and surface deformation following intensity gradients to optimally place the gray/white and gray/cerebrospinal fluid borders at the location where the greatest shift in intensity defines the transition to the other tissue class (Dale, et al., 1999; Dale & Sereno, 1993; Fischl & Dale, 2000). We inspected each dataset at multiple points within the processing stream. We verified the Talairach transform, the accuracy of the skull strip, the accuracy of the white matter and pial surface segmentation, and finally inspected the cortical surface reconstruction for topological defects. Error correction was performed as necessary. Cortical thickness was measured as the distance between the gray/white matter boundary and the pial surface at each point on the cortical mantle. Procedures for the measurement of cortical thickness have been validated against histological analysis (Rosas, et al., 2002) and manual measurements (Kuperberg, et al., 2003; Salat, et al., 2004). The data for each participant was resampled to an average participant and surface smoothing was performed using the ‘qcache’ command and a 10mm full-width half-maximum Gaussian kernel, prior to statistical analysis.

Once the processing stream and manual editing were satisfactorily completed, the FreeSurfer QDEC application was used to fit a between-subject general linear model at each surface vertex for cortical thickness differences between groups and the relation of cortical thickness to the PM variable while controlling for age. Statistical parametric maps of the entire cortical mantle were generated to show group differences as well as the relation of cortical thickness to PM variables. The results were displayed on a customized pediatric template that was created using data from the children with OI. Due to the exploratory nature of the analysis, a statistical threshold of $p < .01$ was used for display purposes, in order to show the spatial extent of the areas involved.

Data Analysis

Statistical significance was defined as $\alpha = .05$ for all analyses unless otherwise specified. Planned comparisons were analyzed holding significance at $\alpha = .05$ and all post-hoc comparisons were adjusted using the Bonferroni correction for multiple comparisons. All analyses were conducted with SAS software for Windows, Version 9.2. Categorical variables were analyzed with chi-square test or Fisher's exact test as appropriate given cell sizes. Analyses for hypothesis 1 included group comparisons of the EB-PM total scores while covarying for age. Analyses of hypothesis 2 included the exploration of cortical areas of thinning between the OI and TBI groups and areas of significant cortical thinning were identified while controlling for age. Addressing hypothesis 3, areas of cortical thinning identified in hypothesis 2 were examined for the presence of a significant relation with the EB-PM total score. Finally, hypothesis 4 included a comparison of areas identified as involved in EB-PM performance in previous functional and neuroanatomical studies to our current results.

Results

Sample Characteristics

The groups did not differ by socioeconomic status (SCI), time postinjury, gender, or race/ethnicity (Table 1). The groups differed significantly by age as the TBI group was significantly older than the OI group. The groups also differed by mechanism of injury as the OI group sustained more low-velocity injuries (e.g., sports/play) compared to the greater proportion of high-velocity injuries (e.g., MVAs) sustained by the TBI group.

Event-Based Prospective Memory Performance

As the detailed results for effect of motivation condition on EB-PM has been reported previously, data for this study was collapsed across motivation conditions to form a single EB-PM score for analysis. Results of analysis of covariance (ANCOVA) revealed an effect of age ($F(1,76) = 3.45, p < .02$), but no effect of gender ($F(1,76) = 2.47, p = .12$), or SCI ($F(1,76) = 2.55, p = .12$). The groups differed significantly for overall EB-PM performance ($F(1,76) = 9.64, p < .003$) in that the OI group outperformed the TBI group (least-squares means and standard errors: OI = 21.4 ± 1.4 vs. TBI = 15.3 ± 1.3).

Cortical Thinning

The FreeSurfer cortical thickness analysis (QDEC) results indicated several areas of significant cortical thinning in the TBI group (Figure 1) including bilateral anterior prefrontal (superior, middle, inferior, and medial cortices), bilateral temporal lobes and parahippocampal gyri, bilateral posterior cingulate, and bilateral parietal and precuneus regions.

Brain-Behavior Relations

Review of the FreeSurfer QDEC output revealed several areas of significant cortical thinning which contributed to the group differences in EB-PM performance (Figure 2). Bilateral middle and inferior frontal, middle and inferior temporal, and parahippocampal and cingulate gyri thicknesses were found to be significantly related to EB-PM performance (Table 2). Regions of significant brain-behavior relation (i.e., greater thinning associated with poorer EB-PM performance) appear to be spatially larger in the left hemisphere.

Discussion

In the present study, we investigated the effect of moderate to severe TBI on EB-PM performance. In support of our first hypothesis, children at three months post-TBI performed poorly compared to children with OI which is consistent with previous findings in a sample of children with chronic TBI (McCauley, et al., 2009). The pattern of cortical thinning is generally consistent with that of pediatric TBI (Merkley, et al., 2008) with prominent frontal and temporal thinning in the context of diffuse atrophy, and these areas of cortical thinning were significantly correlated with EB-PM performance supporting our second and third hypotheses. Specifically, regions including bilateral middle and inferior prefrontal cortex and middle and inferior temporal lobe areas bilaterally were related to impaired EB-PM performance; structures including the parahippocampal gyrus and both anterior and posterior cingulate regions were also identified as relating to EB-PM. Supporting our fourth hypothesis, these regions have been shown to be involved in various processes underlying PM performance through functional neuroimaging studies (e.g., PET and fMRI) in healthy adults.

The roles of the distributed prefrontal neural networks involved in EB-PM are complex and overlapping. For example, the left dorsolateral prefrontal cortex (middle frontal gyrus in particular) has been shown to be active in maintaining a sustained response to PM, but so has the left and right anterior cingulate cortex (Reynolds, et al., 2009). Conversely, the right dorsolateral prefrontal cortex is involved in anticipatory PM processes (Burgess, et al., 2001) and intention retrieval (Simons, et al., 2006); however, intention retrieval is also subserved by the left medial orbital gyrus, and right inferior gyrus and the ventromedial frontal area, gyrus rectus, and premotor cortex (Eschen, et al., 2007; Simons, et al., 2006). The right ventromedial frontal region has been implicated in attentional control during EB-PM tasks (Okuda, et al., 1998). Bilateral inferior frontal gyri are involved in PM cue identification (Simons, et al., 2006) and the right inferior frontal gyrus is also key to the online maintenance of future intentions.

The role of temporal lobe structures in EB-PM is comparatively more straightforward. The left middle and inferior temporal gyri have been shown to be important in the encoding of preparatory motor movements necessary for EB-PM behavioral responses (Eschen, et al., 2007) and the left parahippocampal gyrus is activated in response to novelty detection (Okuda, et al., 1998). The right middle temporal gyrus is transiently activated in response to the detection of a PM cue (Reynolds, et al., 2009). Other structures identified in the FreeSurfer QDEC analysis of our study have also implicated the left posterior cingulate, superior temporal and fusiform gyri, and the right inferior temporal gyrus which may be involved in RM processes integral to EB-PM functioning; however, specific roles for these structures have not been specifically elucidated in previous functional neuroimaging studies of EB-PM.

Lesion studies, although less specific in terms of implicating discrete brain regions or specific etiologies, have supported the view that damage to the medial prefrontal, temporal cortex, and even the thalamus (Burgess, et al., 2003; Daum & Ackermann, 1994) impair PM performance. Our results compare well with brain regions identified as important in EB-PM functioning in healthy adults and in studies of patients with brain lesions of mixed etiologies supporting our final hypothesis.

This study is innovative as it is the first to examine the relation between cortical thinning following moderate to severe TBI in children and EB-PM performance. Future studies will be needed to determine the degree to which temporal lobe integrity (particularly the hippocampus and parahippocampal gyri) individually contribute to impairments in EB-PM

in children following TBI. Advanced forms of neuroimaging, such as diffusion tensor imaging (DTI), could potentially shed light on the degree to which the structural integrity of key structures and pathways identified as important in PM affect EB-PM performance in children following TBI. Studies to further investigate this line of research are currently underway.

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Figure 1.
Areas of significant cortical thinning are shown in sagittal, inferior, medial, and coronal views.

Figure 2. Areas of cortical thinning that were significantly associated with EB-PM performance are shown in sagittal, inferior, medial, and coronal views.

Table 1

Demographic and Injury Variables of the Sample

Variable	OI (n= 41)	TBI (n= 40)	Statistical Comparison
Age (years), mean (SD)	12.4 (2.4)	13.8 (2.5)	F (1,79)= 6 .57, p < .02
Gender (female : male)	11 : 30	14 : 26	$\chi^2(2)$ = 0.64, p = .43
SCI, mean (SD)	0.04 (0.81)	0.04 (0.87)	F (1,79)= 0.0, p= .99
Race / Ethnicity, n (%)			
<i>African American</i>	13 (31.7)	5 (12.5)	$p = .10^*$
<i>American Indian</i>	0 (0)	1 (2.5)	
<i>Asian</i>	1 (2.45)	0 (0)	
<i>Biracial</i>	1 (2.45)	0 (0)	
<i>Euro-American</i>	13 (31.7)	16 (40.0)	
<i>Hispanic</i>		18 (45.0)	
Time Postinjury (days), mean (SD)	123.1 (28.5)	124.8 (30.9)	F (1,79)= 0.06, p= .80
GCS (lowest in 1 st 24 hours)	15.0 (0)	7.9 (4.2)	N/A
Mechanism of Injury, n (%)			
<i>MVA</i>	1 (2.4)	13 (32.5)	$p < .0001^*$
<i>MCA / Scooter / Moped</i>	4 (9.8)	5 (12.5)	
<i>RV</i>	1 (2.4)	3 (7.5)	
<i>Bicycle</i>	4 (9.8)	3 (7.5)	
<i>Fall</i>	6 (14.6)	0 (0)	
<i>Hit by falling object</i>	2 (4.9)	2 (5.0)	
<i>Sports / Play</i>	19 (46.3)	6 (15.0)	
<i>Hit by motor vehicle</i>	2 (4.9)	0 (0)	
<i>Other</i>		0 (0)	

SCI = Socioeconomic Composite Index

* Fisher's exact test

GCS = Glasgow Coma Scale score

MVA = motor vehicle accident

MCA = motorcycle accident

RV = recreational or other off-road vehicle

Table 2

Brain Regions Significantly Correlated with EB-PM Performance

Hemisphere	Brain Region	Brodmann's Area
Left	Dorsolateral Prefrontal Cortex	9 / 46
	Middle Frontal Gyrus	46
	Inferior Frontal Gyrus	45
	Medial Orbital Gyrus	11
	Dorsal Anterior Cingulate	32
	Posterior Cingulate	23
	Superior Temporal Gyrus	22
	Middle Temporal Gyrus	21
	Inferior Temporal Gyrus	20, 37
	Parahippocampal Gyrus	35
	Fusiform Gyrus	37
Right	Dorsolateral Prefrontal Cortex	9 / 46
	Inferior Frontal Gyrus	45
	Gyrus Rectus	11
	Ventromedial Prefrontal Cortex	25
	Dorsal Anterior Cingulate	32
	Premotor Cortex	6
	Middle Temporal Gyrus	21
	Inferior Temporal Gyrus	20, 37