Findings of Mild Traumatic Brain Injury in Combat Veterans With PTSD and a History of Blast Concussion

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Veterans with chronic posttraumatic stress disorder were evaluated for a history of blast concussion, controlling for confounding conditions. Electroencephalograms were analyzed by discriminant function for traumatic brain injury. A difference was found in discriminant scores between veterans with and without blast concussion. More members of the blast group had attentional symptoms and attentional dysfunction. Combat veterans with a remote history of blast injury have persistent electroencephalographic features of traumatic brain injury as well as attentional problems. The authors hypothesize that these constitute a type of chronic postconcussive syndrome that has cognitive and mood symptoms overlapping those of posttraumatic stress disorder.

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The authors, in an attempt to treat posttraumatic stress disorder (PTSD) patients with an innovative but not proven intervention (alpha-theta brain wave biofeedback),[1] discovered a subgroup of PTSD patients who had a history of mild concussion on exposure to explosions and who had never been diagnosed with brain injury. This subgroup had quantitative electroencephalogram (qEEG) findings of mild traumatic brain injury (MTBI) by Thatcher and colleagues' discriminant function analysis.[2]

Because this preliminary finding had implications for assessment and treatment, a systematic study of PTSD patients comparing those with a history of mild concussion due to blast injury and those without such a history was undertaken with the specific goals of seeing if qEEG findings would support 1) the diagnosis of MTBI as a partial explanation of the patients' symptoms and 2) the possibility that patients with a history of blast concussion plus PTSD might benefit from treatments shown to be effective for MTBI.

Thatcher and colleagues[2] have reported on the use of electroencephalogram (EEG) discriminant analysis in MTBI. This method has been validated as affording an objective finding of MTBI in subjects who have a history of trauma, often when other findings are absent.[3–5] In the Thatcher discriminant analysis study, subjects from

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the ages of 15 to 65 who had recent mild traumatic brain injuries, defined as a Glasgow Coma Scale[6] score of 13–15 at the time of the injury, were identified as the MTBI group. Using comparisons of complex demodulation analysis of coherence, phase, and amplitude across 19 International 10-20 EEG sites and four bandwidths, Thatcher et al. compared the known MTBI population and a normal population. An MTBI discriminant function was developed to provide the maximum discrimination between normal and mild brain injury subjects, based on a selected set of 20 qEEG indices. The MTBI discriminant score is a global index based on a structured set of indices using specific electrode locations, measurement indices, and the direction of change.

The primary changes in MTBI that emerge from the discriminant analysis are 1) increased coherence in the left frontotemporal areas, 2) decreased beta phase in the right dorsofrontal areas, 3) increased alpha amplitude asymmetries within local frontal and between long-distance frontal and occipitoparietal connections, and 4) depressed alpha power across the posterior hemispheres. The discriminant scores for the normal population ($n = 394$, mean $\pm$ SD $= -2.223 \pm 1.07$) and for the MTBI population ($n = 394$, mean $= 0.661 \pm 0.956$) can be used to determine the probability of membership of any subject in either the MTBI or normal population. The discriminant function provides an overall discrimination between normal and MTBI subjects with 94.8% accuracy, and with an average accuracy of 96.2% for MTBI and 90.5% for normal subjects, respectively.

There are several potential confounding variables to consider in discriminant analysis for MTBI. Thatcher et al. did not control for psychoactive substance use disorder (PSUD) in their MTBI population, even though substance use disorder has been described as producing qEEG changes[7] and may predispose to head trauma. Persons with attention-deficit/hyperactivity disorder (ADHD) are more prone to MTBI, and this population also has been described as having qEEG abnormalities,[8] but ADHD was not controlled for in Thatcher's MTBI group. Prior TBI and MTBI are associated with a higher discriminant score, may dispose to repeat head injuries, and were not controlled for in Thatcher's MTBI group.

Thatcher and colleagues' analysis is based on mechanical trauma subjects, and it is not certain that blast injury is the same as mechanical trauma, although there are some indicators that they are similar. There are no reports regarding findings of combat brain injury associated with blast, save for the report by Levi et al.[9] of CT studies of the brain in subjects who had prolonged unconsciousness following blast injury. Here, a spectrum of blast injuries to the brain, ranging from severe with pronounced CT scan findings to mild with no CT scan findings, was seen, similar to those seen in mechanical trauma. A fluid percussion model of brain injury with dynamics very much like those of a blast has been widely studied in animals,[10] and these injury changes in turn have been used to hypothesize the more subtle and microscopic changes of human MTBI resulting from mechanical forces.[11] The studies of human blast injuries in organs other than the brain[12] suggest that ordnance used in combat can produce blast energies transmitted through air sufficient to produce 2- to 3-atmosphere percussion waves in the fluid media of the brain, the amount of force needed to produce microscopic MTBI findings in animal studies.

The major functional sequela of MTBI of clinical importance is postconcussive syndrome,[13] consisting of attention, memory, and executive function deficits. Tests of attention, processing time, and memory have been used to measure the severity of postconcussive syndrome associated with MTBI.[14] The Test of Variables of Attention (TOVA) is a standardized computer-administered test that accurately and reproducibly measures functions of attention expressed as T-scores on four scales (omission errors, commission errors, time of response, and response variability), with norms established for gender and age to the ninth decade.[15] The TOVA is now being used widely in clinical applications of postconcussive evaluation (L. M. Greenberg, personal communication).

PTSD in combat veterans costs the federal government millions of dollars each year in disability payments and treatment costs. Reports reveal that treatment is not very successful for many veterans. If treatment were more successful, disability from the disorder could be lessened and costs for care could be reduced. Two problems may exist: 1) treatments may be ineffective, and 2) subgroups of PTSD patients need interventions that vary from the general approaches.

This article explores one aspect of combat PTSD, namely subtle MTBI induced by blast injury, that bears further investigation for its influence on treatment response. The *primary hypothesis* is that a history of blast injury in combat PTSD veterans is associated with EEG findings of MTBI independent of other head injuries, ADHD, and PSUD. A *secondary hypothesis* is that blast injury history is associated with deficits of attentional function.

METHODS

Subjects

The subjects were all outpatient male combat veteran volunteers actively enrolled in either a posttraumatic

stress disorders recovery program, an addictive disorders treatment program, or both. Inclusion criteria used were 1) clinical diagnosis of postcombat PTSD (typically for 10 years or more) and 2) a willingness to participate. Exclusion criteria used were 1) active PSUD (other than nicotine), 2) seizure disorders, and 3) the taking of neuroleptics. One of the subjects with current alcohol dependence had recently detoxified; the others with PSUD had been abstinent by history and observation for at least 12 weeks. There was no exclusion for concurrent therapeutic psychoactive medication use because Thatcher et al. did not find that subjects' medication use influenced their findings. None of the subjects was receiving medication for ADHD at the time of study. The average age of subjects was 52, with a range of 26 to 72. Subjects were 6 World War II veterans, 7 veterans of the Korean conflict, 28 veterans of the war in Viet Nam, 1 Cold War–era minefield duty veteran, and 1 Desert Storm veteran. The protocol was approved by the human subjects studies committee of the Minneapolis Veterans Affairs Medical Center, and written informed consent was obtained from each subject.

Assessments

MTBI: Subjects were assessed for MTBI by blast injury by meeting the following criteria: While filling out a questionnaire for concussions, and without knowing the nature of the study, the subject described 1) being present at a detonation of ordnance occurring as the result of mortar, rocket, mine, or munitions cache explosions, often resulting in serious injury or fatality of others who were closer to the blast; 2) as a result, experiencing unconsciousness lasting for no more than 20 minutes or a dazed feeling lasting for at least 1 hour without loss of consciousness; and 3) not requiring medical attention for the concussive episode alone.

Because TBI and MTBI other than blast injury are likely to influence discriminant function scores for MTBI, data were gathered by clinical interview about lifetime history of brain injury from cause other than blast. Possible MTBI (other than the blast episode) was defined as any injury resulting in brief loss of consciousness and/or brief disorientation, confusion, or amnesia. TBI was defined as any injury resulting in prolonged unconsciousness and/or requiring hospitalization for brain injury. The results are presented in Table 1.

qEEG: A 19-channel EEG sufficient to get at least 30 seconds of artifact-free data was obtained from each subject by using an Electrocap (Electro-Cap International, Inc., Eaton, OH) for International 10-20 placement and a Neurolex-24 EEG with Neurosearch software (Lexicor, Boulder, CO) for eyes-closed-awake condition. Artifacting was done with high-resolution graphics using Neurorep software (Neuropsychometric Laboratory, Los Osos, CA). Analyses were done by programmed processing of digitized EEG,[16] resulting in a discriminant score based on Thatcher and colleagues' comparisons between a known MTBI population and a known normal population.

PSUD: Subjects were assessed for a lifetime history of psychoactive substance use disorder (based on history of diagnosis), and for current alcohol or other drug dependence if they were dependent and drinking or using during the past year. The subjects were well known to clinical staff, and records were available for review to confirm the history of abstinence. The results are presented in Table 1.

Attention: Subjects were judged to have a lifetime diagnosis of ADHD if they met the following criteria: 1) having a history of childhood clinical diagnosis of ADHD or a score of at least 46 on the Wender Utah questionnaire,[17] 2) currently meeting adult modified DSM-IV criteria for ADHD,[18] and 3) exhibiting abnormalities on the TOVA.[19] The criteria for lifetime ADHD were met by 18% (7/38). The results are presented in Table 1. "Acquired attentional problem" was defined as being present if the subject met current DSM-IV criteria for ADHD and had a negative childhood history or a Wender Utah score of less than 46. The findings for attentional differences are given in Table 2.

Statistical Analysis

For normally distributed continuous data, a *t*-test for equality of means was used to compare differences in mean values by groups. For nonparametric measures, Pearson's chi-square test was used.

TABLE 1. Study subjects by history of blast injury and comorbidities

	Blast ($n=27$)		No Blast ($n=16$)		Pearson Test[a]	
Condition	*n*	%	*n*	%	χ^2	*P*
Prior MTBI	11/27	41	4/15	27	0.81	0.37
Prior TBI	6/27	22	4/15	27	0.10	0.75
PSUD lifetime	13/27	48	5/16	31	1.15	0.28
PSUD 1 year	6/27	22	5/16	31	0.42	0.51
Lifetime ADHD	4/25	16	3/13	23	0.28	0.60

Note: Data are missing regarding MTBI and TBI in 1 subject and regarding ADHD in 5 subjects. MTBI = mild traumatic brain injury; TBI = brain injury; PSUD = psychoactive substance use disorder; ADHD = attention-deficit/hyperactivity disorder.

[a] df = 1.

[b] One subject recently detoxified.

RESULTS

A *t*-test applied to Thatcher discriminant scores comparing the blast history group ($n = 27$, mean ± SD = –0.36 ± 0.72) with the no–blast history group ($n = 16$, mean = –1.49 ± 0.56) demonstrates a significant difference ($t = -5.4$, df = 41, $P < 0.0001$). Analysis of covariance of means reveals that the presence of lifetime ADHD, other MTBI history, TBI history, or PSUD does not influence these results. It is possible that any prior MTBI or TBI could be expected to influence the Thatcher discriminant score; however, a *t*-test applied to Thatcher discriminant scores comparing the group with any other prior TBI or MTBI ($n = 21$, mean = –0.82 ± 0.78) to those without any other prior MTBI or TBI ($n = 22$, mean = –0.74 ± 0.96) shows no significant difference ($t = 0.32$, df = 41, $P = 0.75$). In addition, if all subjects with prior TBI and MTBI are removed from the analysis, a *t*-test applied to the Thatcher discriminant scores comparing the blast history group ($n = 13$, mean = –0.28 ± 0.88) with the no–blast history group ($n = 8$, mean = –1.47 ± 0.55) continues to demonstrate a significant difference ($t = -3.4$, df = 19, $P = 0.003$). Using a discriminant score cutoff of –1.201, Thatcher et al. were able to predict 96.2% for MTBI and 90.5% for normal subjects in their study. Using this cutoff value, we were able to correctly identify 88% of the blast history–positive group and 75% of the blast history–negative group using discriminant scores alone.

As already noted (see Table 2), there were differences in the blast and the no-blast veterans in regard to meeting current DSM-IV ADHD criteria modified for adults, when those with lifetime ADHD were eliminated (14/21 or 67% vs. 2/10 or 20%; $\chi^2 = 5.91$, df = 1, $P = 0.015$). In other words, those with blast history met criteria for an attentional disorder that was not explained by childhood ADHD. The blast group had more abnormal TOVAs (any of four scales with T-score >65) than the no-blast group when lifetime ADHD was controlled (89% or 23/26 vs. 60% or 9/15; $\chi^2 = 4.49$, df = 1, $P = 0.034$).

TABLE 2. Attentional differences between groups with blast injury and no blast injury

Condition	Blast		No Blast		Pearson Test[a]	
	n	%	*n*	%	χ^2	*P*
Acquired attentional problem[b]	14/24	58	2/14	14	5.91	0.015
TOVA abnormal						
Inattention (scale 1)	9/26	38	6/15	40	0.01	0.922
Impulsivity (scale 2)	13/26	50	3/15	20	3.59	0.058
Response time (scale 3)	11/26	42	3/15	20	2.10	0.147
Variability	14/26	53	6/15	40	0.73	0.393
Any scale	23/26	88	9/15	60	4.49	0.034

Note: Findings of attentional problems under TOVA and DSM-IV ADHD criteria. TOVA = Test of Variables of Attention; ADHD = attention-deficit/hyperactivity disorder.

[a]df = 1.

[b]Defined as present if subject meets current DSM-IV adult criteria for ADHD and has negative childhood history or Wender Utah score <46.

DISCUSSION

This study presents EEG evidence of MTBI in a group of combat veterans with clinical chronic PTSD who had a history of blast concussion. The presence of PSUD, prior TBI or MTBI, or adult residual ADHD did not influence these results. Even when subjects with any prior TBI or MTBI were removed from the analysis, the results remain significant despite substantial loss of statistical power. In all cases, the blast concussion was relatively mild and medical evaluation and attention were not sought for it.

Because of the small sample size and the limited amounts of literature available in the matter of blast injury to the brain, this is an exploratory study that permits generation of hypotheses. It is particularly interesting that prior MTBI and TBI did not influence the results even though blast injury did. One possible explanation is that healing of the prior injury occurred. Thatcher et al. noted that the discriminant score from MTBI tended to improve over time, and this improvement was felt to be associated with clinical healing of axonal injury. The hypothesis that axonal injury is the event of MTBI is currently being tested in quantitative MRI studies (R. W. Thatcher, personal communication); these ongoing studies indicate that MTBI is associated with subtle changes in white matter that are associated with the qEEG changes described in the discriminant analysis. It may be that the degree of axonal injury generated by blast injury is more "permanent" than that generated by other types of trauma, and that this would explain the durability of the qEEG findings in the blast-injured combat veterans. It would be interesting to study veterans with a remote history of blast MTBI with quantitative MRI and quantitative SPECT.

In addition to the findings of MTBI, two possible indicators that blast-injured veterans have attentional problems, a feature of postconcussive syndrome, emerge from this study. One is a measure of attentional performance, the TOVA. The second is the presence of DSM-IV criteria for ADHD in the absence of a lifetime diagnosis.[20] Because the diagnosis of ADHD was rarely considered back when most of the studied population were children, the Wender Utah, a retrospective instrument, was used as an alternative to an established child-

hood diagnosis. More than half of the blast-injured group without lifetime ADHD met criteria for current ADHD. That is to say, they showed significant problems with attention, impulsivity, or hyperactivity that interfered with their daily function.

There are several confounding variables of cognitive testing that should be considered in postconcussive syndrome. Adult residual ADHD also affects processing time and attention. PSUD, a common comorbidity of combat PTSD, and previous TBI or MTBI would also be expected to affect cognitive testing results. Because of the small sample size in this study, it was not possible to exclude prior MTBI/TBI or PSUD as a variable influencing attentional symptoms and performance.

The relationship of MTBI to chronic postconcussive syndrome is not a linear one. The severity of postconcussive syndrome is not related to the severity of the apparent precipitating trauma, and persistence of postconcussive syndrome beyond 1 year in an estimated 10% of cases is also not related to trauma severity.[21] Thus, it seems possible that mild concussion due to blast could produce MTBI findings as well as a prolonged postconcussive syndrome that in turn could influence the clinical course of postcombat PTSD. This hypothesis could be explored in future studies using a detailed psychometric approach in a larger number of subjects.

These possibilities raise the question of symptom crossover between postconcussive syndrome and combat PTSD. The two conditions have in common physiologic hyperactivity, memory deficits, fatigue, increased sensitivity to noise and light, insomnia, irritability, decreased concentration, and anxiety.[22] It is possible that some patients with postcombat PTSD also have some features of blast injury–related postconcussive syndrome. If this is the case, it would be important to identify and treat the postconcussive syndrome because of its influence on one's ability to benefit from therapy that involves recollection, insight, planning, judgment, and other integrative functions.[23]

It should be noted that the EEG discriminant analysis used was based on a study of persons who had MTBI following mechanical accidents (mostly motor vehicle acceleration/deceleration accidents), and it has not been standardized for blast injury. Because this study is done on a small sample, further study should be considered to validate these findings, including as subjects veterans with a history of blast injury but without a chronic PTSD diagnosis. This study has several other important limitations. There is no measure of PTSD symptom severity to use as a comparison between the blast-injured group and the non–blast-injured group. Other comorbidities, such as mood disorders, are not studied. There is no control for medication or other therapies that the subjects have used or are currently using (other than ADHD medication). Imaging technologies such as quantitative SPECT and quantitative MRI were not employed. Age-related confounding was not studied, and other variables that may effect qEEG, such as time of day, serum glucose, and nicotine and caffeine use, were not controlled. The subjects in this study all came from a population of chronic patients in the Veterans Affairs system and may have a bias to maximize combat injury history to obtain financial benefits, although this bias would be expected to be uniform in the blast history–positive and the blast history–negative groups. This study relies on subjects' recollections of a concussion (or their recollections of others telling them about it), and concussions often produce amnesia of such extent that clear recollection is not possible.[24] As a retrospective study, it generates variables of interest rather than generating a causal effect relationship between the history of blast concussion and the existence of MTBI and any effect on PTSD.

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