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Neuropsychological evaluation of blast-related concussion: Illustrating the challenges and complexities through OEF/OIF case studies

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Neuropsychological Evaluation of Blast-Related Concussion: Illustrating the Challenges and Complexities Through OEF/OIF Case Studies

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Abstract

Background/objective: Soldiers of Operations Enduring Freedom (OEF) and Iraqi Freedom (OIF) sustain blast-related mild traumatic brain injury (concussion) with alarming regularity. This study discusses factors in addition to concussion, such as co-morbid psychological difficulty (e.g. post-traumatic stress) and symptom validity concerns that may complicate neuropsychological evaluation in the late stage of concussive injury.

Case report: The study presents the complexities that accompany neuropsychological evaluation of blast concussion through discussion of three case reports of OEF/OIF personnel.

Discussion: The authors emphasize uniform assessment of blast concussion, the importance of determining concussion severity according to acute-injury characteristics and elaborate upon non-concussion-related factors that may impact course of cognitive limitation. The authors conclude with a discussion of the need for future research examining the impact of blast concussion (particularly recurrent concussion) and neuropsychological performance.

Introduction

Mild traumatic brain injury (MTBI or concussion) occurs with alarming regularity in Operations Enduring Freedom (OEF) and Iraqi Freedom (OIF) [1, 2]. Recent estimates suggest that between 12–23% of OEF/OIF personnel report a history of in-theatre concussion [3, 4] and as many as 300,000 OEF/OIF personnel may have sustained a combat related concussion in the current conflicts [5]. Survey data suggest that blast represents one of the most common mechanisms of concussion in warfare [4, 6].

In this context, clinical neuropsychologists of the Veterans Affairs (VA) system are often called upon to evaluate whether OEF/OIF veterans' cognitive limitations reflect historical blast concussion(s). Neuropsychological evaluation of cognitive status in the wake of blast exposure can be challenging for a variety of reasons. In particular, clinicians may have difficulty assessing: (a) true concussion *severity*, (b) true concussion *frequency* and (c) the extent to which *non-concussion factors* may underlie long-term cognitive difficulties.

Difficulty assessing concussion severity often reflects limited knowledge of the blast events themselves. Information pertaining to blast exposure is commonly restricted to self-report months or years after the event(s). Understandably, veterans often show limited ability to describe acute-injury characteristics that accompanied the blast events. The accuracy of self-report regarding contextual issues, such as distance from the blast, is difficult to evaluate because primary records (e.g. Military Acute Concussion Evaluation [MACE; see www.DVBIC.org]) are often unavailable to VA providers. Concussion severity is conventionally rated according to acute-injury characteristics [1]. Thus, lack of reliable information regarding acute injury characteristics makes it challenging to determine concussion severity and expected course of cognitive recovery.

Moreover, concussion severity cannot be reliably determined by endorsement of current post-concussive symptoms (PCS) on screening instruments as PCS are not necessarily specific to concussion. Fatigue, headache, dizziness and other PCS are common in healthy [7, 8] and non-TBI clinical samples [9]. Benge et al. [10], for example, found that PCS endorsed on the Neurobehavioural Symptom Inventory (NSI [11]) were strongly associated with issues unrelated to brain injury, such as post-traumatic stress. Other researchers have also raised concern that PCS may be more reflective of PTSD and other mental health issues [3, 4, 12] than concussion itself.

Neuropsychologists may also have difficulty assessing concussion *frequency*. Many OEF/OIF veterans report extended histories of blast exposure, sometimes spanning multiple deployments. Whereas a single uncomplicated concussion typically results in a favourable course of cognitive recovery within initial weeks

or months [13–15], recurrent concussion may complicate recovery [16, 17]. Extensive blast exposure may obscure the ability to understand the extent to which cognitive limitations reflect a single concussion or the cumulative effect of multiple injuries. Also, not all blast exposures necessarily result in blast concussion. To further complicate matters, blast events may be associated with *non-concussive factors* that affect cognitive performances. Blast may contribute to orthopaedic injuries [12] and pain that impact cognition. Blasts frequently give rise to post-traumatic stress. Survey data suggest that nearly one-half of OEF/OIF personnel who report a history of loss of consciousness also met criteria for post-traumatic stress disorder [12]. The deployment process itself, with or without blast exposure, may impact neuropsychological performances [18]. It is also conceivable that post-deployment stressors (e.g. re-adjustment to personal relationships, civilian employment) impact cognitive performances.

Thus, discriminating the source of cognitive impairment in the late stage of blast-related concussion is an inherently complex endeavour. The objective of the current study is to illustrate these challenges through presentation of three OEF/OIF blast concussion case studies to promote awareness of various non-concussive factors that may complicate interpretation of neuropsychological performances in the late stage of injury. Ultimately, it is the authors' hope that these case studies may assist the clinician to conceptualize potential source(s) of cognitive limitation in the wake of blast-related concussion and inform appropriate treatment recommendations.

Method and procedure

Assessment of blast concussion

In light of the high prevalence of blast concussion in the current military conflicts, the Departments of Defense (DoD) and Veterans Health Administration (VHA) have developed TBI screening instruments to identify veterans who may have sustained historical concussions [22]. The 'TBI Checklist', for example, is a mandated

screening instrument administered within the VA system among returning OEF/OIF veterans [23]. Veterans with a 'positive' history of concussion according to the TBI checklist undergo more comprehensive evaluation via the 'TBI secondary level evaluation' [24].

During the TBI secondary evaluation, the clinician obtains information pertinent to the three most significant concussive events. The veteran is asked to approximate the year, month and date that the injuries were sustained. An estimate of proximity to blast(s) and whether additional factors may have mediated blast exposure(s) (e.g. utilization of protective gear; debris or shrapnel projected toward veteran) may be obtained. The veteran may be asked whether medical attention was provided (including administration of cognitive screening measures) and whether additional physical injuries were sustained. Most concussion rating criteria, including those presented by the American Congress of Rehabilitation Medicine (ACRM [25]), define injury severity according to loss of consciousness (LOC) and duration, post-traumatic amnesia (PTA) and duration and evidence of acute-injury neurologic symptoms or signs. As such, the veteran is asked to estimate duration of LOC, PTA and symptoms or signs (e.g. dizziness, headache) that may have been the direct result of concussion. Post-event information may be obtained to infer course of recovery (e.g. length of light duty; work accommodations). Obtaining information regarding whether peers were simultaneously injured as a result of blast may also assist in conceptualization of the blast event. Whenever possible, the provider attempts to corroborate self-report information with primary records (e.g. emergency medical documents; eyewitness accounts; Military Acute Concussion Evaluation [MACE; see www.DVBIC.org]) to further inform plausibility that concussion was sustained.

Minnesota Blast Exposure Screening Tool (MN-BEST)

The Minnesota Blast Exposure Screening Tool (MN-BEST; see Appendix) was developed by the current researchers to be used in conjunction with the TBI clinical reminder and TBI secondary level evaluations previously described. A primary rationale in developing the

MN-BEST was to generate a single, composite numerical rating of one or more blast concussions. The current researchers reasoned that this single quantitative indicator may facilitate an expedient method of examining the cumulative effects of blast concussion and may be useful in optimally understanding and predicting functional outcomes (e.g. neuropsychological performances). To complete the MN-BEST, the examiner first requests that the veteran estimate the total number of blast exposures experienced, whether or not they may have contributed to concussion. Next, consistent with the second level TBI evaluation [24], the veteran is asked to provide the date and location of the three most significant blast events. The three most significant events are assessed given evidence that risk of persisting symptoms increases following two or more concussions [16, 17].

For each of the three events, researchers offer an opinion as to whether historical blasts plausibly met a 'minimal biomechanical threshold' of concussion [26]. Those events that 'more likely than not' or 'likely' contributed to concussion are rated on a concussion severity continuum. This study has modified a rating scheme initially proposed by Ruff and Richardson [27] that includes three concussion severity classifications: Type I, II or III. Expanding upon this scheme, concussions contributing to neurologic symptoms in the absence of LOC or PTA are rated as 'Type 0' and assigned an overall blast related TBI score of '1'. Type I concussions are assigned an overall blast-related TBI score of '2' and include 'altered state or transient loss of consciousness', PTA of no more than 60 seconds and one or more neurologic symptom. Type 0 and Type I concussions are considered to be consistent with ACRM [25] criteria. Type II and Type III concussions receive blast-related TBI scores of '3' and '4', respectively. Type II concussions consist of definite LOC of unknown duration to no more than 5 minutes, PTA from 60 seconds to 12 hours and at least one neurologic symptom. At the most severe end of the mild (uncomplicated) TBI spectrum, Type III concussions resemble criteria provided by the Diagnostic and Statistical Manual–Fourth Edition (DSM-IV [28]). Type III concussions consist of complete LOC for 5 to no more than 30 minutes, PTA greater than 12 hours and one or more neurologic symptoms. Mild complicated injuries, with indisputable evidence of structural injury, and moderate injuries (GCS 9–12; LOC no longer than 6 hours; PTA 1–24 hours [29, 30]) are assigned a

severity score of '15'. Severe injuries (GCS 3–8; LOC>6 hours; PTA>24 hours [29, 30]) are assigned a score of '30'. Based upon this scheme, the total blast-related TBI score for mild uncomplicated blast-concussion ranges from 0 (no brain injury) to 12 (three Type III concussions). Inclusive of mild complicated, moderate and severe injuries, injury severity scores range from 0 (no brain injury) to 90 (three severe injuries).

It must be emphasized that the MN-BEST is a research instrument that was developed as a method of systematically describing historical blast concussions and their severity. Similar to the TBI clinical reminder and secondary TBI evaluation administered throughout the VA healthcare system [23, 24], the psychometric utility of the MN-BEST has yet to be comprehensively examined. Preliminary interrater reliability for the MN-BEST is encouraging. In a random sampling of MN-BEST concussion ratings from a sub-sample of 10 OEF/OIF veterans presented elsewhere [21], Cohen's alpha among the current research team was 0.98 ($p < 0.001$). Efforts are currently under way to identify MN-BEST validity with regard to convergence with diffuse tensor imaging (DTI) and electroencephalography (EEG) information. It is recommended that researchers and clinicians implement the MNBEST cautiously and in conjunction with additional forms of information (e.g. in-theatre records; neuroimaging studies) until additional reliability and validity data has been successfully attained in sizeable blast concussion samples.

Case Reports

The following case studies were obtained in three assessment settings: a research setting (Case A), clinical setting (Case B) and forensic setting (Case C). Case A was evaluated in the context of ongoing research studies at the Minneapolis VA Medical Center. Case B was evaluated in an extended rehabilitation Polytrauma inpatient setting and allowed for complete record review (including neuroimaging study). Case C was evaluated in the context of compensation and pension examination related to a claim of blast-related TBI. In compliance with regulations of the Minneapolis VA Medical Center, background information has been modified in the interest of protecting patient privacy.

Case A: An OEF/OIF veteran evaluated in a research context

Background.

Mr A is a 28-year old, Caucasian, married, right handed, high school-educated, OEF/OIF veteran who presented for neuropsychological testing in the context of an ongoing research study at the Minneapolis VAMC. Mr A served as an Army infantryman for six years and recently completed multiple tours. He was discharged ~18 months prior to assessment. Mr A reportedly sustained six blast exposures during service in Iraq. He provided precise dates and locations for each event. PCS at the time of assessment included photophobia, tinnitus, irritability, headaches, sleep problems and diminished concentration. Mr A also disclosed that results of a recent compensation and pension evaluation supported 50% service-connection for PTSD. He was a full-time college student at the time of evaluation.

Blast event #1. The most significant blast event transpired in 2005, near a metropolitan area in Iraq. Mr A was an unrestrained passenger riding in the back of a Humvee when an artillery round exploded 15 feet away from the right side of the vehicle. He was wearing full body armour and a helmet. Shrapnel from the blast struck his right leg. The blast contributed to LOC for 20 seconds. PTA was minimal. Acute stage neurologic symptoms included headache, dizziness, disorientation, difficulty tracking, tinnitus, nausea, photophobia, phonophobia and imbalance. He continued to experience headache, tinnitus and dizziness for several hours after the event. He resumed usual military duties the day after the event. Mr A did not seek medical care following the blast. Shrapnel from the blast killed two peers who were travelling with him.

Blast event #2. The second-most significant blast transpired 1 week prior to Blast event #1. Mr A was standing in the cab of a Humvee. An IED exploded 25 feet behind the vehicle. Mr A was wearing full body armour and a helmet. He denied LOC, but did experience alteration of consciousness and disorientation. He denied

PTA. He experienced headache and dizziness lasting a couple of hours, disorientation for 30 minutes, tinnitus for 24 hours, nausea for 1 hour and sensitivity to noise for 24 hours. He did not undergo medical care as a result of the blast. He maintained regular full-time military duties following the event. A peer lost his foot as a result of the blast.

Blast event #3. The third most significant blast event also occurred in 2005, 4 months subsequent to the aforementioned events. Mr A was riding in the back of a heavily armoured vehicle when an IED exploded 500 metres to the left. He denied LOC or PTA. He experienced brief dizziness after the event but denied other neurologic signs. He denied that the event contributed to cognitive or functional difficulties.

Blast exposure assessment.

On MN-BEST team consensus, each of these events was agreed to have been consistent with mild uncomplicated concussion. Event #1 was rated as a 'Type II' concussion given report of definite LOC between 1–60 seconds. Injury #2 was rated as a 'Type 0' concussion given no definite LOC or PTA, but acute-injury neurologic signs. Although external documents corroborating the events were not available, the consensus team agreed that it was 'more likely than not' that these two blast events contributed to concussion. At face value, blast event #3 was classified as being most consistent with 'Type 0' concussion given a single neurologic sign (dizziness) and no evidence of LOC or PTA. Upon consensus, however, it was reasoned that brief dizziness was not necessarily indicative of concussion and may have represented transient autonomic changes or other non-concussion related factors. Blast #3 was therefore considered as 'less likely than not' to have caused a concussion and did not contribute to the overall Blast-related TBI score.

The overall MN-BEST Blast-related TBI score included event #1, which contributed a severity score of '3' and event #2, which contributed a severity score of '1'. Event #3 contributed a score of '0'. As such, the MN-BEST Total Blast-related TBI score amounted to '4'.

Neuropsychological assessment.

Mr A completed a neuropsychological test battery that is routinely administered as part of an ongoing research project at the Minneapolis VA Medical Center (see Table I). Effort performances were within normal limits, suggesting that the profile represents an accurate reflection of cognitive functioning. Estimated level of pre-morbid intellectual ability was within the average range (WTAR FSIQ = 102). Performances on every measure administered, across the domains of simple attention, language, visual-spatial, executive, visual and verbal learning/memory functioning were within normal limits. In fact, Mr A demonstrated relative strengths on a number of tasks (e.g. visuoconstruction) that ranged from high average to superior.

Psychological assessment.

Results of the Clinician- Administered PTSD Scale (CAPS [31]) supported formal PTSD diagnosis. Mr A described multiple traumatic events during deployments. Two peers were killed as a result of one blast event. Multiple additional combat-related events entailed threat of being killed. Mr A experiences intrusive thoughts when reminded of these events. He actively avoids triggers. He experiences sleep problems, irritability, hypervigilance and increased startle response. The Structured Clinical Interview for DSM-IV-TR Axis I Disorders (SCID [32]) was suggestive of major depressive disorder in partial remission and alcohol dependence in remission. Validity scales from the Minnesota Multiphasic Personality Inventory–2nd edition (MMPI-2 [33]) were within normal limits (see Figure 1). The clinical profile was consistent with emotional distress, particularly paranoia, consistent with Mr A's ongoing symptoms of posttraumatic stress.

Conclusion.

The MN-BEST disclosed two plausible blast-related concussions and a total blast-related TBI score of '4'. However, there was not evidence of cognitive impairment that might correlate with the history of blast-related concussions. Emotionally, Mr A continued to experience subtle paranoia and anxiety, consistent with the history of

post-traumatic stress. As concerning as ongoing emotional difficulties may be, they did not clearly impact cognitive performances.

Case B: OEF/OIF veteran evaluated in a clinical VA polytrauma rehabilitation setting

Background.

Mr B is a 40-year-old, Caucasian, right-handed, high school-educated, OIF Army infantryman referred for neuropsychological evaluation 3 months subsequent to blast exposure in Iraq. He sustained a penetrating left temporal brain injury secondary to projected shrapnel from an IED. There is indication of definite LOC of unknown duration. Mr B has no memory of the blast event and limited recall of being transported afterward. His first memory after the blast is 15 days later when he was aroused at a regional medical centre in Germany. It is unclear whether PTA was a manifestation of brain injury or related to intentional sedation. Computed tomography (CT) conducted in the acute-stage of recovery disclosed left temporal and parietal lobe contusions and a subdural haematoma with 4-mm shift. Repeat head CT conducted ~1 month after the initial study showed stable involvement of the left temporal and parietal lobes (see Figure 2).

At the time of evaluation, Mr B endorsed difficulty with word-finding and memory. Residual symptoms of blast exposure included imbalance, limited audition to the left side and dizziness with rapid movement. Mr B denied any history of psychiatric treatment. He denied any current symptoms of depression or anxiety but did acknowledge ongoing fatigue. He denied symptoms of post-traumatic stress.

Blast exposure assessment.

The MN-BEST was not administered during the clinical evaluation, but was applied retrospectively by the current researchers. Duration of LOC could not be determined by self-report or record review. There appears to have been some period of PTA, although precise duration was obscured by what may have been intentional

sedation soon after the injury. Upon arrival at a military medical unit soon after the injury GCS was 14/15. Records confirmed indisputable evidence of injury to portions of the left temporal and parietal lobes. Injury severity was consistent with a complicated, mild TBI. The consensus team determined plausibility of brain injury to be 'likely'. The nature of his mild complicated concussion was consistent with a composite MN-BEST rating of '15'.

Neuropsychological assessment.

Table II presents neuropsychological test performances for Mr B. He demonstrated diminished effort on one embedded indicator (Reliable Digit Span [34]), but performances on other effort measures were within normal limits. Pre-morbid level of intellect was within the average range (WTAR FSIQ = 91) and is relatively consistent with available WAIS-III intellectual performances. Attention and concentration was variable, with diminished simple auditory attention and select impairments in visual and auditory sustained attention. Language, visual-spatial and motor performances were within normal limits. Executive functioning was variable, with select impairments in concept formation and cognitive efficiency (simple reaction time). Notably, visual and verbal learning/ memory performances were within normal limits.

Psychological assessment.

On the MMPI-2, Mr B responded defensively (see Figure 1). The profile was interpreted as under-estimating psychological and emotions symptoms and was interpreted cautiously. In general, there were no meaningful elevations on traditional clinical scales reflecting emotional distress. Mr B did endorse items in a manner that conveys a tendency to have difficulty expressing anger openly. Individuals with similar profiles tend to behave in an over-controlled manner and may have a history of behaving aggressively when their defenses are overtaxed (MMPI-2 Overcontrolled-Hostility Scale *T*-score=69; MMPI-2 Aggressiveness Scale *T*-score=69).

Conclusion.

In summary, Mr B clearly sustained a brain injury as a result of blast exposure. On MNBEST consensus, it was agreed that he had sustained a mild complicated TBI (rating of '15'). Despite this, it is notable that he demonstrated intact performances in many areas of cognitive functioning. Impairments on select measures of attention and executive functioning were believed to be the direct result of brain injury. Consequently, it was reasoned that he would likely experience mild decrease in cognitive efficiency and problem-solving ability in complex, unfamiliar and demanding situations. Although Mr B appears to have adopted a defensive response style on the MMPI-2, there was not clear evidence of significant depression, anxiety or other psychological issues that would account for cognitive limitations.

Case C: OIF veteran evaluated in a forensic VA compensation and pension context

Background.

Mr C is a 25-year-old, right-handed, Caucasian, married, high school-educated, OIF veteran with a history of blast exposure referred for compensation and pension examination related to claim of TBI while deployed to Iraq in 2007. He reports longstanding cognitive limitations attributed to this event. In addition to claims of TBI, medical records indicate Mr C is pursuing disability claims for 11 additional medical (e.g. bilateral loss of hearing; chronic back pain) and psychiatric (PTSD and depression) conditions. At the time of neuropsychological evaluation, he worked as a full-time carpenter. Mr C was evaluated 8 months after an IED exploded ~20 feet away from his location. He was not wearing protective gear. He estimated that he was thrown 12 feet and rendered unconscious for ~5 minutes. He experienced minimal retrograde amnesia and ~20 minutes of anterograde amnesia. His first memory after the blast was being aroused by medical providers in a forward medical unit. He experienced dizziness, disorientation, headache, nausea and tinnitus for several hours after the event. After 2 weeks of light duty, he resumed usual infantry duties.

External records verified that Mr C was exposed to explosion/blast at the reported time and place. He was administered a brief concussion evaluation, the Military Acute Concussion Evaluation (MACE; see www.DVBIC.org), on three occasions: 2 hours, 2 days and 6 days post-injury. The MACE is derived from the Standardized Assessment of Concussion

(SAC [35]) and briefly assesses orientation, immediate memory, concentration and delayed memory. On initial MACE, Mr C reported sustaining LOC for seconds and a brief experience of PTA (seconds). He endorsed items of confusion, feeling dazed and tinnitus across the first two MACE administrations. During the third evaluation, he endorsed symptoms of headache, irritability, ringing of ears and difficulty concentrating. Initial MACE performance was 23/30. Subsequent MACE performances were 25/30 and 24/30, respectively. In light of acute-stage postconcussive symptoms and diminished cognitive performances, medical personnel provided a diagnosis of 'Concussion'.

Three months prior to neuropsychological evaluation, Mr C underwent secondary TBI examination [24] upon his return from deployment. Neurologic examination was normal, with the exception of low back pain and headaches. LOC at the time of the secondary TBI evaluation was reported to be '1 minute and 30 seconds' as a result of the blast. Mr C denied any experience of PTA. He endorsed 'moderate' to 'severe' PCS on the Neurobehavioural Symptom Inventory (NSI [11]).

Mr C also underwent mental health compensation and pension examination 20 days before neuropsychological evaluation. The blast event and an additional combat related-experience that involved the deaths of his peers were considered to represent plausible 'Criterion A' traumatic events [28], although additional diagnostic criteria for PTSD were not met. Mr C acknowledged that he was somewhat more irritable than usual since return from Iraq. He acknowledged that his cognitive limitations coincided with increased irritability and other emotional difficulties that he faced postdeployment. The examiner concluded that irritability, subtle emotional distress, and other activation symptoms were related to combat experiences. Findings

supported Adjustment Disorder related to adjustment to post-deployment process.

Blast exposure assessment.

The MN-BEST was not administered during the forensic examination but was applied retrospectively by the current researchers. Although discrepancies were noted over time regarding precise duration of LOC and PTA, the consensus team concluded that Mr C likely sustained a 'Type II' blast-related concussion. Plausibility of injury was supported by external records confirming definite brief LOC with brief PTA. Mr C also endorsed multiple neurological signs during the acute-stage of injury. MACE performances across the acute stage of injury were also diminished. This was consistent with a MNBEST overall blast-concussion rating of '3'.

Neuropsychological assessment.

Multiple effort performances were below expectation (see Table III), which suggests the neuropsychological profile is unlikely to represent an accurate reflection of Mr C's current cognitive functioning. At face value, estimated level of pre-morbid intellectual functioning was within the average range (Barona Pre-morbid FSIQ = 108), while prorated level of intellectual ability was within the low average range (Pro-rated WAIS-III FSIQ = 84). Attention/concentration was generally intact, although recitation of digits was well below expectation. Language was variable, with impaired phonemic fluency. Visual-spatial performances were grossly intact. Executive performances were variable, with select impairments in cognitive efficiency. Visual memory was variable, with impaired delayed recognition of geometric figures. Verbal learning/memory was variable, with impaired delayed recognition of story details and select impaired trails in verbal list-learning and recognition.

Psychological assessment.

On the MMPI-2 (see Figure 2), Mr C showed limited insight into psychological functioning and denial of minor shortcomings that most individuals are willing to acknowledge. The clinical profile suggested an

experience of diffuse somatic symptoms, such as headaches, extreme pre-occupation with health, unusual sensory experiences and a subjective experience of cognitive limitation. Overall, the MMPI-2 profile is consistent with Mr C's endorsement of chronic low back pain and headaches described during the clinical interview.

Conclusion.

Although Mr C appears to have sustained a blast-related concussion, the progressive cognitive decline described in the months following the blast event is inconsistent with the usual course of recovery following a single concussion. Cognitive limitations in the late stage of recovery are believed to reflect factors unrelated to brain injury (e.g. emotional difficulties related to post-deployment adjustment, chronic pain). Results of neuropsychological evaluation suggest multiple indications of insufficient effort, which precluded an accurate understanding of Mr C's cognitive status. Select effort performances were well beneath what is observed, even among patients with significantly debilitating neurologic conditions such as dementia. At face value, the profile would suggest severe impairment across domains of cognitive function, which is inconsistent with a history of mild concussion and satisfactory work performance as a carpenter. There was enough evidence of insufficient effort to raise suspicion of *intentional* subversion of performance and, by at least one diagnostic scheme, the profile is consistent with criteria for Probable Malingered Neurocognitive Dysfunction [36].

General discussion

The above descriptions represent additions to the few case reports of OEF/OIF veterans with histories of blast concussion that have appeared in the clinical literature. The reports highlight complexities that often accompany interpretation of individual neuropsychological performances. Three OEF/OIF personnel, each with reasonably well-defined histories of blast exposure and concussion, exhibited unique patterns of cognitive performances and psychological profiles when evaluated in the late stage of recovery. These cases highlight several key points that clinical neuropsychologists should

consider when evaluating OEF/OIF personnel with histories of blast concussion.

The case of Mr A illustrates the importance of simultaneous assessment of cognitive and psychological functioning among veterans presenting with persisting PCS. Mr A described two events that plausibly resulted in concussion. Subjective report of cognitive limitation was inconsistent with invariably intact neuropsychological performances. As such, ongoing subjective experience of cognitive difficulty was believed to be a manifestation of PTSD and emotional distress.

The serious nature of blast concussion is illustrated in the case of Mr B. Based upon what was known of the blast event, Mr B was likely to have sustained both the primary (direct) effects of the blast pressure wave, as well as secondary injury as a result of shrapnel that was lodged in the brain [2]. Head CT disclosed injury involving the left temporal and left parietal regions (see Figure 2). Overall history was believed to be consistent with a mild complicated brain injury. Given the serious nature of the injury, it was notable that Mr B demonstrated a variety of cognitive strengths on formal testing. On the other hand, he also showed a number of cognitive limitations (e.g. sustained attention, concept formation) that were believed to reflect residua of brain injury. The case of Mr B also bears relevance to a growing literature suggesting that 'mild' but complicated TBIs may follow a discrepant trajectory of cognitive recovery relative to mild uncomplicated concussions. Mild TBIs accompanied by visible structural injury may complicate recovery [26].

The remaining case study, Mr C, illustrates the importance of symptom validity assessment among OEF/OIF veterans with persisting PCS, particularly in forensic contexts [20, 21]. Mr C presented for neuropsychological evaluation in the context of a compensation and pension claim for TBI. It is likely that Mr C sustained a concussion related to blast exposure based upon information obtained through the clinical interview and external record review. Information directly relevant to the blast concussion in the form of serial MACE performances was helpful in determining plausibility of concussive

injury. Although there was strong reason to believe that Mr C had sustained a blast-related concussion, he demonstrated numerous indications of insufficient effort on formal neuropsychological testing, which precluded a precise understanding of his cognitive strengths and weaknesses. In the context of secondary gain, the profile as a whole was consistent with probable malingered neurocognitive dysfunction [36].

The case of Mr C also illustrates that insufficient effort may be present simultaneously with documented history of concussion. In other words, brain injury and symptom exaggeration may co-exist [37]. Moreover, it should be noted that evidence of insufficient effort is not necessarily evidence of malingering. For some OEF/OIF veterans, variable task engagement may be associated with psychological distress, pain or sleep difficulty rather than deliberate subversion of performance [38].

Each of these case studies emphasized the importance of rating concussion severity according to acute-injury characteristics as opposed to current PCS. This study introduced the MN-BEST as one example of a systematic approach that may assist clinicians and researchers during the clinical inquiry process. Detailed accounts of the circumstances surrounding blast events may assist in determining whether it is plausible that a minimum biomechanical threshold of concussion was met [26]. It should be reiterated, however, that the MN-BEST was used as a research tool and, like the TBI clinical reminder [23] and second level TBI evaluation [24], the psychometric utility of the instrument is not yet fully understood. Ongoing studies are being conducted to examine whether MN-BEST scores are meaningfully related to white matter integrity on diffuse tensor imaging (DTI), electrophysiological function (EEG), psychological symptoms and neuropsychological function following blast-related concussion. Nevertheless, until the instrument can be correlated with acute-injury information, reliability and validity cannot be determined. It is strongly recommended that the MN-BEST be used cautiously until this additional psychometric data is obtained.

In conclusion, understanding the cognitive effects of blast concussion is vital given the unprecedented rate of injured soldiers in

the current military conflicts. It has been the aim of this study to present just a few of the challenges that accompany neuropsychological evaluation of blast-related concussion in OEF/OIF personnel. Larger-scale empirical investigations are needed to clarify expected courses of recovery following isolated and recurrent blast exposure. Continued efforts to better understand how co-morbid non-concussive factors impact neuropsychological performances are also needed. Ultimately, clarifying the most probable source(s) of cognitive impairment, blast-related or otherwise, will inform treatment recommendations and ensure optimal care of OEF/OIF veterans.

Declaration of Interest:

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Appendix

Table I. Neuropsychological profile for Mr A (research context).

Measure	Raw score	Standard score	Classification
<i>Effort/Motivation</i>			
VSVT (Easy, Hard, Total)	24, 24, 48	n/a	Sufficient effort
Rey FIT (Recall + Recog – FP)	30 (15, 15, 0)	n/a	Sufficient effort
CVLT-II Forced-Choice	16/16	n/a	Sufficient effort
Reliable Digit Span*	10	n/a	Sufficient effort
<i>General Intelligence</i>			
WTAR Pre-morbid FSIQ	35	SS = 102	Average
WAIS-III Information	18	SS = 12	High average
<i>Attention/Concentration</i>			
WAIS-III Digit Span (F/W)	17 (5/6)	SS = 10	Average
<i>Language</i>			
COWAT (FAS)	54	T = 59	High average
<i>Visual-Spatial Function</i>			
CFT Copy Trial	34	> 16%ile	WNL
WAIS-III Block Design	61	SS = 15	Superior
<i>Verbal Learning/Memory</i>			
CVLT-II			
Trials 1–5 (Total)	59	$z = 0.9$	High average
Trial B	7	$z = 0.0$	Average
SF Recall	15	$z = 1.5$	Superior
SC Recall	14	$z = 1.0$	High average
LF Recall	14	$z = 1.0$	High average
LC Recall	15	$z = 1.0$	High average
Recog Disc	4.0	$z = 1.0$	High average
<i>Visual Memory</i>			
CFT 3' Delay	29.5	86%ile	High average
<i>Executive Function</i>			
Trail Making Test A	16	T = 64	Superior
Trail Making Test B	48	T = 54	Average
WAIS-III Digit-Symbol	90	SS = 12	High average
Stroop Word	107	T = 50	Average
Stroop Colour	83	T = 52	Average
Stroop Colour–Word Interference	46	T = 51	Average

VSVT = Victoria Symptom Validity Test [39]; Rey FIT = Rey 15-Item Test [40]; WTAR = Wechsler Test of Adult Reading [41]; WAIS-III = Wechsler Adult Intelligence Scale – Third Edition [42]; COWAT = Controlled Oral Word Association Test [43]; CFT = Rey-Osterrieth Complex Figure Test [44]; CVLT-II = California Verbal Learning Test, 2nd edition [45]; Stroop = Stroop Colour and Word Test [46]; Normative data for Trail Making Test and COWAT were derived from Heaton et al. [47].

*After Greiffenstein et al. [34].

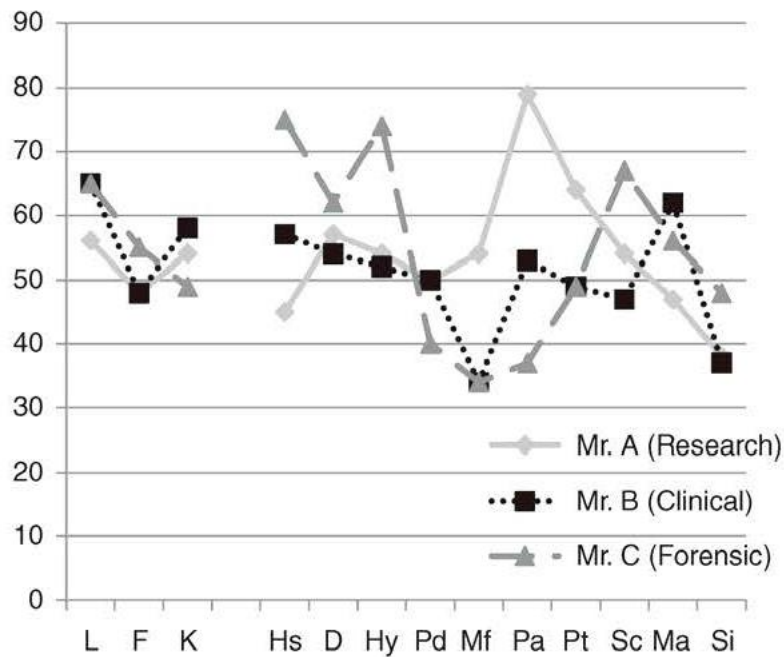


Figure 1. MMPI-2 profiles for three OEF/OIF personnel.

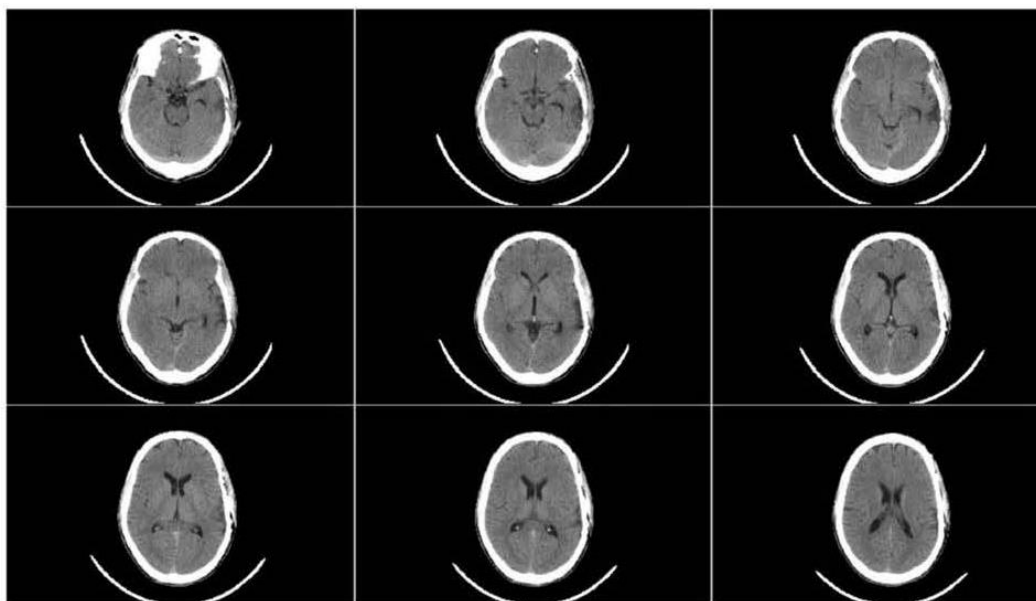


Figure 2. Conventional CT of Mr B's head depicting contusions to the left temporal lobe and portions of the left parietal lobe.

Table II. Neuropsychological profile for Mr B (clinical context).

Measure	Raw score	Standard score	Classification
<i>Effort/Motivation</i>			
TOMM (Trial 1, Trial 2)	48, 50	n/a	Sufficient effort
WCST Regression*	-0.661	n/a	Sufficient effort
Reliable Digit Span +	3	n/a	Poor effort
<i>General Intelligence</i>			
WTAR Pre-morbid FSIQ	25	SS = 91	Average
WAIS-III Vocabulary	27	SS = 6	Low average
<i>Attention/Concentration</i>			
WMS-R Digit Span (F/W)	6 (4/3)	$z = -3.0$	Impaired
WAIS-III LN Sequencing	7	SS = 6	Low average
<i>PASAT</i>			
Trial 2.4s	29	$z = -3.72$	Impaired
Trial 2.0s	31	$z = -1.03$	Low average
Trial 1.6s	19	$z = -2.21$	Impaired
Trial 1.2s	20	$z = -1.19$	Low average
<i>VIGIL</i>			
K Omissions	0	$z = 0.47$	Average
K Commissions	2	$z = 0.14$	Average
K Reaction Time	426.6	$z = -0.55$	Average
AK Omissions	2	$z = -0.69$	Low average
AK Commissions	0	$z = 1.06$	High average
AK Reaction Time	452.8	$z = -1.74$	Impaired
<i>Language</i>			
WAIS-III Similarities	24	SS = 10	Average
COWAT (FAS)	32	T = 41	Low average
Animal Naming	26	T = 58	High average
<i>Visual-Spatial Function</i>			
WAIS-III Block Design	26	SS = 7	Low average
<i>Verbal Learning/Memory</i>			
<i>WMS-R</i>			
Logical Memory I	29	64%ile	Average
Logical Memory II	21	46%ile	Average
<i>CVLT-II</i>			
Trials 1-5 (Total)	47	$z = -0.3$	Average
Trial B	$z = 0.5$	Average	
SF Recall	12	$z = 0.5$	Average
SC Recall	12	$z = 0.0$	Average
LF Recall	13	$z = 0.5$	Average
LC Recall	13	$z = 0.0$	Average
Recog Disc	2.9	$z = -0.5$	Average
<i>Visual Memory</i>			
<i>BVMT-R</i>			
Trials 1-3 (Total)	28	T = 54	Average
Delayed Recall	10	T = 51	Average
Recognition Hits	6	>16%ile	WNL
<i>Executive Function</i>			
<i>WCST</i>			
Categories Completed	3	2-5%ile	Impaired
Total Errors	56	2%ile	Impaired
Perservative Errors	38	1%ile	Impaired
Failures to Maintain Set	1	>16%ile	WNL
Trail Making Test A	21	T = 56	Average
Trail Making Test B	52	T = 55	Average
WAIS-III Digit-Symbol	77	SS = 10	Average

(continued)

Table II. Continued.

Measure	Raw score	Standard score	Classification
Stroop Word	98	T = 45	Average
Stroop Colour	68	T = 42	Low average
Stroop Colour-Word Interference	41	T = 46	Average
<i>Motor Function</i>			
Grooved Pegboard Dominant	73	T = 40	Low average
Grooved Pegboard Non-dominant	71	T = 48	Average

TOMM=Test of Memory Malinger [48]; WCST=Wisconsin Card Sorting Test [49]; WTAR=Wechsler Test of Adult Reading [41]; WAIS-III=Wechsler Adult Intelligence Scale – Third Edition [42]; WMS-R=Wechsler Memory Scale – Revised [50]; PASAT=Paced Auditory Serial Addition Task [51]; VIGIL=VIGIL/W Continuous Performance Test [52]; COWAT=Controlled Oral Word Association Test [43]; CVLT-II=California Verbal Learning Test, 2nd edition [45]; BVMT-R=Brief Visuospatial Memory Test – Revised [53]; Stroop=Stroop Colour and Word Test [46]; Rey-O=Rey CFT=Rey-Osterrieth Complex Figure Test [44]; Normative data for Trail Making Test, Grooved Pegboard, Finger Tapping, Animal Naming, COWAT and BNT were derived from Heaton et al. [47]. *After King et al. [54]. +After Greiffenstein et al. [34].

Table III. Neuropsychological profile for Mr C (forensic context).

Measure	Raw score	Standard score	Classification
<i>Effort/Motivation</i>			
TOMM (Trials 1, 2, 3)	23, 36, 38	n/a	Poor effort
VSVT (Easy, Hard, Total)	23, 15, 38	n/a	Poor effort
Rey FTT (Recall + Recog – FP)	18 (9, 9, 0)	n/a	Poor effort*
CVLT-II Forced-Choice	12/16	Cum % < 1	Poor effort
Finger Tapping DH	24.8	T = 12	Poor effort+
Reliable Digit Span	6	n/a	Poor effort†
<i>General Intelligence</i>			
WAIS-III Pro-rated FSIQ		84	Low average
Information	17	SS = 10	Average
<i>Attention/Working Memory</i>			
WAIS-III Digit Span (F/W)	11 (4/4)	SS = 6	Low average
WAIS-III Arithmetic	9	SS = 6	Low average
WAIS-III L/N Sequencing	6	SS = 5	Impaired
<i>Language</i>			
WAIS-III Similarities	21	SS = 9	Average
COWAT (FAS)	19	T = 28	Impaired
Animal Naming	17	T = 39	Low average
BNT	54	T = 40	Low average
<i>Visual-Spatial Function</i>			
WAIS-III Matrix Reasoning	14	SS = 9	Average
WAIS-III Picture Completion	17	SS = 7	Low average
<i>Verbal Learning/Memory</i>			
WMS-III			
Logical Memory I	34	SS = 9	Average
Logical Memory II	19	SS = 9	Average
Logical Memory Recognition	22/30	n/a	Diminished
CVLT-II			
Trials 1–5	22	$z = -3.0$	Impaired
Trial B	4	$z = -1.0$	Low average
SF Recall	5	$z = -2.0$	Impaired
SC Recall	7	$z = -1.5$	Impaired
LF Recall	6	$z = -1.5$	Impaired
LC Recall	6	$z = -2.0$	Impaired
Recog Hits	7	$z = -5.0$	Impaired
Recog FP	1	$z = -0.5$	Average
Recog Disc	1.7	$z = -2.0$	Impaired
<i>Visual Memory</i>			
WMS-III			
Visual Reproduction I	72	SS = 6	Low average
Visual Reproduction II	64	SS = 10	Average
Visual Reproduction Recog	35	SS = 5	Impaired
<i>Executive Function</i>			
WMS-III Mental Control	16	SS = 5	Impaired
Trail Making Test A	35	T = 36	Impaired
Trail Making Test B	49	T = 52	Average
WAIS-III Digit-Symbol	55	SS = 7	Low average
Stroop Word	69	T = 31	Impaired
Stroop Colour	49	T = 52	Average
Stroop Colour-Word Interference	35	T = 40	Low average
WCST			
Categories Completed	6	>16%ile	WNL
Total Errors	32	19%ile	Low average
Perseverative Errors	18	12%ile	Low average
Failures to Maintain Set	1	>16%ile	WNL

(continued)

Table III. Continued.

Measure	Raw score	Standard score	Classification
<i>Motor Function</i>			
Finger Tapping Dominant	24.8	T = 12	Impaired
Finger Tapping Non-dominant	23.0	T = 6	Impaired
Grooved Pegboard Dominant	95	T = 26	Impaired
Grooved Pegboard Non-dominant	97	T = 31	Impaired

TOMM = Test of Memory Malinger [48]; VSVT = Victoria Symptom Validity Test [39]; Rey FIT = Rey 15-Item Test [40]; WAIS-III = Wechsler Adult Intelligence Scale – Third Edition [42]; WMS-III = Wechsler Memory Scale – Third Edition [55]; CVLT-II = California Verbal Learning Test, 2nd edition [45]; BNT = Boston Naming Test [56]; COWAT = Controlled Oral Word Association Test [43]; Stroop = Stroop Colour and Word Test [46]; WCST = Wisconsin Card Sorting Test [49]. Normative data for Trail Making Test, Grooved Pegboard, Finger Tapping, Animal Naming, COWAT and BNT were derived from Heaton et al. [47]. *Based upon Boone et al. [40]; +Based upon Arnold et al. [57]; † Based upon Greiffenstein et al. [34].

Appendix: Minnesota Blast Exposure Screening Tool (MN-BEST)

Appendix: Minnesota Blast Exposure Screening Tool (MN-BEST)

Patient Name _____ Date of Clinical Interview _____

A. Blast Exposures

- A1. Estimated number of blast exposures (i.e. times the participant felt pressure wave from an explosion) _____
 A2. Worst three blast exposures (i.e. greatest likelihood of injury to brain) - **complete attached Table A1**
 A3. Estimated total number of probable or definite blast-related mTBIs (complete after Table A1 is finished) _____
 A4. Estimated total number of possible, probable, or definite blast-related mTBIs (complete after Table A1 is finished) _____
 A5. Estimated total number of unlikely, possible, probable, or definite blast-related mTBIs (complete after Table A1 is finished) _____
 A6. Estimated total number of probable or definite blast related TBIs (**moderate or severe**) (complete after Table A1 is finished) _____

Classification of mTBI (code TBI according to symptom of greatest severity)

	Type 0	Type I	Type II	Type III
LOC	Definite no LOC	Altered state (including dazed, confused, disoriented) or transient loss and unsure LOC	Definite loss with time unknown or < 5 minutes	Loss 5–30 minutes
PTA	Definite no PTA	1–60 seconds	60 seconds–12 hours	> 12 hours
Neurological symptoms	One or more	One or more	One or more	One or more

A1. Worst three BLAST EXPOSURES (i.e. greatest likelihood of injury to brain)

Event description	Date	LOC (dur)	PTA (dur)	Neurological sign(s)	TBI severity	mTBI type	Rating of certainty	Severity score (if Rating of certainty ≥ 2)
1.				Headache _____ Dizzy/Disor _____ Trbl Tracking _____ Tinnitus _____ Nauseous _____ Sens Light/Noise _____ Other _____ Comments: _____	Type: _____ Rationale: _____ Severity score: _____ Mild = 0 Mod* = 15 Sev = 30	Type: _____ Rationale: _____ Severity score: _____ Type 0 = 1 Type I = 2 Type II = 3 Type III = 4	Rating: _____ Rationale: _____ 0 = unlikely 1 = less likely than not 2 = more likely than not 3 = likely	Rating: _____ Rationale: _____
Deployed: Y/N								
2.				Headache _____ Dizzy/Disor _____ Trbl Tracking _____ Tinnitus _____ Nauseous _____ Sens Light/Noise _____ Other _____ Comments: _____	Type: _____ Rationale: _____ Severity score: _____ Mild = 0 Mod* = 15 Sev = 30	Type: _____ Rationale: _____ Severity score: _____ Type 0 = 1 Type I = 2 Type II = 3 Type III = 4	Rating: _____ Rationale: _____ 0 = unlikely 1 = less likely than not 2 = more likely than not 3 = likely	Rating: _____ Rationale: _____
Deployed: Y/N								
3.				Headache _____ Dizzy/Disor _____ Trbl Tracking _____ Tinnitus _____ Nauseous _____ Sens Light/Noise _____ Other _____ Comments: _____	Type: _____ Rationale: _____ Severity score: _____ Mild = 0 Mod* = 15 Sev = 30	Type: _____ Rationale: _____ Severity score: _____ Type 0 = 1 Type I = 2 Type II = 3 Type III = 4	Rating: _____ Rationale: _____ 0 = unlikely 1 = less likely than not 2 = more likely than not 3 = likely	Rating: _____ Rationale: _____
Deployed: Y/N								
* Includes complicated mTBI						Total blast-related TBI Score: (0–90):		