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An Investigation of Neurological soft signs as a discriminating factor between Veterans with Post-traumatic Stress Disorder, mild Traumatic Brain Injury, and co-occurring Post-traumatic Stress Disorder and mild Traumatic Brain Injury

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AN INVESTIGATION OF NEUROLOGICAL SOFT SIGNS AS A DISCRIMINATING FACTOR BETWEEN VETERANS WITH POST-TRAUMATIC STRESS DISORDER, MILD TRAUMATIC BRAIN INJURY, AND CO-OCCURING POST-TRAUMATIC STRESS DISORDER AND MILD TRAUMATIC BRAIN INJURY

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Table of Contents

Page

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List of Tables

List of Figures

Abstract

AN INVESTIGATION OF NEUROLOGICAL SOFT SIGNS AS A DISCRIMINATING FACTOR BETWEEN VETERANS WITH POST-TRAUMATIC STRESS DISORDER, MILD TRAUMATIC BRAIN INJURY, AND CO-OCCURING POST-TRAUMATIC STRESS DISORDER AND MILD TRAUMATIC BRAIN INJURY

By David J. Rothman, MS

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University.

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While multiple Operation Enduring Freedom/Operation Iraqi Freedom/Operation New Dawn veterans suffer from mild Traumatic Brain Injury (mTBI), Post-traumatic Stress Disorder (PTSD), and co-morbid mTBI and PTSD, there remains difficulty disentangling the specific symptoms associated with each disorder using self-report and neurocognitive assessments. We propose that neurological soft signs (NSS), which are tasks associated with general neurologic compromise, may prove useful in this regard. Based on our review of the literature we hypothesized that individuals with PTSD would present with a greater number of NSS than controls or individuals with mTBI. Further, we hypothesized a synergistic effect, such that individuals with mTBI + PTSD would present with the greatest number of NSS. To test these hypotheses, we analyzed a subset of individuals (N=238) taken from a larger study of neurocognitive functioning in veterans. Participants completed a battery of neuropsychological measures, which included the Behavioral Dyscontrol Scale (BDS), the current study's measure

of NSS. A subset of other neuropsychological measures were also included to examine the utility of NSS over and above traditional neuropsychological measures. Individuals were removed from the study if they sustained a moderate/severe TBI or did not meet validity criteria on the Green's Word Memory Test or the Negative Impression Management subscale of the Personality Assessment Inventory. Binomial logistic and multinomial logistic regression were used to examine the ability of NSS to discriminate between the study groups, first by themselves and then after the variance explained by the traditional neuropsychological measures was accounted for. Exploratory cluster analyses were performed on neuropsychological measures and NSS to identify profiles of cognitive performance in the data set. Results indicated that individuals in the mTBI and/or PTSD group had more NSS compared to controls. Of the individual NSS items only a go/no-go task of the BDS discriminated between groups, with worse performance among individuals in the mTBI, PTSD, and mTBI + PTSD group compared to controls. In contrast, the overall BDS score and individual NSS, in general, did not discriminate between the mTBI, PTSD, and mTBI + PTSD group. Overall, the current study suggests that, when eliminating participants who do not meet validity criteria, NSS do not aid in discriminating between individuals with mTBI, PTSD, and mTBI + PTSD.

An Investigation of Neurological soft signs as a discriminating factor between Veterans with Post-traumatic Stress Disorder, mild Traumatic Brain Injury, and co-occurring Post-traumatic Stress Disorder and mild Traumatic Brain Injury

The most recent military conflicts, Operation Enduring Freedom (OEF), Operation Iraqi Freedom (OIF), and Operation New Dawn (OND), have been marked by two disorders, Traumatic Brain Injury (TBI) and Post-Traumatic Stress Disorder (PTSD) (Hoge et al., 2004; Tanielian & Jaycox, 2008; Vasterling, et al., 2006). Among OEF/OIF/OND veterans, estimates of PTSD indicate a 23% prevalence in a recent meta-analysis (Fulton et al., 2015). Using DSM-5 criteria, 18% of veterans exposed to combat met criteria for PTSD (Hoge, Riviere, Wilk, Herrel, & Weathers, 2014). Furthermore, between 7.6% and 19% of OEF/OIF veterans are diagnosed with a mild traumatic brain injury (mTBI) related to their service (Hoge, et al., 2008; Vasterling et al., 2006). Recent estimates find that prevalence of mTBI ranges from 7.9 to 18.2% for OEF/OIF/OND veterans (Schwab et al., 2017; Stein et al., 2016). Thus, these two conditions affect a significant portion of individuals deployed to OEF/OIF/OND.

Although prevalence estimates often discuss these conditions independently, multiple studies have discussed their co-morbidity and the impact when they occur concurrently (Iverson et al., 2011; Lew et al., 2008). Further, the presence of an mTBI increases the likelihood of developing PTSD among individuals in car accidents and OEF/OIF/OND veterans (Bryant, Creamer, O'Donnell, Silove, Clark, & McFarlane, 2009; Hoge et al., 2008). Consistent with this finding, 66% of OEF/OIF veterans with mTBI reported symptoms consistent with PTSD (Ruff, Riechers, Wang, Piero, & Ruff, 2012). One difficulty associated with understanding these conditions when co-occurring is the high degree of overlap between symptoms of PTSD and long term symptomatic mTBI, often referred to as post-concussive symptoms (Lange et al., 2014; Stein & McAllister, 2009). Among individuals who endorsed PTSD symptoms, 89.1 endorsed post concussive symptoms (PCS: Lange et al., 2014). Moreover, consistent with the

findings of Ruff et al. (2012), 57.5% of individuals who endorsed PCS symptoms endorsed symptoms of PTSD (Lange et al., 2014). One possible reason for the difficulty disentangling the unique contribution of PTSD and mTBI is that clinicians lack the ability to accurately diagnose the two conditions separately due to their high degree of overlap. Current research has shown limited efficacy for self-report measures (Brenner, Vanderploeg, & Terrio, 2009; Carlson et al., 2011). As such, the need for other forms of measurement among individuals with both mTBI and PTSD are needed to help disentangle the unique contribution of each disorder, aiding in the development of treatment targets.

One method that has shown some promise in the ability to disentangle the unique contribution of mTBI and PTSD is neuropsychological assessment of individuals with comorbid mTBI and PTSD. Among individuals diagnosed with both mTBI and PTSD there is evidence of worse performance on tasks of executive functioning and processing speed (Campbell, Nelson, Lumpkin, Yoash-Gantz, Pickett, & McCormick, 2009; Nelson, Yoash-Gantz, Pickett, & Campbell, 2009) when compared to individuals with either PTSD or mTBI only. Furthermore, when compared to individuals with mTBI only, PTSD only, and controls, individuals with comorbid PTSD and mTBI performed worse on a variety of neuropsychological tasks (Combs et al., 2015). Further, using meta-analysis Karr, Areshenkoff, Dugan, & Garcia-Barrera (2014) found multiple mTBIs result in executive deficits above the effect of PTSD symptoms. Thus, some evidence supports individuals with mTBI and PTSD experience long lasting deficits in neurocognitive performance above that experienced by individuals with a single diagnosis.

Conversely, other evidence has provided mixed results with comorbid PTSD and mTBI. In one study, individuals with PTSD performed worse on measures of executive functioning when compared to a comorbid PTSD and mTBI group (Campbell et al., 2009). Further, others

have noted no differences between individuals with mTBI alone, PTSD alone, and comorbid PTSD and mTBI (Gordon, Fitzpatrick, & Hilsabeck, 2011). Moreover, other studies have found that the presence of mTBI does not contribute to the neuropsychological deficits seen in comorbid PTSD and mTBI but rather these deficits are a result of PTSD (Belanger, Spiegel, & Vanderploeg, 2010; Shandera-Ochsner, et al., 2013; Soble, Spanierman, & Fitzgerald-Smith, 2013; Vasterling, Brailey, Proctor, Kane, Heeren, Franz, 2012; Verfaellie, Lafleche, Spiro III, & Bousquet, 2014). These findings contrast with the studies of cognitive performance discussed above, highlighting that PTSD drives long-term deficits in cognition for individuals with comorbid PTSD and mTBI.

Based on the above mixed results for individuals with comorbid PTSD and mTBI on neuropsychological measures, examination of other domains may be useful to disentangle the contribution of each disorder. One such domain is motor functioning between the two disorders, specifically, neurological soft signs (NSS). NSS encompass a set of abnormalities in both sensory and motor performance during clinical examination (Chen et al. 1995). NSS are "soft" as previous research has indicated that they do not localize to a specific brain region; rather, they are suggestive of general neurologic dysfunction (Shaffer et al., 1985). These soft signs may be useful when examining both PTSD and mTBI due to their greater ability to connote general rather than specific neurologic compromise. Examination of these generalized changes are consistent with volumetric, white matter, and grey matter changes in both disorders (mTBI: Asken, Dekosky, Clugston, Jaffee, & Bauer, 2018; Bigler & Bazarian, 2010; Shenton et al., 2012; PTSD: Fani et al., 2012; Liberzon & Sripada, 2007; O'Doherty, Chitty, Saddiqui, Bennett, Lagopoulos, 2015; Villarreal et al., 2002). Thus, use of NSS may be useful to gain further understanding into individuals with PTSD, mTBI, and comorbid PTSD and mTBI.

In support of this hypothesis, NSS have shown promise to discriminate individuals with PTSD from controls. Among a sample of twenty-seven male Vietnam veterans with PTSD and fifteen combat exposed veterans without PTSD, those diagnosed with PTSD exhibited a significantly greater number of NSS (Gurvits, Lasko, Schachter, Kuhne, Orr, & Pitman, 1993). In two follow up studies (Gurvits, Gilbertson, Lasko, Orr, & Pittman, 1997; Gurvits et al., 2000), NSS discriminated individuals with PTSD from controls across trauma type (sexual and military). These results highlight an overall increase in NSS among individuals with PTSD, independent of their exposure to traumatic events and type of trauma. Further, using a case control sample of 49 identical twin pairs, with 25 pairs of one sibling with combat related PTSD paired with a combat exposed twin without PTSD and 24 pairs with a combat veteran without PTSD paired with a non-combat exposed twin, Gurvits et al. (2006) found that individuals with PTSD exhibit a greater number of NSS. Additionally, the unexposed twin, who was considered to be at high risk because their twin developed PTSD, exhibited a greater number of NSS than did the low risk twin (combat exposed without PTSD pairing). The results of this study are highlighted as they represent unique and novel findings among individuals with PTSD and highlight a possible genetic predisposition. Thus, NSS have shown utility in discrimination of individuals with PTSD from controls.

Conversely, investigations with NSS have occurred sparingly among individuals with mTBI. In a recent preliminary examination, pediatrics patients with mTBI exhibited worse motor performance shortly after injury on a standardized measure of NSS (Stephens, Salorio, Denckla, Mostofsky, & Suskauer, 2017). Other studies have demonstrated mTBI is associated with increased NSS overall among individuals admitted to an inpatient psychiatry unit for suicidal ideation (Chapman, Andersen, Roselli, Meyers, & Pincus, 2010). Moreover, individual soft signs

(e.g. Tandem Gait) have also shown a relationship with mTBI (Vanderploeg, Curtiss, & Belanger, 2005). Furthermore, Greenberg et al. (2015) found that NSS present among individuals with mTBI assessed 1 to 3 days post injury, though these findings did not extend to individuals with mTBI 1 to 3 months post injury. These findings indicate that individuals with mTBI may present with NSS in the acute aftermath of mTBI but likely remit over time. Additionally, Ruff et al., (2012) found that neurologic dysfunction was more common among individuals with mTBI and PTSD. Therefore, NSS may provide some utility in understanding if there is a persistent neurologic compromise among individuals with mTBI months after their injury, as noted in PTSD.

Based on the above research, the current study will look to examine the ability of NSS to discriminate between individuals with PTSD and mTBI. The current study will examine NSS in a sample of OEF/OIF/OND veterans who had neither PTSD nor mTBI, mTBI only, PTSD only, and mTBI + PTSD. Examination of NSS in this sample will provide a comparison of veterans on these measures with the ability to clarify the association of NSS within each diagnosis and the possible impact of co-morbidity. The literature review will first review mTBI and PTSD in veterans to highlight the difficulty of using self-report measures to understand the unique contribution of each disorder. Then, a review of neuropsychological measures and their use in understanding these two disorders will occur, with a more extensive review of NSS in both PTSD and mTBI. Based on this literature, hypotheses about the role of neurological soft signs in discriminating PTSD from mTBI will be presented.

Literature Review

The current military conflicts, Operation Enduring Freedom (OEF), Operation Iraqi Freedom (OIF), and Operation New Dawn (OND) have produced an increased focus on two disorders, Post-Traumatic Stress Disorder (PTSD) and mild Traumatic Brain Injury (mTBI) (Hoge et al., 2004; Tanielian & Jaycox, 2008; Vasterling, et al., 2006). Post-Traumatic Stress Disorder occurs 1-month after the experience of a traumatic event and is characterized by symptoms of re-experiencing, avoidance, negative thoughts/emotions, and increased arousal associated with this event (DSM-5: American Psychiatric Association (APA), 2013). During the early phases of OEF and OIF, estimates of PTSD among soldiers ranged from 4.7% to 13.8% (Hoge, Auchterlonie, & Milliken, 2006; Tanielian & Jaycox, 2008). Further, diagnosis of chronic PTSD among veterans was ranged from16.6% to 30.5% using self-reported symptoms (Thomas et al., 2010). Moreover, according to a recent meta-analysis focused on Diagnostic and Statistical Manual-IV criteria (DSM-IV: APA, 2000), 23% of OEF/OIF/OND veterans are diagnosed with PTSD across studies using self-report measures, interview based assessment, and clinician diagnosis (Fulton et al., 2015). Using DSM-5 criteria (APA, 2013), estimates of lifetime PTSD among Veterans across multiple trauma types was 8.1%, independent of combat exposure (Wisco et al., 2016). Among individuals who had deployed to active warzones, 12% of soldiers were considered to screen positive for PTSD using DSM-V criteria (Hoge et al., 2014). Additionally, 18% of individuals who were exposed to combat during deployments met screened positive for PTSD using DSM-V criteria (Hoge et al., 2014). These findings highlight a high prevalence of PTSD symptoms and distress among OEF/OIF/OND veterans irrespective of diagnostic criteria used.

Similar to PTSD, mTBI is frequently diagnosed among OEF/OIF/OND veterans. According to Tanelian & Jaycox (2008), 20% of veterans have sustained an mTBI. Further, among an army unit exposed to combat during OIF, 22.8% of individuals screened positive for experiencing an mTBI (Terrio et al., 2009). In a large study of active duty soldiers, 15% reported experiencing a loss of consciousness (LOC) or alteration of consciousness (AOC) associated with a direct head injury, the primary criteria for diagnosis of mTBI (Hoge, et al., 2008). More recently in a prospective study of soldiers deployed to OEF, 18.2% of individuals sustained mTBI during their deployment based on self-report (Stein et al., 2016). Further, on a self-report measure of mTBI among individuals returning from military deployment found that 7.9-9.5% of soldiers screened positive for mTBI (Schwab et al., 2017). In addition to screening positive for mTBI based on symptoms at the time of injury, a proportion of individuals report continued difficulties associated with mTBI over time, termed post-concussion symptoms (PCS). According to Ryan and Warden, (2003) PCS often resolve within one month, though rates of long-term symptoms vary depending on the study. In both veteran and the general population, prevalence estimates range from 31 to 38.9% of the population endorsing PCS (Dean, O'Neill, & Sterr, 2012; Meares et al., 2011; Terrio et al., 2009). Thus, mTBI affects a significant number of individuals both at time of injury and over time.

Though these two conditions affect a large number of veterans independently, PTSD and mTBI often occur co-morbidly. Early studies found that 33 % to 42% of veterans diagnosed with mTBI also met criteria for PTSD (Hoge et al., 2008; Lew et al., 2008; Tanelian & Jaycox, 2008). More recent estimates have found that 30- 66% of veterans with mTBI report symptoms consistent with a PTSD diagnosis (Polusny, Kehle, Nelson, Erbes, Arbisi, & Thuras, 2011; Ruff et al., 2012; Wilk, Herrell, Wynn, Riviere, & Hoge, 2012). Additionally, in a large chart review

study, of those diagnosed with mTBI, 73% were diagnosed with comorbid PTSD by the Veterans Health Administration (Taylor et al., 2012). Further, in a meta-analysis of OEF/OIF veterans considered to have a probable mTBI, 33 to 39% met criteria for probable PTSD (Carlson, et al., 2011). Studies in the general population have shown that mTBI and PTSD co-occur in 11.8% of patients three months after emergency room admission (Bryant et al., 2009). These prevalence rates indicate a significant discrepancy among veterans and the general population in the development of PTSD after mTBI. Further, when assessed longitudinally, sustaining an mTBI during deployment was a predictor of PTSD symptoms (Yurgil, et al., 2014; Stein et al., 2015). Thus, the diagnosis of both mTBI and PTSD is common among veterans and active duty soldiers who served during the OEF/OIF/OND conflicts.

The common co-occurrence of mTBI and PTSD has important implications for physical and mental health. When compared to soldiers with only a diagnosis of mTBI, those with co-morbid mTBI and PTSD reported significantly worse physical functioning (Hoge et al., 2008). Similarly, the experience of comorbid mTBI and PTSD tends to be predictive of worse outcomes when compared to controls or mTBI only (Amick et al., 2018; Bomyea et al., 2019; Haagsma, et al., 2015; Tsai, Whealin, Scott, Harpaz-Rotem, Pietrzak, 2012). Additionally, comorbid PTSD mediated the relationship between mTBI and outcomes measures of vocational and psychological functioning (Pietrzak, Johnson, Goldstein, Malley, & Southwick, 2009). Further, individuals with an mTBI from a blast injury (plus another mechanism of injury), who were experiencing symptoms of PTSD and depression, scored higher on measures of disability than control counterparts (MacDonald et al., 2014).

Consistent with worse functioning among veterans with a comorbid diagnosis of mTBI and PTSD, solders experiencing both disorders are a greater burden upon the healthcare system.

Among individuals with mTBI, those diagnosed with comorbid PTSD had the second highest cost per patient, only trailing individuals with mTBI, PTSD, and chronic pain (Taylor et al., 2012). Additionally, multiple studies have demonstrated that veterans with mTBI and PTSD use VHA services at a higher rate and cost than their PTSD-only or mTBI only counterparts (Kehle-Forbes, Campbell, Taylor, Scholten, & Sayer, 2017; King, Wade, & Wray, 2013). Furthermore, individuals with mTBI and PTSD had the highest number of inpatient admissions among veterans, accounting for 32.7% of all inpatient admissions among individuals who screened positive for mTBI (Stroupe et al., 2013). These findings show that mTBI and PTSD, when diagnosed co-morbidly, have a substantial overall impact on both the individual and system in which they are treated.

Despite the high prevalence, impact on healthcare system, and cost of mTBI and PTSD, multiple challenges persist in understanding this co-morbid condition. One challenge is that clinicians lack the ability to discriminate between mTBI and PTSD at the time of injury (Brenner, Vanderploeg, & Terrio, 2009; Carlson et al., 2011). Currently, individuals can report either LOC or AOC at the time of injury and be diagnosed with mTBI, though direct impact to the head is not required (Taber, Warden, & Hurley, 2006). This presents a challenge in accurate diagnosis, as feeling "dazed" or "confused" may be a result of an emotional reaction to a traumatic experience, rather than head injury (Hoge, Goldberg, & Castro, 2009; Ruff, et al., 2009). Thus, an individual may be diagnosed with mTBI, when their change in consciousness is a result of emotional reactions, rather than or in conjunction with physical forces placed upon the head (Bahraini, Breshears, Hernandez, Schneider, Forster, & Brenner, 2014; Hoge et al., 2009; Ruff et al., 2009). Further, as the precipitating event for mTBI is often traumatic in nature, determination of the primary driver of current symptoms becomes difficult (Menon, Schwab,

Wright, & Maas, 2010; Stein & McAllister, 2009). Although current diagnostic definitions require alteration in brain functioning to diagnose mTBI, PTSD is commonly associated with similar deficits as those seen in mTBI (Kennedy et al., 2007; Rauch, Shin, Phelps, 2006; Stein & McAllister, 2009). Thus, the development of PTSD or mTBI, or a comorbid diagnosis after a traumatic event is difficult to understand as both are associated with an individual's emotional and physical reactions at the time of injury and present with similar symptoms post injury.

In addition to difficulty differentiating between the two disorders at the time of injury, differentiation between the two disorders months after injury becomes difficult, as there is high degree of overlap between the long-term symptoms of mTBI and PTSD. According to Stein and McAllister (2009) there are multiple emotional and behavioral symptoms associated with PTSD and mTBI, including depression/anxiety, insomnia, irritability/anger, concerns related to concentration, fatigue, avoidance of stimuli, and hyperarousal. Lange et al. (2014) reported that among individuals with PTSD, 89.1% endorsed mTBI, while 57.5% with mTBI endorsed symptoms of PTSD. Furthermore, symptoms of comorbid depression also result in a high degree of mTBI symptom endorsement (Lange et al., 2014). These findings implicate the role of mental health on mTBI symptom reporting and are consistent with other studies finding that mTBI symptoms are often endorsed by individuals with PTSD and other mental health disorders (Belanger et al., 2011; Cooper, Kennedy, Cullen, Critchfield, Amador, & Bowles, 2011; Manners, Forsten, Kotwal, Elbin, Collins, & Kontos, 2016). Moreover, other studies have noted that individuals who report no history of traumatic brain injury or PTSD endorse symptoms associated with mTBI at rates ranging from 35.9% to 75.7% (Iverson & Lange, 2003; Wäljas et al., 2015). Furthermore, severity of mTBI does not affect symptom reporting, and instead was associated with pre-injury mental health concerns (Wäljas et al., 2015). Thus, there is a high

degree of overlap between the symptoms of mTBI and PTSD, further complicating the ability to discriminate between these two disorders. Moreover, the rather general nature of mTBI symptoms, which are frequently endorsed, decreases the ability to discriminate between mTBI and PTSD based upon self-report measures. Therefore, exploration of other methods of assessment, not associated with self-report among individuals with both mTBI and PTSD, are needed to disentangle the unique contribution of each disorder.

One method often used to understand changes among individuals with mTBI and PTSD is neuropsychological assessment (Dolan et al., 2012; Scott et al., 2015). According to Lezak, Howieson, & Loring (2004), neuropsychological assessment is focused on measuring behavioral manifestations of brain dysfunction. Further, neuropsychological assessment looks to integrate questions associated with both neurological and psychological influences on behavior. Consistent with the aims of the current study, neuropsychological assessment is often used to assist in diagnosis and treatment selection/planning for individuals experiencing a variety of psychological and neurological changes, often co-occurring (Lezak, et al., 2004). Neuropsychological assessment can be broken into multiple categories including orientation, attention, perception, memory, verbal, visuospatial, reasoning, executive functioning, motor functioning, and personality (Lezak et al., 2004). The use of neuropsychological measures may provide an ability to discriminate between mTBI and PTSD as the reliance on self-report and symptoms is decreased, which is especially important given the issues of self-report noted above. Thus, these domains can be examined in an effort to understand their role discriminating between mTBI and PTSD.

Neuropsychological Assessment among individuals with mTBI and PTSD

Attention

One domain commonly associated with mTBI, PTSD, and comorbid mTBI and PTSD is attention. Multiple studies have demonstrated decreased attention among individuals with PTSD when compared to controls (Dolan et al., 2012; Marx, Doron-Lamarca, Proctor, & Vasterling, 2009; Scott et al., 2015; Vasterling, Duke, Brailey, Constants, Allain, & Sutker, 2002) and mTBI (Combs et al., 2015; Konrad et al., 2011; Landre, Poppe, Davis, Schmaus, & Hobbs, 2006; Raskin, Mateer, & Tweeten, 1998; Vanderploeg, Curtiss, & Belanger, 2005). Though some studies have highlighted a decrease in attention among individuals with mTBI, meta-analyses indicate that attention may return to baseline after three months (Belanger, Curtiss, Demery, Lebowitz, & Vanderploeg, 2005; Belanger et al., 2010; Vasterling et al., 2012). Despite some evidence supporting this conclusion, a recent study examining individuals with a history of mTBI compared to PTSD found no difference in attention (Combs et al., 2015). Thus, among individuals with mTBI or PTSD, attention may be impaired both in the early phases and persist over time.

Among individuals with mTBI and PTSD, studies have found limited evidence of the impact of comorbidity on attention when compared to individuals with mTBI only and PTSD only (Gordon et al., 2011; Soble, Spainerman, & Fitzgerald-Smith, 2013; Combs et al., 2015). While previous studies have found no effect, Brenner et al., (2010) indicated large effect sizes on measures of attention among individuals with co-morbid mTBI and PTSD when compared to those with mTBI only. These findings, as with the above literature on mTBI and PTSD alone, present a mixed picture associated with attention. Together, they highlight that mTBI and PTSD present similarly with deficits in attention, especially when individuals are experiencing symptoms of each disorder. Further, evidence supporting a clear direction in co-morbid PTSD and mTBI is not identified yet in the current research on attention.

Memory

Similar to attention, studies assessing memory do not provide increased resolution into discrimination of mTBI and PTSD when co-occurring. As with attention, multiple studies and meta-analyses have demonstrated that individuals with PTSD perform worse on memory tasks when compared to trauma exposed and healthy controls (Brewin, Kleiner, Vasterling & Field, 2007; Gilbertson et al., 2006; Johnsen & Asbjørnsen, 2008; Scott et al., 2015). Further, consistent with findings in the attention literature, some studies have indicated that individuals with a history of mTBI experience a return to baseline for verbal, working, and spatial memory (Belanger et al., 2010; Rohling et al., 2011; Vasterling et al., 2012), though others report impaired visual and spatial memory when compared to controls (Combs et al., 2015). Further, working memory may continue to be impaired three months and beyond after mTBI (McAllister et al., 2001). Therefore, the current literature when examined for each diagnosis in isolation indicates memory deficits exist for both mTBI and PTSD.

When examining individuals with a dual diagnosis of mTBI and PTSD, memory does not seem to provide increased resolution into the primary driver of symptoms. Multiple studies have found that no differences emerge for the co-morbid mTBI and PTSD groups when compared to single-diagnosis groups (Brenner et al., 2010; Gordon et al., 2011; Soble, Spainerman, & Fitzgerald-Smith, 2013; Wrocklage et al., 2016). Although multiple studies have noted this effect, a recent study comparing comorbid PTSD and mTBI to controls, mTBI, and PTSD only groups found the co-morbid diagnosis group performed worse on a task of verbal memory (Combs et al., 2015). Thus, findings with mTBI and PTSD continue to be mixed across measures of memory. Therefore, use of this domain in discrimination between mTBI and PTSD is limited

as the unique contribution of each disorder is not apparent and no clear picture of the influence of co-morbidity can be drawn.

Executive Functioning

As with other domains of neuropsychological assessment, results with executive functioning show decreased performance for both mTBI and PTSD. Among individuals with PTSD, there is a lengthy literature associated with deficits in executive functioning (Aupperle, Melrose, Stein, Paulus, 2012; Dolan et al., 2012; Polak, Witteveen, Reitsma, & Olff, 2012; Scott et al., 2015; Woon, Farrer, Braman, Mabey, & Hedges, 2017). Similar deficits in executive functioning have emerged among individuals with mTBI (Collins et al., 1999; Combs et al., 2015; Howell, Osternig, Van Donkelaar, Mayer, Chou, 2014; Nelson et al., 2009; Karr, Areshenkoff, Duggan, Garcia-Barrera, 2014). Moreover, when compared to other domains, Karr, Asreshenkoff, & Garcia-Barrera (2014) found that executive functioning was the most vulnerable to long-term changes after mTBI.

A similar picture is noted among individuals with mTBI + PTSD. Previous evidence indicated that on executive tasks was dual diagnosis was associated with worse performance when compared to individuals with a single diagnosis (Amick et al., 2013; Lopez, et al., 2017; Nelson et al, 2009; Brenner et al., 2010). Additionally, Campbell et al., (2009) found mixed results when comparing mTBI + PTSD to mTBI only and PTSD only. Moreover, Amick et al., (2013) found that increased PTSD symptoms among individuals with mTBI led to worse performance on an attentional go/no-go task when compared to individuals without mTBI and PTSD symptoms. Conversely, with other samples assessing executive functioning, no differences have emerged for the comorbid group when compared to mTBI only and PTSD only (Gordon et al., 2011; Soble, Spainerman, & Fitzgerald-Smith, 2013; Swick, Honzel, Larsen,

Ashley, & Justus, 2012; Wrocklage et al., 2016). Furthermore, Shandera-Oschner et al., (2013) found that individuals with mTBI + PTSD did not differ from individuals with PTSD but significantly differed from controls and individuals with mTBI only. Thus, although there is consistent evidence for worse executive functioning performance among individuals with mTBI and PTSD alone, the results are mixed for individuals with comorbid mTBI and PTSD when compared to single diagnosis.

Processing Speed

Among individuals with mTBI and PTSD, processing speed is shown to be significantly decreased. Multiple studies have identified deficits in processing speed among individuals with PTSD (Cooper et al., 2018; Samuelson et al., 2006; Schuitevoerder et al., 2013; Scott et al., 2015; Twamley et al., 2009), and in two meta-analyses, processing speed was found to have a large effect size among individuals with PTSD when compared to healthy controls (Schuitevoerder et al., 2013; Scott et al., 2015). Consistent with findings in PTSD, deficits in processing speed have been noted consistently among individuals with mTBI (Cooper et al., 2018; Johansson, Berglund, & Ronnback, 2009; Karr, Areshenkoff, Duggan, Garcia-Barrera, 2014; Kaup et al., 2017; Levin et al., 2013). Thus, similar to other areas of neurocognitive functioning, mTBI and PTSD are associated with decreased performance on processing speed tasks when assessed in comparison to controls.

In association with comorbid mTBI and PTSD, some evidence has supported a synergistic effect of dual diagnosis on processing speed (Brenner, Ladley O'Brien et al., 2009; Campbell et al., 2009; Lopez et al., 2017; Nelson et al., 2009). Furthermore, Combs et al. (2015) noted that individuals with mTBI + PTSD performed worse than controls and PTSD only on measures of processing speed but had similar performance to individuals with mTBI. In contrast,

other studies have demonstrated no synergistic effect of comorbid mTBI and PTSD on processing speed (Brenner et al., 2010; Gordon et al., 2011; Soble et al., 2013). Further, Verfaellie et al., (2014) found that deficits in processing speed were associated with PTSD symptoms and not attributable to mTBI. Thus, deficits in processing speed may be effected among individuals with dual diagnosis.

The research presented above demonstrates that assessment of neurocognitive functioning rarely discriminates between mTBI and PTSD when co-occurring. Neurocognitive assessments are relatively consistent in providing evidence that individuals with mTBI only and PTSD only, experience deficits across the domains of attention, memory, executive functioning, and processing speed, when compared to healthy controls. While research tends to support the conclusion that individuals experiencing mTBI and PTSD perform worse than controls (Combs et al., 2015; Ruff et al., 2012; Swick, Honzel, Larsen, Ashley, & Justus, 2012; Vasterling et al., 2012) the literature when compared to mTBI alone or PTSD alone is mixed, as studies report both synergistic and no effect when compared to mTBI and PTSD only. Moreover, multiple recent studies highlight that deficits in mTBI no longer exist when PTSD or mental health are considered (Donnelly, Donnelly, Warner, Kittleson, & King, 2018; Merz, Roskos, Gfeller, & Bucholz, 2017; Storzbach et al., 2015; Vasterling, Jacob, & Rasmusson, 2017). Thus, the current neuropsychological literature only provides clear support that mTBI, PTSD, and comorbid mTBI + PTSD perform worse than controls. As such, they highlight that neurocognitive assessment has limited utility when efforts are made to determine if an individual is experiencing symptoms more commonly associated with mTBI or PTSD. Further, evidence for a unique effect of dual-diagnosis associated with worse neurocognitive effects is not supported in general by the literature.

Neurological Soft Signs

Although there is limited evidence supporting the use of neuropsychological assessment to discriminate mTBI, PTSD, and dual diagnosis, one domain that may show promise is assessment of neurological soft signs. Neurological soft signs (NSS) are a group of sensory and motor abnormalities manifest during clinical examination. NSS are considered "soft" as they are discussed in the context of general neurologic compromise and do not locate to a specific area of the brain (Shaffer et al., 1985). NSS are behavioral tasks that examine multiple areas of neurologic functioning, including motor coordination, sensory integration, and sequencing of complex tasks (Buchanan & Heinrichs, 1989; Shaffer et al., 1985). Motor NSS include tests of gait and finger-thumb opposition tasks. Sensory tasks include stereognosia (recognize objects without looking), graphesthesia (the capability to identify writing on the skin with eyes shut), and extinction. Complex motor sequencing NSS include fist-edge-palm task, go-no-go tasks, and rhythm tapping (Bombin, Arango, & Buchanan, 2005). NSS are examined using a variety of measures, with the two most prominent being the Cambridge Neurologic Inventory (CNI: Chen et al., 1995) and Neurologic Examination Scale (NES: Buchanan & Heinrichs, 1989). Additionally, multiple other measures have been used to assess for NSS, which vary in length, scoring system, and validity (Bombin, Arango, Buchanan, 2003; Bombin et al., 2005). A trained individual typically administers these assessments, scoring items based on the level of dysfunction manifest by the individual.

Historically, research has focused on NSS in schizophrenia. In an early study of NSS, 62% of individuals diagnosed with schizophrenia exhibited two or more soft signs (Kolakowska, Williams, Jambor & Arden, 1985). In a comprehensive review, neurodysfunction (presenting with a greater number of NSS compared to healthy controls) ranged from 38.6 to 65% among

individuals with schizophrenia (Bombin et al., 2005). To compile a more accurate estimate of prevalence, Chan, Xu, Heinrichs, Yu, & Gong, (2010) limited their search to two widely used measures with strong psychometrics of NSS, the CNI (Chen et al., 1995) and NES (Buchanan & Heinrichs, 1989). They found that 73% of individuals with schizophrenia present with a greater number of NSS when compared to healthy control subjects. Additionally, NSS can be used to discriminate controls from individuals with schizophrenia (Chan et al., 2015; Flyckt et al., 1999; McCreadie, Wiles, Moore, & Grant, 1987) and are predictive of later development of schizophrenia (Carr et al., 2000; Lawrie et al., 2001; Mittal et al., 2013). Furthermore, in schizophrenia, NSS are considered an endophenotype for the diagnosis (Chan & Gottesman, 2008). Thus, NSS have demonstrated significant utility in discrimination of schizophrenia.

Cognitive Dysmetria

Although the literature on NSS is compelling in schizophrenia, the current study looks to apply this concept to mTBI and PTSD. This requires an examination of the neurologic and theoretical underpinnings of NSS. From a theoretical perspective, one model used to conceptualize the increased prevalence of NSS in schizophrenia is the theory of cognitive dysmetria, which focuses on the interconnectivity between the frontal cortex, subcortical structures, and the cerebellum (Andreasen, Paradiso, O'Leary, 1998). This theory highlights the fact that deficits in processing, prioritization, retrieval, and expression of information can occur in a broad range of symptoms, including hallucinations, delusions, disorganized speech and behavior, altered affect, anhedonia, or changes in attention (Andreasen et al., 1998). Unlike the anatomical substrates of motor dysmetria (motor cortex cerebellum, pons, thalamus, and modulated by the basal ganglia), cognitive dysmetria focuses on three structures, the prefrontal cortex, thalamus, and cerebellum (Andreasen et al., 1999). Each of these structures plays an

important function in overall human behavior. The pre-frontal cortex is associated with multiple higher-level functions, including regulation and modification of behavior, willed action, encoding and retrieval, and perception of emotions (Miller & Cohen, 2001). The thalamus is thought to play a role in gating of stimuli and as a relay for information (Saalmann & Kastner, 2015). Finally, the cerebellum plays a role in the coordination of movement, cognition and limbic systems (Schmahmann & Caplan, 2006). These structures are important not only in isolation but in their interconnectivity.

Underlying the theory of cognitive dysmetria is the cortico-cerebellar-thalamic-cortico circuit (CCTCC). Consistent with the theory of cognitive dysmetria, the CCTCC is a feedback loop that both controls and monitors mental activity that affects cognitive abilities (Andreasen et al., 1999; Sheffield & Barch, 2016). As detailed above, the CCTCC is comprised of multiple frontal structures (dorsolateral prefrontal cortex, dorsal anterior cingulate cortex, and medial prefrontal cortex), thalamus, and cerebellum. The role of these structures has been shown across multiple studies in individuals with schizophrenia (Barch, 2014; Klingner et al. 2014; Minzenberg, Laird, Thelen, Carter, & Glahn. 2009). Although the CCTCC may explain some of the alterations among individuals with schizophrenia, a recent integrative model hypothesized that the dopaminergic Go/NoGo network (located in the striatum) and task positive/task negative functional networks are altered among those with schizophrenia (Sheffield & Barch, 2016). In their model Sheffield and Barch (2016) hypothesize that Default Mode Network (DMN) is impacted by the task-positive and task-negative networks in association with go/no-go pathways in the cortex. Areas of the DMN show decreased activation when performing goal-directed tasks and therefore are active during stimulus-independent thought (Daselaar et al., 2009). Contained within the task positive network are two areas, the fronto-parietal network and cingulo-opercular

network, which are primarily located in frontal cortical regions. These networks, which are task-positive (focused on external stimuli) work in opposition to the DMN. Recent studies have highlighted that alteration of activity between the task-positive and task-negative networks among those with schizophrenia (Unschuld et al., 2013). Moreover, alterations to the task positive and task negative networks are associated with multiple performance decrements on cognitive tasks among individuals with schizophrenia (Sheffield & Barch, 2016). Thus, when integrated, individuals with schizophrenia exhibit altered task-positive/task negative dynamics, leading to a change in the cortex's activation on cognitive tasks. This leads to an alteration of the Go/NoGo network, which changes the CCTCC, resulting in a decrease in the ability to control and monitor mental activity (Sheffield & Barch, 2016). Overall, these findings highlight that via alterations to the CCTCC (due to changes in the DMN and go/no-go networks), individuals with schizophrenia perform worse on cognitive tasks, consistent with the theory of cognitive dysmetria.

Neurologic Findings in PTSD and mTBI associated with cognitive dysmetria.

Consistent with the theory of cognitive dysmetria, individuals with PTSD exhibit hypoactivation of the anterior cingulate cortex (ACC), ventromedial prefrontal cortex (VmPFC), and thalamus when compared to other anxiety disorders (Etkin, & Wager, 2007). In a meta-analysis of resting-state fMRI studies, individuals with PTSD presented with hyperactivity in the cerebellum and ventral medical prefrontal cortex, with a contrasting hypoactivation in the dorsal medial pre frontal cortex (Hayes, Hayes, & Mikedis, 2012; Wang et al., 2016). Further, research highlighted that longer illness duration for PTSD is associated with an increase in cerebellar activity (Wang et al., 2016). Studies have also highlighted that among individuals with PTSD there is decreased activation and a reduction in cerebral blood flow to the thalamus (Hayes et al.,

2012; Yin et al., 2011). Further, alterations of both the go/no-go system and DMN are consistently found among individuals with PTSD (Anticevic et al., 2012; DiGangi et al., 2016; Patel, Spreng, Shin & Girard, 2012; Lindemer, Salat, Leritz, McGlinchey, Milberg, 2013; Santhanam, Wilson, Oakes, & Weaver, 2019; Shucard, McCabe, & Szymanski, 2008; Sripada et al., 2012). Thus, among individuals with PTSD, there is likely an alteration in neural activity within the CCTCC, specifically in areas associated with cognitive dysmetria and NSS.

Among individuals with mTBI, structures implicated in cognitive dysmetria show a similar pattern as those in PTSD. According to a large meta-analysis of fMRI and Diffusion Tensor Imaging studies of mTBI, when compared to healthy controls, individuals with mTBI show decreased frontal lobe activity, specifically in the medial frontal gyrus, anterior cingulate cortex, precentral gyrus, and dorsolateral prefrontal cortex (Eierud et al., 2014). Furthermore, among individuals with mTBI, increased activity of the cerebellum was found and is associated with a diagnosis of mTBI (Eierud et al., 2014). Moreover, multiple studies have demonstrated an alteration of thalamic activity among individuals with mTBI (Banks et al., 2016; Grossman et al., 2012). Thus, mTBI presents with neurologic defects consistent with cognitive dysmetria. Moreover, alterations in the DMN are consistently reported among individuals with mTBI (Nathan et al., 2015; Santhanam et al., 2019; Sours, Zhuo, Janowich, & Aarabi, 2013; Zhou et al., 2012). Although there is evidence-supporting deficits in the CCTCC among individuals with mTBI, these studies have specific limitations. Across most neuroimaging studies of mTBI, individuals with diagnosable mental health conditions are screened out, meaning that symptoms of mental health disorders are unaccounted for. Moreover, in a recent diffusion tensor imaging systematic review, the presence of mental health diagnoses was associated with similar white matter changes as those seen in mTBI (Asken et al., 2018). As noted earlier in this paper, there is

a high degree of overlap between PTSD symptoms and mTBI symptoms. As a result, conclusions about the primary driver of these neurologic changes in mTBI are limited. Consistent with this concern, individuals with mTBI examined within two weeks of injury show inverse associations with cognitive performance and areas of neurologic changes when compared to individuals assessed one month post injury, indicating that these groups may represent different cohorts (Eierud et al., 2014). Further, in a recent study, the association between the DMN among individuals with mTBI + PTSD and mTBI only group was inverse in nature (Santhanam et al., 2019), presenting early support for a unique change in the DMN among individuals with mTBI and PTSD. Other studies have noted that mTBI symptoms are not associated with neurologic changes and instead may be associated with mental health (Ponsford et al., 2012; van der Horn et al., 2016; Wäljas et al., 2015). Thus, the CCTCC may also be impaired among individuals with mTBI, though psychiatric comorbidity has not been ruled out as a possible contaminating factor.

Neurological Soft Signs in PTSD and mTBI.

Given that structures often associated with cognitive dysmetria, and subsequently NSS, are similarly affected in mTBI and PTSD, examination of existing literature is needed to determine the association of each disorder with NSS. Investigations of PTSD have indicated that NSS are a useful tool in discriminating individuals with PTSD from controls. Among twenty-seven male Vietnam veterans with PTSD and fifteen combat exposed veteran controls, a diagnosis of PTSD was associated with greater NSS (Gurvits, Lasko, Schachter, Kuhne, Orr, & Pitman, 1993). Gurvits et al. (1993) used combat-exposed controls to determine if exposure to trauma was the mechanism of change, instead of the symptoms associated with PTSD.

Two follow-up studies used similar methodology (Gurvits, Gilbertson, Lasko, Orr, & Pittman, 1997; Gurvits et al., 2000) both of which assessed a sample of adult women who were sexually abused as children, and a sample of Vietnam War veterans. Both samples were composed of individuals with PTSD and trauma exposed controls without PTSD. Gurvits et al. (1997; 2000) found that the ability to copy a multi-dimensional figure and the fist-edge-palm task completed over fifteen repetitions discriminated individuals with PTSD from controls in both samples. Thus, among individuals with PTSD, there is an overall increase in NSS independent of their exposure to traumatic events and type of trauma, further extending the findings of Gurvits et al. (1993).

In another study Gurvits et al., (2006) looked at the possible genetic link between PTSD and NSS. Using a case control design, Gurvits et al., (2006) identified 49 identical twin pairs, where 25 pairs of twins contained a sibling with combat-related PTSD and a sibling that was non-combat exposed ad not diagnosed with PTSD, and 24 pairs with a combat exposed sibling without PTSD paired with a non-combat exposed twin without PTSD (Gurvits et al., 2006). Gurvits et al. (2006) found that individuals PTSD exhibit a greater number of NSS. Additionally, the unexposed twins, who were considered high risk because their twin developed PTSD, presented with a higher number of NSS than did individuals in the low risk groups, the twins exposed to combat who did not develop PTSD and their sibling. These results indicated that, NSS discriminate the siblings in the PTSD twin group from the non-PTSD twin group. The results of this study are noteworthy as they highlight that there is a possible genetic predisposition to PTSD, which can be detected via NSS.

NSS show an association with mTBI immediately after injury, with preliminary evidence of long-term effects. When examining individuals both at the time of injury and at multiple

follow-up time points, Heitger et al. (2006) noted the presence of neurologic impairment across all time points for individuals with mTBI. Problematically, no assessment of mental health occurred, eliminating the ability to determine if these soft signs were associated with PTSD after mTBI. Similarly, Stephens, Salorio, Denckla, Mostofsky, and Suskauer (2017) found that neurological deficits were present among children across mild, moderate, and severe TBI. This study, though, was limited as they used a non-trauma control group and did not assess for mental health among any participants after initial assessment. In a study of veterans across military conflicts admitted to an inpatient psychiatric unit for suicidal ideation, the presence of NSS was greater among the mTBI group when compared to controls (Chapman, Andersen, Roselli, Meyers, & Pincus, 2010). Further, these effects were not attributable to mental health diagnosis or PTSD, but rather were solely associated with mTBI when entered into a regression model (Chapman et al., 2010). Additionally, Vanderploeg, et al., (2005) found that tandem gait was associated with a history of mTBI. In contrast, Greenberg et al. (2015) found that mTBI was associated with the presence of NSS immediately post injury but returned to baseline after 1 and 3 months. Moreover, they found depression was not associated with NSS (Greenberg et al., 2015). Thus, NSS may exist in mTBI, though support for these findings are not as robust as those in PTSD.

To date, only one study has examined the role of neurologic deficits among individuals with PTSD and mTBI occurring concurrently. Ruff et al. (2012) found that a comorbid diagnosis of mTBI and PTSD was associated with both soft and localized neurological deficits among half of the individual's assessed (Ruff et al., 2012). Conversely, only 4% of the sample with mTBI alone presented with a neurological deficit. Moreover, veterans with mTBI and PTSD had significantly lower Montreal Cognitive Assessment (MOCA) scores than did veterans with

mTBI only (Ruff et al., 2012). Although they did not assess NSS specifically, evidence from Ruff et al. (2012) support the hypothesis that PTSD may have a unique association with the presence of neurologic dysfunction. Although the findings of Ruff et al. (2012) provide support for neurologic changes associated with PTSD and mTBI, replication and further investigation is needed to determine the extent to which NSS are uniquely associated with mTBI, PTSD, and comorbid mTBI and PTSD.

Current Study

The current study will examine NSS in veterans without mTBI or PTSD, with mTBI but not PTSD, with PTSD but not mTBI, and with comorbid mTBI and PTSD. Participants in the current study were initially enrolled in a larger repository study examining post-deployment mental health during which measures of general mental health were completed (Brancu et al., 2017). They were then subsequently called to participate in other studies associated with the larger study, including the current study, focusing on neurocognition among veterans after returning from deployment. Veterans completed a battery of neurocognitive tasks, which included the Behavioral Dyscontrol Scale (BDS), the current study's measure of NSS. The current study is a secondary data analysis of the general neurocognitive study, focusing on NSS as a discriminating factor between mTBI, PTSD, and comorbid mTBI and PTSD.

Hypotheses

Hypothesis 1: Of the PTSD symptom clusters, cluster D – hyperarousal will be associated with a greater number of NSS when compared to other PTSD symptom clusters

Hypothesis 2: Veterans in the control group will have fewer NSS (e.g., score higher on the BDS Total Score and individual items) than will individuals in the illness group (mTBI, PTSD, and comorbid mTBI+PTSD) and the BDS will predict group membership.

Hypothesis 3: Veterans with PTSD will present with a greater number of NSS (e.g. score lower on the BDS Total Score and individual items) when compared to individuals in the mTBI group only. Further, the BDS will correctly predict group membership to either the PTSD or mTBI group.

Hypothesis 4: Veterans diagnosed with comorbid PTSD + mTBI will present with the most NSS (e.g. score the lowest on the BDS Total Score and individual items) when compared to healthy controls, or single illness group classification (mTBI or PTSD), and correctly predict group membership.

Hypothesis 5: Veterans in the healthy control group will present with fewer NSS (e.g. present with higher scores on the BDS Total Score and individual items on the BDS) when compared to individuals in the illness group, and the BDS will predict group membership over and above the effect of neuropsychological measures.

Hypothesis 6: Veterans in the mTBI+PTSD group will present with the most NSS (e.g. score the lowest on the BDS Total Score and individual items) when compared to healthy controls, mTBI only and PTSD only group and the BDS will predict group membership over and above the effect of neuropsychological measures.

Methods

The data analyzed for this paper were collected over a 12-year period beginning in 2005 and ending in 2017 as part of a project by the Mental Illness Research Education and Clinical Center (MIRECC), as a part of a multisite program conducted within Veterans Integrated Service Network 6 (VISN6). Methodology for the collection of this data, a portion of the participants, and measures have previously been described in a number of papers (Campbell et al., 2009, Belanger, Kretzmer, Yoash-Gantz, Pickett, & Tupler, 2009; McCormick, Yoash-Gantz,

McDonald, Campbell, & Tupler, 2013; Shura et al., 2014; Shura et al., 2015). The current project included assessments of multiple dimensions of cognitive and emotional functioning. The purpose of the broader study, from which this data was a part of, was to investigate post-deployment PTSD and TBI in recently discharged veterans, active-duty military personnel, and returning National Guard personnel (Brancu, et al., 2017). Participants were recruited from an IRB-approved protocol at Hunter Holmes-McGuire Veterans Affairs Medical Center (VAMC, Richmond, Virginia), Hefner VAMC (Salisbury, North Carolina) and Durham VAMC (Durham, North Carolina). Individuals were recruited via phone, letters mailed to their home, word of mouth, and from clinics within the VISN, including both inpatient and outpatient clinics. Additionally, some subjects completed neuropsychological testing as a part of their clinical care and their data was used as a part of the study. Subjects consisted of veterans, active-duty personnel, and reserve forces (National Guardsmen and Reservists) who have served since September 11, 2001. Exclusion criteria for the current study included individuals who were presently unable to provide consent, did not speak English, or who did not serve during the current conflicts.

Participants

To address the hypotheses presented above, groups were created based upon previously noted cut-offs and criterion. Individuals with PTSD Checklist scores above 50 or met symptom criteria for PTSD based on our putative diagnosis method, and who do not endorse mTBI were designated to the PTSD group. Individuals who endorse any of the following, consistent with ACRM (Mild Traumatic Brain Injury Committee, 1993) & VA/DOD guidelines (The Management of Concussion/mTBI Working Group, 2009) guidelines: loss of consciousness lasting less than thirty minutes, alteration of consciousness, any period of pre-traumatic or post-

traumatic amnesia lasting less than one day, and dizziness were placed into the history of mTBI group, provided their PCL score is below 50 or they did not meet symptom criteria using our putative diagnosis method. Individuals who endorse loss of consciousness above 30 minutes, Glasgow Coma Scale (GCS) below 13, or post-traumatic amnesia greater than 24 hours were excluded from analyses as they represent moderate to severe traumatic brain injuries. Additionally, individuals who had evidence of a penetrating injury or abnormal imaging (when available) were removed. Individuals who met both the history of mTBI and PTSD criteria above will constitute the mTBI + PTSD group. Finally, individuals who scored below 50 on the PCL-M or did not meet symptom criteria for putative diagnosis and do not endorse characteristics of mTBI were placed into the control group. These groups are coded in the dataset as: 1 = "control", 2 = "mTBI", 3 = "PTSD", 4 = "mTBI + PTSD".

To determine if the current study was adequately powered for the use of our analyses, we referenced previous research into the topic. According to Hsieh (1989), using a power of 0.8, the current study is adequately powered to detect an odds ratio of 2.5, which is a medium effect size for logistic regression. Additionally, previous studies examining neurological soft signs with four groups have used samples far smaller than the current study and included a greater number of variables. For example, Gurvits et al. (2000) had a total sample of 59 individuals across four groups with 41 total neurological soft signs. Therefore, based on Hsieh (1989) the current study is adequately powered to detect a medium sized effect using logistic regression.

Before conducting analyses, individuals were removed via the Word Memory Test (Green, 2005) and PAI Negative Impression Management scale (Morey, 1991) were excluded from analyses. Individuals who scored below 82.5 on the immediate recall (IR), delayed recall (DR), and consistency (CNS) measures of the WMT were removed from analyses. Additionally,

individuals who obtained a raw ≥ 8 (e.g. 73T) on the Negative Impression Management (NIM) scale of the PAI were removed. This is consistent with previous investigations using the NIM (Calhoun, Earnst, Tucker, Kirby, & Beckham 2000; Dretsch et al., 2017; Morey, 1991).[1] Of note, two individuals only completed one portion of the Green's WMT. They were retained for the purposes of the current analysis as they did not score below 82.5 on the DR or CNS portion (described below).

The current study was comprised of four groups: a control group with neither mTBI nor PTSD (-mTBI/-PTSD), PTSD (-mTBI/+PTSD), mTBI (+mTBI/-PTSD), and Comorbid (+mTBI/+PTSD). The original sample consisted of 442 individuals for whom measures were available. 48 individuals were removed because they did not complete either the Personality Assessment Inventory, Green's Word Memory Test, or the Behavioral Dyscontrol Scale. Subsequently 55 individuals were removed from the data as their TBI was classified as moderate to severe or penetrating injury for the purposes of this study. This resulted in a full dataset of 339 individuals who met criteria for study inclusion. Of these individuals, there were 60 individuals who scored below criterion for valid performance on the Word Memory Test (WMT) and 53 individuals who scored below acceptable criterion for valid symptoms on the Personality

[1] The current investigation included individuals who scored an 82.5 on the Word Memory Test's IR, DR, CNS. According to Green (2005), individuals who score less than or equal to 82.5 should be considered validity failures. For the PAI individuals were only removed from the current study for raw scores greater than or equal to 8 on the NIM (8=73T). Individuals were not removed for scoring above established criteria on the inconsistency or infrequency measures of the PAI (ICN ≥73 and INF ≥ 75) (Morey, 1991).

The results are based on the *N*= 238 individuals as described in the Participants section. Twelve additional individuals would be removed if the criteria above (Green's WMT less than or equal to 82.5, and individuals who performed above established cutoffs (ICN ≥73 and INF ≥ 75) on the PAI were used. The analyses were re-run using these criteria and there were no changes to the main study findings. Minor changes were noted, though they do not change the overall conclusions of the study and were associated with small effects (see Appendix E for the results with individuals removed based on these criteria).

Assessment Inventory (assessed via the negative impression management subscale). 15 individuals performed below acceptable criterion on both the WMT and PAI. Furthermore, one subject was removed from the study as they were missing neuropsychological measures and one individual was removed as they were missing the PCL at the time of study closure (see Appendix B). In total, 98 individuals were removed for validity concerns, leaving a final sample of 238 individuals. A t-test was conducted to test for differences on variables of interest between the individuals excluded from and included in the current study. Table 1 shows that individuals who were removed from the sample due to poor performance and symptom validity presented with a greater number of total PTSD symptoms, perform worse on the BDS, were more likely to have a mild Traumatic Brain Injury, and reported fewer years of education.

Table 1
Differences between Validity Pass and Fail Groups

Measure	Passed Validity Testing, *N* = 238	Failed Validity Testing *N*=98	*t*-test
	M (SD)	M (SD)	
PCL	36.47 (17.01)	55.92 (18.49)	9.29**
BDS	22.04 (2.77)	20.62 (3.52)	3.97**
Education	14.34 (2.07)	13.40 (9.17)	3.82**
Age	36.50 (9.94)	33.76 (2.07)	2.40*

Notes. *$p<0.05$, **$p<0.01$ level; $N = 93$ for education due to missing data or impossible values

Additionally, as noted in Table 2, the original sample consisted of many more individuals who met criteria for PTSD or mTBI+PTSD group prior to implementation of validity testing. These results were expected, as previous literature has highlighted increased reporting of PTSD and mTBI symptoms among individuals who score poorly on symptom and performance validity measures (Armistead-Jehle, 2010; Merz et al., 2017; Nelson et al., 2010). Moreover, previous

studies assessing neurocognitive functioning across similar groups have identified the impact of symptom and performance validity (Combs et al., 2015).

Table 2
Group makeup prior to removal of individuals for effort testing failure

Group	PCL ≥ 50 Before Effort	Putative Diagnosis Before Effort	PCL ≥ 50 After Effort	Putative Diagnosis After Effort
Control	153	147	138	134
mTBI	57	48	42	37
PTSD	66	72	33	37
mTBI + PTSD	64	73	29	34

The demographics of the final sample are listed in Table 3. Of note, as some subjects at one of the sites were collected during clinical care, their marital status, rank, time since TBI and conflict participation was not collected for the purposes of the study. All data represented in Table 3 is based on data that was available at the time of this project (see Appendix B for more details).

Table 3

Characteristics of Final Sample

	Demographics of Sample after SVT and PVT removal
Gender	
Male	84.50%
Female	15.5%

Age – mean years *(SD)*	36.50 *(9.94)*
	Range: 19 - 63
Education	26.89% High school graduate or GED
	40.76% Some College
	20.20% Bachelors
	12.18% Graduate Education
Marital Status*	
	66.82% Currently Married
	12.73% Divorced
	2.73% Separated
	0.91% Widowed
	16.82% Never Married
Ethnicity	
Hispanic or Latino	4.24%
Race*	
White	70.59%
Black	28.99%
American Indian	2.52%
Asian/Pacific Islander	0.4%
Highest Rank**	
E1-E6	76.02%
E7-E9	12.67%
Warrant Officer	1.36%
Commissioned Officer	9.95%
Military Conflict***	
Operation Enduring Freedom	25.21%
Operation Iraqi Freedom	73.10%

Desert Storm/Desert Shield	11.7%
Kuwait	37.8%
Traumatic Brain Injury	
Years Since Most Recent Injury	8.60 (9.43)

Note. *Three individual's reported as bi-racial**Numbers based on available data ***Does not sum to 100% as individuals reported on and were able to serve in multiple conflicts

Procedures

Subjects were given a verbal description of the current protocol and invited to participate. Upon providing written informed consent, subjects were be assessed by a trained mental-health psychometrist with a comprehensive neuropsychological battery. Psychometrists were trained by a licensed neuropsychologist and needed to demonstrate competence in administration prior to engaging with participants. Competence was assessed by administering a mock assessment that was monitored for administration fidelity. Participants in the current study were then administered a comprehensive battery of assessments, of which a selected number are used in the current study. Typical administration began at 9am and was completed at 4pm with a 1-hour break for lunch. The assessments in the current study were given in the same order to each individual due the number of long-term memory tasks requiring specific delays to assess possible interference. All measures were given in the same order and were not counterbalanced to ensure that interference of other information did not impact delayed recall measures.

Measures

The measures included in the current study are a selected subset of measures used in the overall battery of neurocognition. They were selected based on their frequent use in neuropsychological assessment and use in previous studies of neurocognition among individuals with mTBI, PTSD, and mTBI + PTSD.

Behavioral Dyscontrol Scale (BDS): The BDS (Grigsby, Kaye, & Robbins, 1992; Grigsby & Kaye 1996) is designed to assess for the ability to independently regulate, initiate, and inhibit behaviors (Leahy et al., 2003; Suchy et al., 2003). Of the nine items on the BDS, seven assess various aspects of regulation of motor activity, which are consistent with Neurological Soft Signs noted in Bombin et al., (2005). The final two items consist of tasks that evaluate working memory/cognitive flexibility and a measure of insight. The BDS is administered and scored by the trained psychometrist who subsequently was tested on scoring procedures by the Principal Investigator. Items are scored on a 0 to 3 scale based upon performance on a given task using the BDS-II scoring system. Previous research has shown that the BDS-II scoring system improves the range of scores for younger, healthier populations (Grigsby & Kaye, 1996; Leahy, Suchy, Sweet, & Lam, 2003; Shura, Rowland, Yoash-Gantz, 2014; Suchy, Leahy, Sweet, & Lam, 2003). Using the BDS-II scoring system, scores can range from 0-27. Studies using the BDS have demonstrated acceptable reliability ($\alpha = 0.87$) among elderly (Grigsby & Kaye, 1996) and borderline reliability among a sample of veterans ($\alpha = 0.62$) (Shura, Rowland, Yoash-Gantz, 2014). In the current study, reliability for this measure was poor ($\alpha = 0.57$), resulting in the use of individual items for analysis. Previous studies have demonstrated that the BDS is a useful and valid measure for discrimination of Alzheimer's and mild cognitive impairment from controls (Belanger et al., 2005) and later functional impairment after hospital discharge (Grigsby, Kaye, Eilertsen, & Kramer, 2000; Suchy, Blint, & Osmon, 1997). Further, the BDS demonstrated an improved ability to classify severity traumatic brain injuries when compared to other measures of executive functioning (Suchy, Leahy, Sweet, & Lam, 2003).

TBI Status: Assessment of a history of TBI was based upon self-report on a single measure in the current study, the TBI screen (Ivins et al., 2003). The Ivins TBI screen is a brief

measure of mTBI focusing on symptoms associated with mTBI. This questionnaire was developed in consultation with the Defense and Veterans Brain Injury Center (DVBIC), to assesses for lifetime "head injuries," mechanism, date, need for hospitalization, altered mental status, loss of consciousness (with response options of : 1–20 min, 21–59 min, ≥59 min), amnesia prior to the event (<24 hrs, 1–7 days, ≥7 days), anterograde amnesia for the injury (none, don't know, or recovered memory in <1 hr, 1–24 hrs, 24 hours–7 days, ≥7 days), and "feeling dazed or confused". On the TBI Screen, the loss of consciousness response items do not directly correspond to ACRM criteria (Mild Traumatic Brain Injury Committee, 1993) or VA/DOD Criteria (The Management of Concussion/mTBI Working Group, 2009). As such, individuals who reported LOC greater than 21-59 minutes were removed from the current study, as these individuals may have sustained a moderate traumatic brain injury. This decision was made to take a conservative approach to mild traumatic brain injury and not overestimate the prevalence of mild injuries in the sample. Additionally, at one site, some individuals did not complete the TBI Screen and so determination of their injury severity was made by medical record review. If a TBI Screen was available, it was used to determine TBI status. For individuals with a completed medical record review, a finding of an abnormal CT moved the individual from an mTBI to a "moderate TBI" for the purposes of our study, consistent with VA/DOD Guidelines (The Management of Concussion/mTBI Working Group, 2009). Additionally, individuals were removed if there was evidence of penetrating injury (e.g. shrapnel).

Green's Word Memory Test (WMT): The WMT is a computerized measure of verbal learning and memory which asks the participant to remember 20 word pairs (Green, 2005; Green, Lees-Haley, Allen, 2003). Individuals are presented with a set of 20 word pairs and

subsequently are asked to pick the word that appeared on the original test within a list of 40 pairs. The computer provides the individual with feedback associated with the correctness of their responses. After a 30-minute delay, a delayed response portion of the test is administered using a similar protocol, where individuals must identify the original 20 word pairs. This test is used to assess performance validity both in the current study and previous work from a portion of the current data set (McCormick et al., 2013). The WMT has been used in a variety of settings including legal (Green, Iverson, & Allen, 1999), custody (Flaro, Green, & Robertson, 2007), and mTBI assessment (Green, Flaro, & Courtney, 2009). The WMT has demonstrated a strong ability to discriminate between those providing full and suboptimal effort can predict up to 50% of the variance in neuropsychological assessment scores (Green, et al., 2003).

PTSD Checklist – Military (PCL-M): This is a 17-item self-report measure of PTSD symptoms based on the DSM-IV diagnostic criteria. (Weathers, Huska, & Keane, 1991; Weathers, Litz, Herman, Huska & Keane, 1993). The PCL-M asks participants to recall their most distressing military experience and report on PTSD symptoms associated with this experience. On the measure, subjects are asked to report how much they have been bothered each PTSD symptom, over the past month, using a 1 to 5 scale. On this measure 1 represents "not at all" and 5 represents "extremely." Multiple studies have highlighted strong internal consistency, test-retest reliability, and convergent and discriminant validity of the PCL-M (Weathers et al., 1993; Wilkins, Lang, & Norman, 2011). Studies examining the PCL-M have used multiple methods and cut scores for determining probable PTSD (McDonald & Calhoun, 2010). The most commonly used method is based upon total score, using a cutoff of 50 to determine probable PTSD (Riviere, Kendall-Robbins, McGurk, Castro, & Hoge, 2011). The current study used two procedures, a cutoff score of 50 and a putative diagnostic method,

requiring an individual to endorse items above a "3" across the three symptom clusters (1 item for cluster B, 3 for cluster C, and 2 for cluster D). This was termed putative diagnosis for the purpose of the current study.

Beck Depression Inventory – II (BDI-II): Is a widely used instrument for measuring symptoms of depression (Beck, Steer, & Brown, 1996). The BDI-II contains 21 items that assess severity of depressed mood. The BDI-II has demonstrated these properties in multiple studies assessing depression in mTBI (Homaifar et al., 2009; Rowland, Lam, & Leahy, 2005). According to Homaifar et al. (2009), the most appropriate cut off score for consideration of probable depression on the BDI-II among individuals with mTBI is 19.

Personality Assessment Inventory (PAI) – Computer Administered: The PAI (Morey, 1991) is a 344-item instrument where each item is rated on a 4-point scale. Prompts on this measure include "false"/"not at all true" to very true, (Morey, 1991). The PAI generates 22 full scale scores. The PAI's full scale scores include 4 validity scales, 11 clinical scales, 5 treatment scales, and 2 interpersonal scales (Morey, 1991). In the current study, the PAI will be used as our measure of symptom validity, as the PAI assess multiple aspects of symptom impression management (Rogers, Sewell, Morey, & Ulstad, 1996). Based on the goals of the current study, to determine if individuals are over-reporting symptoms, the negative impression management subscale was used to determine symptom validity, by employing a cut-off score of ≥8, such that only participants scoring below eight were included in the current study (Calhoun, et al., 2000; Dretsch et al., 2017; Morey, 1991).

Grooved Pegboard: The Grooved Pegboard (GP: Ruff & Parker, 1993; Trites, 2002) assesses fine-motor speed and is a measure of dexterity (Hanna-Pladdy, Medoza, Apostolos, & Heilman, 2002). On the GP, subjects are required to rapidly place metal pegs into a pegboard

with keyhole shaped openings. The task requires the individual to manipulate small pegs into 25 holes with arbitrarily situated slots (Trites, 2002). The current study used measures of time for both dominant and non-dominant hand as study variables to determine fine motor speed and dexterity. To create standard scores, tables in the manual (Trites, 2002) were used and raw scores were converted to *z*-scores.

Wechsler Adult Intelligence Scale – Third Edition (WAIS-III): The WAIS-III is the third edition of an often-used instrument for the assessment of IQ (Wechsler, 1997). Subjects in the current study completed Digit Symbol Coding, Block Design, Symbol Search, Similarities, and Letter Number Sequencing Subtests. These subtests were used as they commonly occur in neuropsychological assessments and tap in to domains previously shown to be impaired among individuals with mTBI, PTSD, and mTBI + PTSD (Fisher, Ledbetter, Cohen, Marmor, & Tulsky, 2000; Samuelson et al., 2006; Taylor & Heaton, 2001). Standard scores were converted to raw scores using the WAIS-III interpretive manual (Wechsler, 1997).

Wechsler Test of Adult Reading (WTAR): The WTAR (Wechsler, 2001) consists of 50 words of increasing difficulty that the subject must read aloud. Individuals are scored "0" for incorrect pronunciations and "1" for correct pronunciations. The WTAR is commonly used as a measure of pre-morbid intellectual functioning (Mullen & Fouty, 2014). Previous research has supported the use of the WTAR among individuals with a history of TBI (Green, et al., 2008). The current study used the WTAR scaled score for the purposes of analyses (Wechsler, 2001).

Conners' Continuous Performance Test (CPT-II): The CPT-II (Conners & Multi-Health Systems [MHS], 2004) is used to measure visual vigilance and sustained-attention deficits. Subjects are presented with a random series of letters, which are presented at a variable rate. Subjects respond to a target stimulus by pressing a key on the computer. Multiple measures are

derived using the CPT including an ADHD clinical confidence interval, and measures of attention, impulsivity, and vigilance. The current study was focused on measures of attention, and as such the detectability and hit rate measures were used. Raw scores were converted into T-scores using the interpretive computer program (Conners & MHS, 2004).

California Verbal Learning Test, Second Edition (CVLT-II): The CVLT-II (Delis, Kramer, Kaplan, & Ober, 2000) examines verbal learning, organization, and memory (Jacobs & Donders, 2007). Subjects are required to listen to and repeat back 16 words during 5 initial trials. After completion of the first five trials, individuals are provided with a distractor list of 16 new words that they must recall. Then, immediately upon completion of the distractor list, subjects are asked to freely recall the initial list that was read five times previously. After a delay of 20 minutes, subjects are asked to recall the initial list of words with and without cues. The current study focused on immediate and long delay (20 minute) verbal recall. The first was obtained using a total score for the first five trials, which was subsequently converted to a T-score. The long delay free recall score was obtained by converting an individual's raw score to a z-score. Conversions for both measures were performed using normative data from the interpretive manual (Delis et al., 2000).

Brief Visuospatial Memory Test-Revised (BVMT-R): The BVMT-R (Benedict, Schretlen, Groniger, Dobraski, & Shpritz, 1996) evaluates aspects of visuospatial learning, memory, and recall. The BVMT-R has the participant complete three learning trials, where they view a page with six figures, for ten seconds, and then draw as many of the figures as possible on a page. In the current study, a single set of stimuli was used. Responses are scored for both correct drawing and location on the page. After a 25-minute delay, there is a single free recall trial, considered the delayed recall task. Then, participants completed a forced choice task. To assess both

immediate and long term visual recall, the current study used scaled score measures of total immediate visuospatial recall (measured across all three trials) and the delayed visuospatial recall, measured by a single trial. Raw scores were converted to T-scores using the interpretive manual (Benedict, 1997). For scores falling below a T-score of 20, a T-score of 19 was assigned, consistent with the manual.

Rey-Osterrieth Complex Figure Test (ROCFT): The ROCFT (Rey, 1941) is a measure of organization, planning, and executive functioning. During this task, individuals are presented with a complex figure and are subsequently asked to copy the figure. Subjects are then asked to recall the figure 3 minutes later to complete an immediate recall trial. They subsequently are asked to complete the task again, 30 minutes later. The test also includes a yes-no recognition trial, to determine if individuals can recognize various elements of the original drawing. The current study used the immediate recall trial (measured 3 minutes after the copy trial). Normative data was taken from the interpretive manual to convert the raw score into a T-score, using the basic scoring system for correctness and accuracy (Meyers & Meyers, 1995). For scores falling below a T-score of 20, a T-score of 19 was assigned, consistent with the manual.

Stroop Color and Word Test: The Stroop Color and Word Test examines attention, processing speed, and response inhibition (Stroop, 1935). There are three trials on this version of the Stroop test, a reading trial (subjects read the presented word), a color trial (read the color of a visual stimulus), and a color word task. On the color word task, subjects read the color of the text, of a word that differs from the color (e.g. red ink used to print the word "green"). The current study used the color word score, as this represents a measure of inhibitory control (Chaytor, Schmitter-Edgecombe, & Burr, 2006). This measure is derived by subtracting an individual's performance on the color word task from their age and education predicted

performance. Normative data from the most recent manual (Golden & Freshwater, 2002) was used to convert scores into interference T-scores.

Trail Making Test (TMT: Tombaugh, 2004): The TMT is a set of two tasks, the Trail Making Test A (TMT A) and Trail Making Test B (TMT B). In the TMT A, subjects are asked to sequence and connect circles as fast as they can, without making mistakes, with only numbers inside, in ascending numerical order. This task measures visuomotor processing speed (Tombaugh, 2004) On TMT B, stimuli contain both numbers and letters, requiring participants to connect circles in alternating numerical and alphabetical order as rapidly as possible. TMT B assesses visuomotor speed with an added cognitive flexibility component (Kortte, Horner, & Windham, 2002). Scores were obtained using the time to complete each task. Given the wide variety of normative data for this test, standardized scores were derived from normative data based on the Tombaugh (2004) article, and norms were used for individuals with above 12 years of education. One individual scored far below the average (*z*-score of -15.27), and as a result their score was moved to the next lowest value contained in the data set to decrease the impact of a univariate outlier.

Wisconsin Card Sorting Test-Computer Administration – 64 Card: CV4 edition (WCST): The WCST (Grant & Berg, 1948; Heaton et al., 1993) is designed to test an individual's ability to form a cognitive set and flexibility problem-solve and shift sets (Anderson, Damasio, Jones, Tranel, 1991). Subjects are asked to a presented stimulus card with one of four target cards. The matching protocol is determined by the computer and is based on a set of predetermined concepts (i.e. color, form, or number). The target concept changes during the course of the test based after a pre-set interval. Individuals are not provided with any instructions on how to sort the cards. Instead the subject must respond to information provided by the computer about the

correctness of their responses. For the purposes of the current study, the number of errors was used and converted to a T-score based on age and education norms (Heaton et al., 1993) using computerized software.

Data Analysis

To address the hypotheses discussed above, the analyses for this study focused on the use of two statistics procedures, logistic and multinomial logistic regression. The independent variable of interest in the current study is the BDS, our measure of NSS. The BDS was entered as an IV in two ways, as a total score and as individual items. The decision to use raw total score and individual items rather than using previously-derived factors from the BDS-II was made for multiple reasons. First, previous research on PTSD and NSS have analyzed data both using individual items and total scores (Gurvits et al., 2000; 2006). As there is limited research on NSS, the current study sought to replicate previously used methods of analysis. This method of analysis was selected by Gurvits et al., (2000; 2006) as measures of NSS have items assessing unique and individual constructs. Additionally, as noted above, the total score has poor internal consistency. In sum, based on previous research, poor psychometrics, and content, the decision was made to conduct two regressions per hypothesis, with the first using BDS Total Score and a second regression that uses BDS individual items as the IV. Hypotheses two through six were analyzed by using both the BDS Total Score and individual BDS items in separate models.

Another decision point in the current study was the determination of individuals who meet criteria for PTSD in the current sample. In this study two different methods of classification were used, as the best approach to the PCL for diagnostic sensitivity and specificity is still up for debate (McDonald & Calhoun, 2010). The first approach was to assign participants to the PTSD group by a PCL of ≥ 50, which is a cut-off score is frequently used in veteran literature

(McDonald & Calhoun, 2010). This method of classification resulted in a PTSD diagnosis for 26.05% of the sample. The second method used to assign participants to the PTSD group is to use the individual items on the PCL to create a putative diagnosis of PTSD based on the DSM-IV criteria. In this method individuals who endorse a 3 ("moderately" or above) on 1 of the first 5 questions (re-experiencing symptom cluster), 3 items from questions 6-12 (avoidance symptom cluster), and 2 items from questions 13-17 (hyperarousal symptom cluster). This method of PTSD diagnosis classified 29.83% of the sample has meeting the current study's PTSD criteria. Classification of individuals into the four groups based on PTSD cutoff can be found in Table 4.

Table 4

Groups after removal of individuals for SVT and PVT Failure

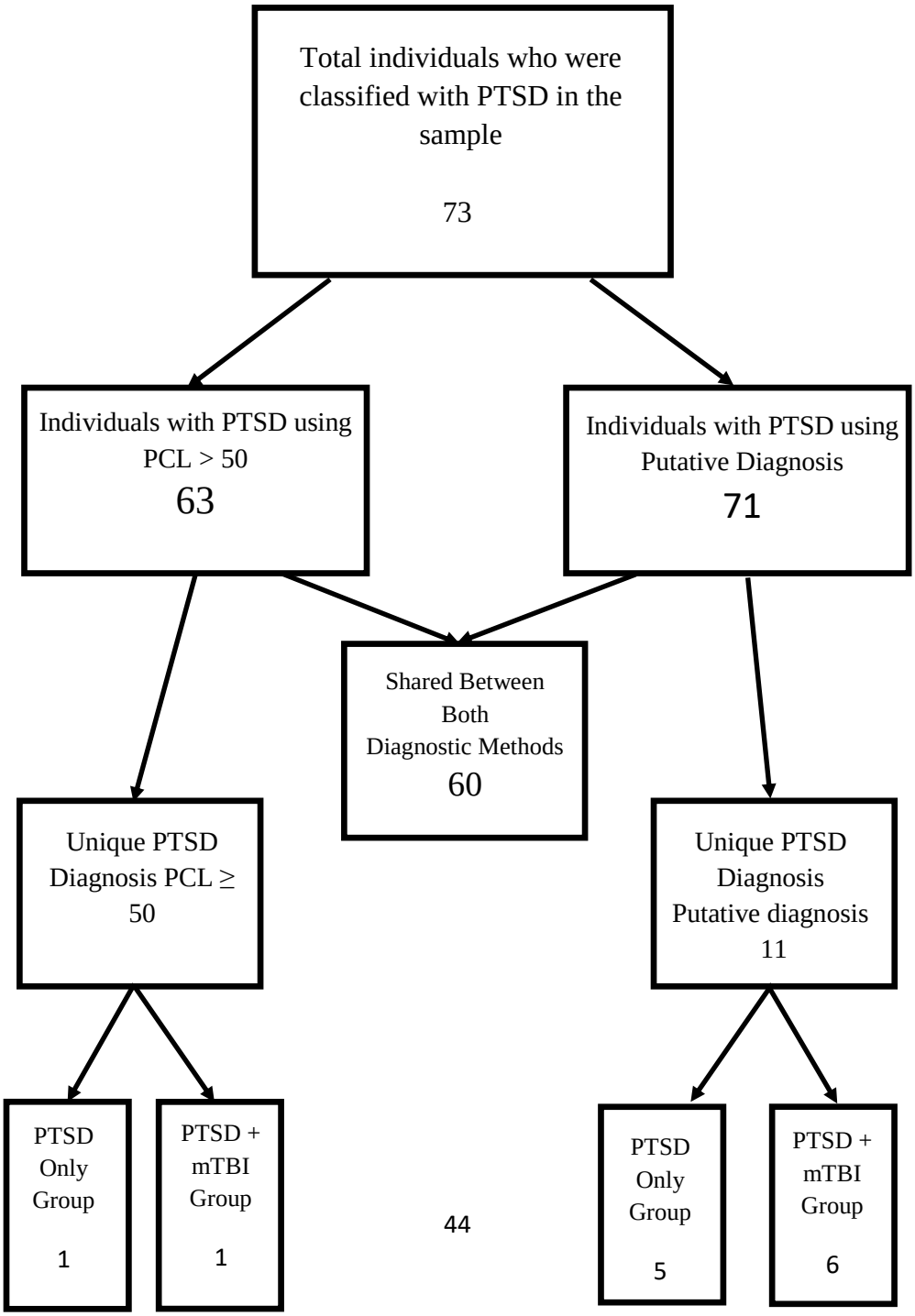
Group	PCL ≥ 50	Putative Diagnosis
Control	140	136
mTBI	36	31
PTSD	33	37
mTBI + PTSD	29	34

A Cohen's kappa analysis was conducted to determine differences between the two methods of assigning individuals to a group with PTSD. This method found strong agreement between the two methods ($\kappa = .86$ $p < .001$). A total of 73 unique individuals met criteria for PTSD using both PTSD criteria. A total of 71 individuals were considered to meet PTSD criteria using the putative diagnosis method and 62 using the PCL ≥ 50 method. Within these two diagnostic methods, the putative diagnosis method classified 11 individuals with PTSD not classified by the PCL ≥ 50 method. Conversely, the PTSD ≥ 50 method classified 2 individuals with PTSD who were not classified by the putative diagnosis method. For a visual representation

of how individuals were diagnosed and placed into groups using different cutoffs please see Figure 1. Thus, while there was strong agreement overall, the number of individuals varied between the groups, necessitating the use of both methods for diagnosing PTSD in the following analyses.

Figure 1

Group membership based on PTSD diagnosis



To examine hypothesis 1, that the hyperarousal symptom cluster of PTSD will show the greatest association with the BDS, a Fisher's Z test was used to compare if there are significant differences between the correlation between the BDS and the hyperarousal symptoms cluster and the BDS and each of the other symptom clusters. This procedure allows for comparison of the magnitude of associations using a parametric test.

To examine hypothesis two, four hierarchical binary logistic regressions were used to examine if the BDS-II can discriminate between control subjects and individuals with a diagnosis (mTBI, PTSD, mTBI+PTSD). The dependent variable of this analysis was the binary group classification ("0" = control; "1" = illness). The independent variables of interest were the BDS Total Score and individual items on the BDS. These were entered into two separate models, the first using the BDS Total Score as the IV and the second using individual items. Within their respective regressions, the BDS Total Score and individual items were entered in step two of the model, after age and years of education were added in step one.

To examine hypothesis three, that the PTSD group will differ from the mTBI group on the BDS-II total score and individual items, and the BDS-II will correctly classify individuals into the mTBI and PTSD groups, four multinomial logistic regressions were run. The first and second model used the BDS Total Score as a predictor of group membership, defined by putative diagnosis of PTSD in the first and PCL $\geq$ 50 in the second. The third and fourth model used the individual BDS items as a predictor of group membership (defined by putative diagnosis and PCL $\geq$ 50 respectively). To look for group differences between mTBI and PTSD, the ANOVA table of this multinomial logistic regression was examined. Additionally, the mTBI and PTSD portion of the classification table was used to determine whether PTSD or mTBI group membership is better predicted by the BDS-II. As multinomial logistic regression does not allow

for hierarchical model procedures in SPSS 17.0[2], in each model all variables (including demographics) were entered simultaneously and allowed to vary.

To examine hypothesis four, a similar procedure was used as in hypothesis three. Four multinomial logistic regressions compared the co-morbid group to the healthy control and single diagnosis groups by using the mTBI+PTSD group as the reference category. Specifically, group membership was entered as the DV (0 = "control", 1 = "mTBI", 2 = "PTSD", 3 = "mTBI + PTSD"). Four separate models were created where the first and second model used the BDS Total Score as a predictor of group membership, defined by putative diagnosis of PTSD in the first and PCL $\geq$ 50 in the second. The third and fourth model used the individual BDS items as a predictor of group membership (defined by putative diagnosis and PCL $\geq$ 50 respectively). In addition to assessing if the overall model was significant, the current hypothesis will be addressed by examining the ANOVA table and selecting mTBI+PTSD as the reference category of the multinomial logistic regression. As noted above, the SPSS 17.0 multinomial logistic regression program does not allow for hierarchical model procedures and so all variables were entered simultaneously and allowed to vary.

Prior to conducting hypotheses five and six, neuropsychological assessment measures examined in these hypotheses were assessed for missing data. 83% of the sample had complete data for all measures. Missing data was handled by using mean imputation. Mean imputation was used because the current statistics package did not contain multiple imputation procedures (refer

[2] Due to policies and procedures across the three sites contained in the current study, the data was not able to be moved from servers at the Department of Veterans Affairs for analyses. The only dedicated statistics program on the computer at the VA was a basic version SPSS 17.0 (2008). This version of SPSS did not permit the development of hierarchical multinomial logistic regressions, necessitating terms to either be forced into the model, or entered stepwise, simultaneously. Additionally, the statistics program did not permit the use of multiple imputation procedures, necessitating the use of mean imputation.

to footnote 2). Only one measure, the CPT-II, had a high degree of missing data. This data was missing because of a computer error resulting in unsaved data at one of the sites.

To examine hypothesis five, that individuals in the healthy control group will perform better than individuals in the illness group on the BDS, and the BDS will predict group membership over and above the effect of neuropsychological measures, four stepwise binary logistic regression were used. Hypothesis five extends hypothesis two, in which the BDS was used to predict control vs. illness group membership; in this hypothesis other neuropsychological measures will be added in a stepwise fashion to the model first to see whether the BDS predicts over and above the effect of these other variables. This decision was made as due to the number of predictors, concerns for model over fitting were considered. As noted earlier in this paper, neuropsychological variables have shown efficacy in discriminating individuals with PTSD, mTBI and mTBI+PTSD from controls (Combs et al., 2015; Dolan et al., 2012). The neuropsychological assessment variables listed in Table 2 were entered stepwise in step 2, following demographic variables and the Wechsler Test of Adult Reading (WTAR) entered in step 1. The BDS-II total score was entered in step three of the first pair were entered simultaneously in step three of the second set of models. The first set of models used putative diagnosis to define the PTSD groups and the second set of models used PCL $\geq$ 50 to define the PTSD groups. The dependent variable of these analyses was the binary group classification ("0" = control; "1" = Illness). To address this hypothesis, the change in chi-square from step 2 to step 3 was the primary outcome measure.

Table 5

Neuropsychological Measures included in the study

Trail Making Test A	Rey-Osterrieth Immediate Recall
Trail Making Test B	WAIS-III Digit Symbol Coding
Grooved Pegboard Dominant Hand	WAIS-III Similarities
Grooved Pegboard Non Dominant Hand	WAIS-III Block Design
Stroop Color Word	WAIS-III Symbol Search
CVLT Total Score Trials 1-5	WAIS-III Letter Number Sequencing
CVLT Long Delay Free Recall	CPT-II Detectability
Wisconsin Card Sorting Test Errors	CPT Hit Rate
Total score BVMT	Wechsler Test of Adult Reading
BVMT delayed free recall	

Notes. WAIS-III = Wechsler Adult Intelligence Scale: Third Edition; CVLT = California Verbal Learning Test-II; BVMT= Brief Visuospatial Memory Test; CPT-II: Conner's Continuous Performance Test: Second Edition

To examine hypothesis six, that the comorbid mTBI+PTSD group will exhibit the worst performance on the BDS-II compared to other groups, and that the BDS-II will predict group membership over and above other neuropsychological measures, four multinomial logistic regressions were conducted. The dependent variable of this analysis was the group classification (0 = "control", 1 = "mTBI", 2 = "PTSD", 3 = "mTBI + PTSD"). The independent variables of interest (used in separate models) were the BDS Total Score and individual items on the BDS. Variables of interest were entered using a stepwise procedure. Additionally, given the number of neuropsychological measures and that multinomial logistic regression requires a greater number of degrees of freedom per predictor (in the case of the current analysis each predictor required 3 degrees of freedom), entering them all would severely limit power and decrease predictive ability. The model was created by forcing demographic variables into the model (age and education) and premorbid ability measured by the WTAR into the first step, as they are important for use with neuropsychological measures. The same neuropsychological measures as employed in hypothesis 5 were entered in a stepwise manner to determine the best

neuropsychological predictors of group membership. Finally the BDS Total Score was forced into the third step into the first and second model (differentiated by use of PCL of ≥ 50 vs. putative diagnosis). For models three and four (differentiated by use of PCL ≥ 50 vs. putative diagnosis), the BDS individual items were entered using a stepwise procedure. This procedure allows the BDS Total Score and individual items to compete with neuropsychological measures to predict unique variance in group membership. To address this hypothesis, differences between the mTBI+PTSD group on BDS predictors will be compared to the other three groups.

Additionally, to determine the utility of the BDS when used within a battery format along with other neuropsychological assessments, a cluster analysis will be conducted. To complete the cluster analysis, neuropsychological measures and the BDS individual items will be included in a single model to allow for NSS variations. In an effort to map the clusters on to the pre-determined groups of control, mTBI, PTSD, and mTBI + PTSD, a four-cluster solution will originally be forced. Subsequently, consistent with hypothesis two and five, a two-factor model will be forced. Determination of the best solution will be based on consistency of classifying variable averages. Additionally, cross tabulations will be used to determine if the cluster analysis created groups map onto the two group ("0" = control; "1" = Illness) and four group (1 = "control", 2 = "mTBI", 3 = "PTSD", 4 = "mTBI + PTSD") classifications created for the purposes of this study.

Results

Correlations.

A correlation matrix was created to compare the relationship between the primary study variables, including the PCL (and associated clusters), BDS Total Score, individual BDS items, TBI classification, and demographic variables used in the models. Correlations of primary study variables, including the BDS total score can be found in Table 6. There was an inverse

association between the BDS and age (r=-.26, p <.001) indicating that greater neurologic dysfunction was found among older veterans. Further, the presence of a history of TBI was not associated with the BDS Total Score (r= -.04, p =.51) or any individual item on the BDS (see Appendix D, Table 11) for correlations between variables included in the study and individual items on the BDS). The BDS Total Score was negatively correlated with the PCL, with the direction indicating greater neurological dysfunction was associated with more symptoms of PTSD, though this relationship fell short of significance (r= -.12, p =.056). While there was not a significant relationship between the BDS Total Score and the PCL, the go/no-go task (BDS 4 (r =-.19, p = .004) and an item related to insight (BDS 9 (r =-.16, p = .015) were both significantly associated with PTSD symptoms. Thus, more impaired performance on the go/no-go task and poorer insight on the BDS were associated with an increased number of PTSD symptoms.

Table 6 Correlations between study primary study variables

	TBI	PCL Total	Cluster B	Cluster C	Cluster D	BDS Total	Education	Age
TBI	1							
PCL Total	.29**	1						
Cluster B	.27**	.85**	1					
Cluster C	.26**	89**	.83**	1				
Cluster D	.29**	88**	.80**	.86**	1			
BDS Total	-.04	-.12	-.11	-.10	-.15*	1.		
Education	-.10	-.15*	-.13*	-.12	-.18**	-0.10	1	
Age	-0.1	-0.06	-0.07	-0.06	-0.02	-.26**	.28**	1.00

*Notes. *. p <.05, ** p <.01*

TBI = Traumatic Brain Injury; PCL Total = Total Score on the PTSD Checklist; Cluster B = Re-Experiencing Symptoms of PTSD; Cluster C = Avoidance Symptoms of PTSD; Cluster D = Hypervigilance symptoms of PTSD
For correlations between clusters B, C, and D and the PCL total score, the corresponding symptom cluster was removed to reduce collinearity.

Hypothesis Testing

Hypothesis one. To address hypothesis one, that hyperarousal symptoms of PTSD will show a greater association with the BDS than the avoidance or numbing symptoms, correlations between these variables were examined. Only PTSD cluster D was significantly negatively

correlated with the BDS Total Score (cluster B (re-experiencing), r =-.11, p =.090, cluster C (avoidance), r =-.10, p =.141, cluster D (hyperarousal), r=-.15, p =.024). The association between Cluster D (hyperarousal) and both Clusters B (re-experiencing: *Fisher's z* = 0.44, p =.329) and C (avoidance: *Fisher's z* =-0.56, p =.287) did not significantly differ from one another. Moreover, while the association between cluster D and the BDS are significant, this is a small effect by conventional standards (Sullivan & Feinn, 2012). Therefore, hypothesis one is not supported; the BDS Total Score does not exhibit greater association with hyperarousal symptoms than with any other symptom cluster of the PCL.

Hypothesis two. To address hypothesis two, that control subjects will perform better on the BDS than individuals with a mTBI, PTSD, or mTBI+PTSD group classification, indicating less neurologic dysfunction, logistic regression was used (regression tables for Hypothesis two analyses are in Appendix D. Table 12-14). The dependent variable of this analysis was the binary group classification with PTSD defined by putative diagnosis ("0" = control; "1" = illness). In the first step of the model, age and education were added to control for their influence on study variables. The BDS total score was significant predictor of group membership ($\chi^2(1) = 4.35$, b= -0.11, p = .037). Further, this effect existed over and above the effect of age and education on group membership (Block χ^2 (1)= 4.44, p = .035). These results indicated that a one-point increase in the BDS Total Score (fewer number of NSS) was associated with a lower likelihood (OR=0.90) of being in the illness group (95% CI: [.82, .99]). Moreover, the model classified 58.0% of individuals correctly. Of note, the model predicted 81.6% of individuals correctly in the control group, while only predicting 26.5% correctly in the illness group.

In a second model, the dependent variable of binary group classification ("0" = control; "1" = illness) was defined using a PCL cutoff of 50. In the first step of the model, age and

education were added to control for their influence on the BDS. BDS Total Score was added next in the second step. In this model the BDS Total Score significantly predicted group membership ($\chi 2(1) = 4.98$, b= -.11 p = .03). Further, this effect existed over and above the effect of age and education on group membership (Block χ^2 (1)= 5.100, p = .024). These results indicated that a one-point increase in the BDS Total Score (fewer number of NSS) was associated with a lower (OR = 0.89) likelihood of being in the illness group (95% CI: [.81, .99]). When the PTSD group was defined by a PCL cutoff of 50, the overall model, including years of education, age, and the total BDS score, correctly classified 59.7% of individuals, predicting 26.5% of the illness group correctly and 82.9% of the control group. Thus, when PTSD is classified by a PCL score greater than 50, higher BDS scores (fewer number of neurological soft signs) predict a greater likelihood of control group membership.

To address concerns about the poor internal consistency of the BDS scale and highlight the unique variance associated with individual NSS, a subsequent pair of analyses using individual BDS items as the predictors of group membership was conducted. For both models, age and education were entered in the first step to control for their impact on the BDS. In the second step, the BDS individual predictors were entered simultaneously. The addition of the BDS individual items to the model significantly improved prediction over and above the effect of age and education (Block $\chi^2(9) = 18.39$, p = .031) when PTSD group membership was defined by putative diagnosis. Moreover, BDS Item 4 (a go/no-go task) emerged as a significant predictor of group membership ($\chi 2(1) = 6.84$, b= -.95 p = .009). For every one point increase on item 4 of the BDS, individuals were less likely (OR =0.39) to be in the illness group (95% CI: [.19, .79]). When the PTSD group was defined by a putative diagnosis, the overall model,

including years of education, age, and the total BDS score, correctly classified 63.0% of individuals, predicting 37.3% of the illness group correctly and 82.4% of the control group.

When a PCL cutoff of 50 was used to define the DV, the addition of the BDS individual items were significant over and above the effect of age and education, (Block $\chi^2(9) = 20.11$, $p = .017$). Within this model, BDS item 4 (a go/no-go task) ($\chi^2(1) = 7.86$, $b = -1.03$, $p = .005$; 95% CI: [.17, .73]) emerged as significant predictors of illness group membership. On BDS Item 4 (go/no go task), a one point increase (less neurologic dysfunction) was associated with a lower (OR = 0.36) likelihood of being in the illness group. When the PTSD group was defined by a PCL cutoff of 50, the overall model, including years of education, age, and the total BDS score, correctly classified 63.4% of individuals, predicting 36.7% of the illness group correctly and 82.1% of the control group. Thus, as the score on item 4 of the BDS increases (decreased NSS), there is a lower likelihood of being in the illness group. These results indicate that, when PTSD group membership was defined by PCL ≥ 50, while the overall model is predictive of group membership, only a go/no-go task (item 4) of the BDS discriminated between individuals in the control and illness group over and above the effect of education.

Hypothesis three. To address hypothesis three, that individuals in the PTSD group will perform worse on the BDS than will individuals with mTBI, a multinomial logistic regression was conducted (regression tables for Hypothesis three analyses are in Appendix D, Table 16-19). Age and education were entered as demographic controls to account for their impact on BDS scores. In the second step, the BDS Total Score was entered. The BDS Total Score was not a significant discriminating variable between individuals in the PTSD or mTBI group using putative diagnosis to define the PTSD group (PTSD as reference group: $\chi^2(1) = 0.76$, $b = .08$, $p = .383$; 95% CI: [.91, 1.29]). In a second model, when individuals items of the BDS were entered

instead of the BDS Total Score, the BDS individual items were not a discriminating predictor of overall group membership over and above the effect of education and age ($\Delta\chi^2(27) = 29.09$, $p = .356$). When examined across groups, only BDS Item 1 (dominant hand initiated alternating rhythm tapping) $\chi^2(1) = 3.99$, $b = 1.23$, $p = .046$; 95% CI: [1.02,11.37], discriminated between the mTBI and PTSD group. These results indicated that for every one point increase on item 1 of the BDS, individuals were 3.41 times more likely to be in the TBI group than the PTSD group. In addition, the PTSD group defined by putative diagnosis scored worse on the BDS Total Score than the control group (total score ($\chi^2(1) = 4.60$, $b = .15$, $p = .032$; 95% CI: [1.01, 1.33]), indicating that for every point increase on the BDS total score, individuals were 1.16 times more likely to be in the control group than the PTSD group. Furthermore, item 4 of the BDS (go/no-go task) was associated with a difference between the PTSD group and control group (item 4 $\chi^2(1) = 3.90$, $b = .90$, $p = .048$; 95% CI: [1.01, 6.02]). For every one point increase on Item 4 of the BDS (indicating better go/no-go performance), individuals were 2.46 times more likely to be in the control group. Additionally, the mTBI group scored worse on a single go no/go task when compared to the control group (Item 4 $\chi^2(1) = 5.13$, $b = 1.10$, $p = .024$; 95% CI: [1.16, 7.81]). Thus, for every one point increase on Item 4 of the BDS (indicating better go/no-go performance), individuals were 3.01 times more likely to be in the control group than the mTBI group. The model including total score correctly predicted 57.1% of individuals into their correct groups (with no individuals correctly classified into the PTSD, mTBI, or PTSD + mTBI group), while the model including individual items correctly predicted 56.3% of individuals, with 5.4% into the PTSD Group and 3.2% into the mTBI group. Thus, BDS Item 1 discriminated between the mTBI and PTSD group, finding that the mTBI group performed better on Item 1 when compared to the PTSD group.

A second model was created using the PCL ≥ 50 to define PTSD group membership. In the first step, age and education were entered as demographic controls to account for their impact on BDS scores. In the second step, the BDS Total Score was entered. The BDS Total Score was not a significant discriminating variable between individuals in the PTSD or mTBI group ($\chi^2(1) = 1.38$, $b = 0.10$, $p = .241$; 95% CI[.93,1.31]). Additionally, when individual items of the BDS were entered into step two instead of the BDS Total Score, no items emerged as significant predictors between the PTSD and mTBI group over and above the effect of age and education ($\Delta\chi^2(27) = 26.51$, $p = .51$). Although there was no difference between the PTSD and mTBI groups on the BDS items, the PTSD group scored worse on the BDS Total Score when compared to the control group ($\chi^2(1) = 5.76$, $b = .18$, $p = .016$; 95% CI [1.03,1.38]), such that for every point increase on the BDS (fewer NSS), individuals were 1.19 times more likely to be in the control group. Furthermore, BDS item 4 (a go/no-go task) discriminated between the PTSD and control group ($\chi^2(1) = 5.02$, $b = 1.04$ $p = .025$; 95% CI [1.13, 7.01]), indicating that for every one point increase on BDS item 4, individuals were 2.83 times more likely to be in the control group than the PTSD Group. Additionally, the mTBI group scored worse on a go/no-go task (item 4) when compared to the control group ($\chi^2(1) = 5.27$, $b=1.07$, $p = .022$; 95% CI: [1.17, 7.30]). Thus, for every one point increase on Item 4 of the BDS (indicating better go/no-go performance), individuals were 2.92 times more likely to be in the control group than the mTBI group. Consistent with the inability of the BDS to predict overall group differences, individual items correctly predicted 0% of individuals correctly in the mTBI and 9.1% into the PTSD group, while the total score only predicted 3.0% of PTSD group membership.

Hypothesis four. To address hypothesis four, that veterans diagnosed with comorbid PTSD + mTBI will perform worse on the BDS when compared to healthy controls, or single

illness group classification (mTBI or PTSD) and correctly predict group membership, four multinomial logistic regressions were run. In step one of all regressions, age and education were entered to control for their effect on the BDS. In step two, the BDS Total Score was entered for the first two models and individual items were entered for the second set (regression tables for Hypothesis four analyses are in Appendix D, Table 20-23). In the first model, using putative diagnosis to define PTSD group membership, the results of the multinomial logistic regression indicated that there were no significant differences between the mTBI+PTSD group and any other group (defined by putative diagnosis) on the total BDS (Control $\chi^2(1) = 1.45$, $b = .09$ $p = .228$; mTBI $\chi^2(1) = .03$, $b = .20$ $p = .864$; PTSD $\chi^2(1) = .52$, $b = -.06$, $p = .472$). When individual items of the BDS were entered instead of BDS Total Score, no items of the BDS discriminated between the mTBI+PTSD group and the mTBI group and the PTSD only group. Of note, BDS Item 4 when compared to the control group approached significance ($\chi^2(1) = 3.10$, $b = .86$ $p = .08$, Odds Ratio 2.36, 95% CI: [.91, 6.13]).

Results with the BDS Total Score were replicated with the PTSD group defined by a PCL of ≥ 50 (Control χ^2 (1) = 1.55, $b = .10$ $p = .214$; mTBI χ^2 (1) = 0.7, $b = -.03$ $p = .790$; PTSD $\chi^2(1) = .72$, $b = -.08$ $p = .405$). When defined by a PCL ≥ 50 no single item of the BDS discriminated individuals in the mTBI + PTSD group from any other group. As with putative diagnosis, BDS Item 4, when compared to the control group, approached significance ($\chi^2(1) = 3.66$, $b = .97$ $p = .056$, OR: 2.63, 95% CI: [.98, 7.10]). Thus, on the BDS, there were no significant differences across the mTBI only, PTSD only, and mTBI + PTSD group on either the BDS Total Score or individual items.

Hypothesis Testing: Neuropsychological Measures and BDS (Hypothesis 5 and 6)

To address hypothesis five and six, that the BDS Total Score and individual items will predict group membership when entered into a model with other neuropsychological tests, four logistic regressions (for hypothesis five) and four multinomial logistic regressions (for hypothesis six) were run, to replicate hypothesis two and four with the addition of neuropsychological tests. Given the volume of neuropsychological tests administered in the current battery and requirements for power in the current study, a forward stepwise approach was used to determine the predictive ability of the neuropsychological tests. When using neuropsychological assessments, raw scores were converted to standard scores for the purposes of the analyses. Additionally, age, education, and the Wechsler Test of Adult Reading (WTAR) were entered into the model to control for their impact on neuropsychological assessments. A correlation table of neuropsychological variables can be found in Appendix D, Table 23.

Hypothesis 5. To address hypothesis five, that the BDS will discriminate between the illness and control group above and beyond other neuropsychological measures, two logistic regressions were conducted. For each model, age, education, and the WTAR Standard score were forced into the first block of the logistic regression to control for these demographic variables. In the second step the neuropsychological assessment measures were entered stepwise. In the third block the BDS Total Score was forced into the equation (regression tables for Hypothesis two analyses are in Appendix D, Tables 25-28). These models indicated that the BDS Total Score did not predict group membership over and above the effect of age, education, and significant neuropsychological measures using putative PTSD diagnosis ($\chi^2(1) = 1.42$, $b = -.07$ $p = .234$; 95% CI [.84, 1.04]) or PCL $\geq$ 50 criteria to define the PTSD group, ($\chi^2(1) = 2.77$, $b = -.91$ $p = .096$; 95% CI [.82, 1.02]). Thus, the BDS Total Score did not predict group membership over and above the effect of age, education, and neuropsychological measures. In a second set of

models, only BDS item 4 improved prediction over and above the effect of significant neuropsychological predictors (Block $\chi^2(1) = 4.32$, $p = .038$) and (BDS 4: $\chi^2(1) = 4.14$, $b = -.70$ $p = .042$; 95% CI [.25, 98]), such that for every one point increase on BDS item 4, individuals were .50 times as likely to be in the illness group. A similar effect was found when using PCL ≥ 50 to define the illness group ($\chi^2(1) = 6.98$, $b = -.90$ $p = .008$; 95% CI [.21, 79]), such that for every one point increase on BDS item 4, individuals were .40 times as likely to be in the illness group.

Across the four models, either Dominant Hand or Non Dominant Hand Grooved Peg Board predicted illness group membership. When using Putative Diagnosis, Non-Dominant Grooved Peg Board predicted illness group membership when BDS total score was forced into the model: $\chi^2(1) = 6.16$, $b = -.34$ $p = .010$; OR: .71, 95% CI [.55, .92] or when using individual items $\chi^2(1) = 5.46$, $b = -.32$ $p = .019$; OR: .73, 95% CI [.56, .95]. When using a PCL ≥ 50 to define PTSD diagnosis, Dominant Hand Grooved Peg Board emerged as a significant predictor when using BDS total score ($\chi^2(1) = 5.78$, $b = -.24$ $p = .016$; 95% CI [.64, .96]), and individual items $\chi^2(1) = 5.60$, $b = -.24$ $p = .018$; 95% CI [.64, .96]) such that for every one unit increase individuals were .78 times as likely to be in the illness group. When using individual items of the BDS and Non-Dominant Hand Grooved Pegboard 63.9% of individuals were classified correctly using Putative Diagnosis (control: 84.9 vs illness: 34.3). When using PCL ≥ 50, along with individual items of the BDS and Dominant Grooved Pegboard, 66.8 of individuals were correctly classified (Control: 88.8 vs Illness 33.7). Thus, the BDS did not predict group membership between the illness and control groups over and above the effect of neuropsychological measures.

Hypothesis 6. To address hypothesis six, two multinomial logistic regressions were conducted using the BDS Total Score. The models were created using a forward stepwise

approach, as due to the nature of multinomial logistic regression, all items could not be entered simultaneously without a significant loss in statistical power. For each model, age, education, and the WTAR Standard score were forced into the first block of the multinomial logistic regression to control for these demographic variables. The neuropsychological assessment measures were entered in a stepwise manner in the second step. The BDS Total Score was also forced into the model (regression tables for Hypothesis six analyses are in Appendix D, Tables 29-30). When the BDS Total Score was entered into the model, it was not a significant predictor when PTSD group membership was defined by putative diagnosis ($\chi^2(3) = 2.26$, $p = .520$) or PCL ≥ 50 ($\chi^2(3) = 4.49$, $p = .213$). Thus, the BDS Total Score does not predict mTBI+ PTSD group membership over and above the effect of neuropsychological assessments.

Hypothesis 6b: Neuropsychological Predictors. When using a PCL cutoff of ≥ 50 to define PTSD groups, no significant neuropsychological predictors were added to the model using a cutoff of 0.05. When using a putative diagnosis to define the PTSD groups, Grooved Pegboard Non-Dominant Hand ($\chi^2(3) = 11.67$, $p = .009$). Additionally, there was a significant difference when the mTBI + PTSD group was compared to the control group ($\chi^2(1) = 5.79$, b=.43, $p = .016$, 95% CI [1.08, 2.17]), such that for every one unit increase on the Non-dominant hand grooved peg board, individuals were 1.53 times more likely to be in the control group. Additionally, this effect existed when the mTBI+ PTSD group was compared to the mTBI group ($\chi^2(1) = 4.65$, b=.54, $p = .031$, 95% CI [1.05, 2.80]), indicating that for every one unit increase on the Non Dominant Hand Grooved Pegboard, individuals were 1.72 times more likely to be in the mTBI group.

In a second set of regressions, focused on individual items of the BDS, a different procedure was used, due to the decrease in power when entering all nine items of the BDS

simultaneously into a multinomial logistic regression. For these two models, age, education, and the WTAR Standard score were forced into the first block of the multinomial logistic regression to control for these demographic variables. In the second step the neuropsychological assessment measures were entered in a stepwise manner as were BDS items using a forward stepwise procedure (regression tables for Hypothesis Six analyses are in Appendix D 31-32). When using a PCL cutoff of ≥ 50 to define PTSD groups, only BDS item 4 emerged as a significant predictor in the model ($\chi^2(3) = 11.14$, $p = .011$) but did not discriminate between the illness groups (mTBI group ($\chi^2(1) = .00$, b=-.01 $p = .986$, 95% CI [.37, 2.68]; PTSD group ($\chi^2(1) = .14$, b=-.19 $p = .712$, 95% CI [.31,2.22]). When compared to controls, the mTBI ($\chi^2(1) = 5.51$, b=-1.03 $p = .019$, *OR:* .36, 95% CI [.15,.84]), PTSD, ($\chi^2(1) = 7.58$, b=-1.21 $p = .006$, *OR:* .30, 95% CI [.13,.71]), and mTBI + PTSD group ($\chi^2(1) = 4.74$, b=-1.02 $p = .029$, *OR:* .36, 95% CI [.14,.90]) all performed worse on BDS item 4. When using putative diagnosis to define the groups, no item on the BDS emerged as a significant predictor when neuropsychological predictors were considered.

Hypothesis 6B: Neuropsychological Predictors. No neuropsychological measures discriminated between individuals in the mTBI + PTSD group when compared to any of the groups in the study using a PCL ≥ 50. When putative diagnosis was used to determine PTSD group membership, the mTBI + PTSD group significantly differed from the control group ($\chi^2(1) = 6.64$, b=.45 $p = .006$, *OR:*1.56, 95% CI [1.11, 2.20]) and the mTBI group ($\chi^2(1) = 4.51$, b=.53, $p = .034$, *OR:* 1.70, 95% CI [1.04, 2.77]) on the Non-Dominant Hand Grooved Pegboard task. No differences emerged between the mTBI + PTSD group and PTSD Group ($\chi^2(1) = .02$, b=-.02 $p = .91$, 95% CI [.69, 1.39]). A similar effect was found when using the PTSD group on Non-dominant grooved pegboard when compared to mTBI when individual items were entered ($\chi^2(1) = 4.95$, b=-.55 $p = .026$. 95% CI [.36, .94]), such that for every one point increase on the Non-

Dominant Hand Grooved pegboard, individuals were .58 times as likely to be in the PTSD group when compared to the mTBI group. Therefore, neither the BDS Total Score nor BDS individual items were predictive of a difference between the mTBI+PTSD group when compared to the mTBI or PTSD group. Additionally, when BDS individual items were entered, the mTBI + PTSD group performed worse on Non-Dominant Hand Grooved Pegboard when compared to the control and mTBI group.

Across all multinomial models, overall prediction was below 65% across the groups. Although predictive ability varied by model, prediction of the control group remained above 95% for all models. Conversely, group membership was only correctly predicted at 9.1% for the illness groups in one model, when PTSD was defined by PCL≥ 50 and individual items were entered. Thus even with the addition of step wise neuropsychological predictors, the ability to correctly classify individuals into the mTBI, PTSD, and mTBI+PTSD group remained below chance (25%) across all models.

Cluster Analysis

As noted in the above analyses, the BDS Total Score and individual items tended to poorly predict individual's membership in the four groups of interest. Based on this finding, a cluster analysis was used to determine what groups exist within the data based on the BDS and neuropsychological assessments. A *k-means* analysis was conducted on the BDS individual items and the neuropsychological assessments listed in Table 2 to determine what groups in the data would be produced should a 4-cluster or 2-cluster solution be selected. A 4-cluster solution was selected to attempt to mirror the *a priori* groups of control, mTBI, PTSD, and mTBI + PTSD. A 2-cluster solution was conducted in an attempt to mirror the *a priori* groups of control and illness.

Of the individuals with valid scores, 238 participants had complete data. Their neuropsychological assessment standard scores and BDS individual item scores were converted to within sample *z*-scores and analyzed using a *k*-means cluster analysis. For our 4 cluster solution, convergence was reached in 11 iterations. Univariate ANOVAs indicated that the clustered groups differed significantly on most classifying variables (all *p*s < .05). The *n* for each cluster varied from 24 to 117. Please see Appendix D, Table 33 for individuals scores across measures included in the cluster analysis. Naming of the groups was determined by examining the *z* scores across the items and subjectively identifying their patterns. Cluster 1 (*n* =51) was termed Mildly Impaired Reasoning and Memory as they scored slightly below average on both BVMT Tasks, Similarities, Block Design and Rey Immediate Recall. Cluster 2 (*n* =24) was most consistent with a Mild Cognitive Impairment (MCI), as they performed slightly to moderately below average on most neuropsychological measures and BDS items. Cluster 3 was termed Mild Processing Speed Deficits (*n* =46) as they scored slightly below average on Trails A and B, Digit Symbol Coding, Symbol Search, and BDS Item 1. Cluster 4 (*n* = 117) was termed Cognitively Healthy, as they tended to perform at or slightly above average across all tasks. The four cluster solution was significantly associated with the *a priori* defined groups (control, mTBI, PTSD, mTBI + PTSD using putative diagnosis [*Cramer's V* = 0.18, *p* = 0.009], and PCL ≥ 50 [*Cramer's V* = 0.18, *p* = 0.006]), though these are considered overall small effects. In Table 7, all percentages indicate what proportion of individuals in the k-means cluster groups fell into the *a priori* putative diagnosis group.

Table 7

Four cluster solution cross tabulation using a with a priori groups defined by putative diagnosis

	Mildly Impaired Reasoning and Memory	MCI	Mild Processing Speed Deficit	Cognitively Healthy
Control	25%	7%	16%	51%
mTBI	23%	10%	6%	61%
PTSD	16%	19%	38%	27%
mTBI+PTSD	12%	12%	24%	53%

Note. Percentages in the above table represent what portion of the *a priori* group fell into the cluster analysis group

A cluster analysis was conducted next on the BDS Individual items and neuropsychological assessments scale to determine what groups in the data would be produced with a two-cluster solution. This method was selected in an effort to mirror the two *a priori* groups of "control" and "illness", given the relatively poor agreement found using a four-cluster solution. Of the individuals with valid scores, 238 participants had complete data. Convergence was reached in 10 iterations. Univariate ANOVAs indicated that the clustered groups differed significantly on all but two classifying variables (CPT Detectability and HIT Rate). The final cluster centers together with the number of participants in each cluster are shown in Appendix.

Participants in Cluster 1 (N=143) named Cognitively Healthy appeared to be very slightly above average to slightly below average across all significant predictors when compared to the overall sample (.11 to .51) within the current study. Cluster 2 (N = 95) was termed Mild Cognitive Impairment as they appeared to be very slightly below average to slightly below average compared to other individuals in the sample across all significant predictors of group membership (-.19 to -.77). Please see Appendix D, Table 34 for final cluster loadings. When compared to the *a priori* defined groups (0 = "control", 1 = "illness"), the two cluster solution evidenced poor agreement with the *a priori* groups. There was not a significant of association

between *a priori* groups of "illness" and "control and the *k-means* cluster groups, when using the two cluster solution (PCL ≥ 50: Φ = 0.95, p =0.141 and Putative Diagnosis: Φ = 0.07, p =0.270). Moreover, most of the sample fell into the Cognitively Healthy cluster (see Table 8 below).

Table 8

Two-cluster solution cross-tabulation with PTSD defined by Putative diagnosis

	Cognitively Healthy	MCI
Control	64%	36%
Illness	55%	45%

Note. Percentages in the above table represent what portion of the *a priori* group fell into the cluster analysis group

Of note, the association using a two-cluster solution and the *a priori* determined four groups was significant independent of PTSD group membership method (Putative Diagnosis: *Cramer's V* = 0.22, $p < 0.01$; PCL ≥ 50: *Cramer's V*: 0.20, $p = .022$). These results are inconsistent with the hypothesized breakdown of groups, as in general, illness groups tended to fall into the cognitively healthy group, with the exception of the PTSD group (see table 9 below using putative diagnosis for PTSD Group membership). Thus, when using a cluster analysis of individuals in the current study, allowing the neuropsychological data and the BDS individual items to identify groups contained within the sample, there is poor agreement between the pre-determined groups and those that exist within the data.

Table 9

Two Cluster solution cross tabulated with a priori groups using putative diagnosis

	Cognitively Healthy	MCI
Control	63%	37%
mTBI	68%	32%
PTSD	35%	65%
mTBI + PTSD	68%	32%

Note. Percentages in the above table represent what portion of the *a priori* group fell into the cluster analysis group.

Discussion

The purpose of this study was to examine the ability of neurological soft signs (NSS) as measured by the Behavioral Dyscontrol Scale (BDS) to discriminate between healthy controls, mTBI, PTSD, and comorbid mTBI + PTSD. The results of the study, in general, indicate that while NSS discriminate between controls and participants with mTBI and/or PTSD, they do not discriminate between groups with these illnesses. Moreover, NSS in general do not discriminate between the mTBI, PTSD, and mTBI + PTSD groups over and above the effect of neuropsychological assessments. Further, only a single NSS evidenced an ability to discriminate between the mTBI only and PTSD only group from controls. When neuropsychological assessments and NSS were entered together into a cluster analysis, the model that emerged which was most consistent with previous research was a two-cluster solution (Jak et al., 2015). These clusters, termed "Cognitively Healthy" and "Mild Cognitive Impairment", were generally not related to the *a priori* groups defined by the presence of mTBI and PTSD.

Within this sample, there was a weak association between the NSS and the presence of total PTSD symptoms. In addition to the total number of PTSD symptoms, only the hyperarousal symptom cluster of PTSD (Cluster D) was significantly associated with NSS, though this was a relatively small effect. The other two PTSD symptom clusters (avoidance and numbing) were not significantly associated with NSS. However, in contrast to hypothesis 1, that the hyperarousal symptom cluster would be associated with a greater number of NSS than the avoidance or numbing symptom cluster, there was no difference between PTSD symptom clusters in their association with NSS. Thus, there is a weak association between PTSD symptoms and NSS.

Based on previous research with NSS (Gurvits et al., 1993, 1997, 2000, 2006; Ruff et al., 2012), we examined whether NSS could discriminate between healthy controls and individuals

with PTSD and/or mTBI. In the current sample of veterans, the control group presented with fewer NSS then did individuals PTSD and/or mTBI. Furthermore, there was a medium-sized effect for a go/no-go NSS showing that the control group is better able to inhibit incorrect responses when compared to the PTSD and/or mTBI group. Thus, hypothesis 2 of the current study was supported, as NSS were found to be a discriminating predictor between the control group and veterans with PTSD and/or mTBI.

To test the main study hypotheses, analyses were conducted to identify if individuals in the PTSD group presented with a greater number of NSS when compared to the mTBI group (hypothesis three) and if the comorbid mTBI + PTSD group presented with the most NSS overall (hypothesis four). In contrast to both hypotheses 3 and 4, total NSS did not discriminate between the mTBI and PTSD only groups, nor did total NSS discriminate between the mTBI + PTSD group and any other group. Only a single predictive relationship was found among individual NSS. Dominant hand initiated rhythm tapping was significantly worse for individuals in the PTSD group compared to individuals in the mTBI group. This effect was only noted when using putative PTSD diagnosis to define groups, though this was a large-sized effect (Sullivan & Feinn, 2012) and thus may have been impacted by familywise error rate. These results provide only a small amount of evidence consistent with the hypotheses that NSS should be more prominent among individuals with PTSD than with mTBI diagnoses.

Further analyses looked at the utility of NSS when considered alongside other neuropsychological predictors. Initially, we sought to replicate the results of hypothesis two, indicating that NSS discriminated between the control and PTSD and/or mTBI groups. For hypothesis five, total NSS did not discriminate above and beyond the effect of neuropsychological measures. Moreover, only a go/no-go NSS discriminated between the PTSD

and/or mTBI group when neuropsychological predictors were considered. Two neuropsychological measures discriminated between the control group and the PTSD and/or mTBI group when entered in a stepwise manner, Dominant and Non-Dominant Hand Grooved Peg Board. Individuals in the PTSD and/or mTBI group performed worse on these measures when compared to the control group, consistent with our expectations. While these neuropsychological predictors were statistically significant, the size of their effect was small by conventional measures (Sullivan & Feinn, 2012). Thus, only a go/no-go item discriminates between the control group and the PTSD and/or mTBI group when neuropsychological predictors are considered. Moreover, only two neuropsychological measures discriminated between the two groups. When taken together, both predictors only explained a small portion of the variance in the current model and were relatively small in their effect (Sullivan & Feinn, 2012).

Contrary to hypothesis six, NSS did not discriminate between the mTBI, PTSD, and mTBI + PTSD groups over and above the effect of neuropsychological measures. One neuropsychological measure emerged as significant predictor of group membership, Non-Dominant Hand Grooved Pegboard. Individuals in the mTBI + PTSD group performed worse on the Non-Dominant Grooved Pegboard than did individuals in the control group and mTBI group. In general, these effects were small based on conventional standards (Sullivan & Feinn, 2012). Additionally, when considered alongside neuropsychological predictors, individuals in the mTBI group, PTSD group, and mTBI + PTSD performed worse than controls on a go/no-go task (BDS item 4). Therefore, in general, NSS do not have utility above and beyond the effect of other neuropsychological measures in discriminating between mTBI, PTSD, and mTBI + PTSD

groups. Moreover, there was limited utility for neuropsychological measures as discriminating factors between the PTSD and/or mTBI groups.

An exploratory analysis was conducted to identify what profiles of neuropsychological and NSS performance exist within our sample, given their limited utility in discriminating between mTBI, PTSD, and mTBI + PTSD. In an effort to attempt to replicate the four *a priori* groups defined in the study, the first model focused on a four-cluster solution. The four-cluster solution produced clusters that were unbalanced in size, as the group Ns ranged from 24 to 117. When compared to others in the sample, the largest cluster consisted of individuals who were "Cognitively Healthy", but only 51% of the *a priori* control group fell into this cluster. Moreover, 61% of individuals in the *a priori* mTBI + PTSD and 53% of the mTBI group fell into these clusters. Additionally, there was only a small but significant relationship between the four-cluster solution and the *a priori* groups of control, mTBI, PTSD, and mTBI + PTSD. This model was not considered a good fit for the data, as the clusters that emerged were only weakly associated with our *a priori* groups.

A second cluster analysis, using a two-cluster solution, was examined to see if a simpler solution provided a better fit. The two clusters that emerged were labelled "Cognitively Healthy" and "Mild Cognitive Impairment" based on an examination of how each cluster performed on neuropsychological measures and NSS. The Cognitively Health cluster tended to perform in the average to slightly above average range across all measures. The Mild Cognitive Impairment cluster tended to perform very slightly below average to slightly below average across neurocognitive measures and BDS items when compared to other individuals in the sample. These two clusters were significantly associated with the *a priori* groups of control, mTBI, PTSD, and mTBI+PTSD, though the strength of the relationship was relatively small

(Sullivan & Feinn, 2012). Interestingly, 65% of the PTSD group fell into our Mild Cognitive Impairment cluster, indicating that the PTSD group tended to be more impaired then the other three groups across all measures. These results indicate that when using NSS and neuropsychological measures together, the clusters that emerge are not strongly associated with a diagnosis of mTBI, PTSD, and mTBI + PTSD.

Theoretical Implications

The results of the current study are consistent with previous research, highlighting that neuropsychological measures and NSS discriminate controls from individuals with PTSD and/or mTBI. Individuals in the combined mTBI, PTSD, and mTBI + PTSD groups in the current study specifically had difficulty on a go/no-go task when compared to controls. Our findings are consistent with previous research (Gurvits et al., 2000; Gurvits et al., 2006) that found that specific neurological soft signs discriminate individuals with PTSD from controls. The finding that the mTBI group evidenced consistently worse performance on a go/no-go tasks when compared to controls is novel, as previous research has indicated that NSS are no longer present in mTBI 30 to 90 days post injury (Greenberg et al., 2015). Of note, these findings approached significance for our mTBI + PTSD group (p = .06 & .08) when compared to controls. Conversely, on a single item, (dominant hand initiated tapping), our mTBI group performed better than controls. This item maps onto a different factor of the BDS than the go/no-go task (Shura et al., 2015). These results indicate that in mTBI, a complex go/no-go task may be differentially affected when compared to a simple motor task. The effect on the dominant hand initiated tapping should be replicated though, as we entered a number of predictors and our significant findings with the simple motor task only emerged when using Putative Diagnosis to define the PTSD group. Our finding with the go/no-go task are a unique finding among

individuals with mTBI, as previous research has only identified this effect in individuals with PTSD (DeGutis, Esterman, McCulloch, Rosenblatt, Milberg, & McGlinchey, 2015; Swick, Honzel, Larsen, Ashley, Justus, 2012). While NSS demonstrated an ability to discriminate the mTBI and PTSD group from controls, consistent differences between mTBI, PTSD, and mTBI + PTSD were not found using NSS. Our results found that the mTBI group performed better on one NSS (the dominant hand initiated rhythm tapping task) compared to the PTSD only group. Importantly, this effect did not persist across method of PTSD group classification. Additionally, the model using these individual NSS items did a poor job in predicting PTSD and mTBI group membership, with only 5.4% of the PTSD group and 3.2% of the mTBI group correctly predicted. These results indicate that while there was a significant difference between the groups, it did not result in improved group classification Thus, our findings with PTSD are consistent with the previous literature on NSS and represent novel findings with mTBI when compared to controls.

Our results also indicated that the existence of mTBI and PTSD together did not result in the worst overall performance across NSS and most neuropsychological measures as originally hypothesized. Thus, NSS may not be sensitive to the unique set of changes that occur among individuals with a history of mTBI + current PTSD when compared to controls. One significant finding did emerge for neuropsychological predictors as the mTBI + PTSD group evidenced worse performance on the Non-Dominant Hand Grooved Pegboard Task when compared to control and mTBI only, with no difference when compared to the PTSD only group. These findings are consistent with previous investigations of neuropsychological functioning, which find no additive effect associated with comorbid mTBI and PTSD compared to PTSD only (Belanger et al., 2011; Brenner, Ladley-O'Brien et al., 2009; Menon et al., 2010; Dolan et al.,

2012; Vasterling et al., 2017; Verfaellie et al., 2014). Thus, these findings indicate that, similar to neuropsychological performance, there is not a negative synergistic effect of mTBI + PTSD on NSS.

In addition to our finding that there is not a synergistic effect of mTBI + PTSD, our finding that PTSD drives deficits on the Grooved Pegboard task is also noteworthy. Previous research using Grooved Pegboard has found no differences between controls and individuals with PTSD (Crowell et al., 2002; Vasterling et al., 2006) and individuals with a history of mTBI (McGlinchey, Milberg, Fonda, & Fortier, 2017; Walker et al., 2018; Vasterling et al., 2006). Moreover, Verfaellie et al. (2014) found that mental health symptoms were the primary driver of performance deficits on neuropsychological measures, including manual dexterity (measured by the Grooved Pegboard task), among individuals with mTBI. In a more recent study, Verfaellie, Lee, Lafleche, and Spiro (2016) found that manual dexterity (measured by the Grooved Peg Board Task) was associated with mTBI among individuals who experienced a loss of consciousness. Moreover, this effect existed after adjusting for PTSD symptoms. Thus, based on the mixed previous research and the small effect sizes noted in the current study, our finding with the Non-Dominant Hand Grooved pegboard should not be over interpreted and should be replicated in other samples.

The finding that the mTBI + PTSD group was difficult to discriminate from the mTBI only group was surprising in the context of the current study. Previous research has found that individuals with a dual diagnosis of mTBI + PTSD tend to perform worse on neuropsychological measures when compared to individuals with a history of mTBI only (Combs et al., 2015; Nelson et al., 2009; Shandera-Ochsner et al., 2013). One possible explanation for our current results is that the more impaired members our mTBI + PTSD group were more likely than

members of other groups to be removed by the validity tests. After removing individuals for validity concerns, our mTBI + PTSD group included only 45% (using PCL ≥ 50) and 47% (using putative diagnosis) of the original sample, whereas the mTBI group contained 74% and 77% of the initial sample, respectively. In addition, one of the sites included in the multi-site study had a disproportionally large number of their participants (45%) assigned to the mTBI group. This likely occurred because individuals at this site were often recruited while they were undergoing clinical care, whereas at the other sites individuals were directly recruited from a larger research repository. This is noteworthy, as some individuals at this site had recently experienced injuries (time since injury range: 7-66 days). Additionally, previous research using a portion of this dataset found that individuals who were dual-enrolled in research and clinical care were more impaired on psychological measures and validity measures (McCormick et al., 2013). Thus, the lack of difference between our mTBI only and mTBI + PTSD group may have been a result of these recruitment procedures and site characteristics.

We conducted two exploratory cluster analyses on NSS and neuropsychological performance. Our first cluster analysis, which selected four clusters, was difficult to interpret as the clusters tended to not map onto specific neuropsychological constructs and was only weakly associated with the *a priori* groups. Our two-cluster solution identified one cluster of individuals that tended to perform within normal limits on cognitive testing and one cluster with generally mild cognitive impairments. Additionally, these clusters were significantly associated with the four *a priori* groups defined for the main hypotheses of this study. These findings are consistent with a recent study that found that after removal of veterans who failed validity testing, 60% of veterans with a history of mTBI were found to perform within normal limits on cognitive testing while 40% were considered impaired on two or more measures of cognition (Jak et al., 2015).

These results are consistent with our findings, as we also tended to have about a 60% healthy and 40% impaired breakdown in the two-cluster solution, irrespective of *a priori* group membership. Furthermore, veterans in the two groups did not differ on their symptoms of PTSD or depression (Jak et al., 2015). These results highlight that neuropsychological assessment is useful for characterizing cognitive profiles but not for differential diagnosis of mTBI, PTSD, and mTBI + PTSD. Consistent with this idea, Prince and Bruhns (2017) indicate that neuropsychological measures should be considered in the context of patterns, rather than examining individual tests, as there is high variability among individuals with mTBI. Thus, the results of the current study and cluster analyses are consistent with current clinical practice recommendations and guidelines for neuropsychological assessment with mTBI and PTSD.

The findings of the current study did not support our hypothesis that cognitive dysmetria would be more evident in mTBI + PTSD and PTSD than in mTBI. As described earlier, cognitive dysmetria implies a disruption of the frontal, thalamic, and cerebellar circuit, resulting in deficits in processing, prioritization, retrieval, and expression of information, and which can be indexed through NSS. Based on our study, the frontal, thalamic, cerebellar circuit (CCTCC) were affected similarly in the mTBI, PTSD, and mTBI + PTSD groups (Andreasen et al., 1998; Sheffield & Barch, 2016). The results of the current study support the hypothesis of greater cognitive dysmetria among individuals with PTSD compared to controls. These findings extend previous research with PTSD and NSS (Gurvits et al., 1993, 1997, 2000, 2006) by showing that individuals in the PTSD only and mTBI only group have more difficulty inhibiting incorrect responses, when compared to controls (Fischer et al., 2014; Vasterling, Verfaellie, & Sullivan, 2009). These results provide preliminary evidence for a go/no-go impairment in PTSD and mTBI, consistent with our original hypothesis of an impaired cortico-cerebellar-thalamic-cortico-

circuit (Sheffield & Barch, 2016). Thus, while there is support for cognitive dysmetria, associated with go/no-go deficits, among individuals with mTBI only and PTSD only when compared to controls, our findings do not support the application of this theory when attempting to discriminate between mTBI, PTSD, and mTBI + PTSD.

Limitations

The current study has a few noteworthy limitations. One limitation is how the NSS were measured. The BDS was selected to investigate neurological soft signs for its efficiency and previously reported reliability and validity (Grigsby & Kaye, 1996). However, the BDS was initially created to measure symptoms of behavioral dyscontrol among elderly, and focused on frontal lobe functions and functional independence (Grigsby, Kaye, & Robbins, 1992; Grigsby & Kaye, 1996). This is problematic in the context of the current study, as the BDS was found in our younger and less impaired sample to have poor internal consistency and a significant restriction in range of scores. Previous studies using the BDS have reported a greater range of scores and better internal consistency when evaluating the elderly (Belanger et al., 2005; Grigsby, Kaye, Eliertsen, & Kramer, 2000) or in a mixed clinical sample with a significant overrepresentation of the elderly (Ecklund-Johnson, Miller, & Sweet, 2004). Thus, the BDS may not be as sensitive to changes in neurologic functioning among younger, healthier individuals. One possible avenue to explore in future studies would be the use of the Cambridge Neurologic Inventory (CNI: Chen et al., 1995) or the Neurological Evaluation Scale (NES; Buchannan & Heinrichs, 1989). These measures are considered the gold standard for assessing NSS and have been used across a variety of studies with schizophrenia, OCD, and bipolar disorder when compared to controls (Bombin et al., 2003; Jaafari et al., 2013; Zhao et al., 2013). Gurvits et al. (2000, 2006) used items from the NES to create their scale, when measuring NSS among individuals with PTSD. Thus, future

studies should consider the use of either the NES or the CNI to examine NSS among younger samples of controls, mTBI, PTSD, and mTBI + PTSD.

There are two primary limitations associated with our TBI data. First, the measure used in the current study was a paper-and-pencil measure asking individuals to report on the duration of their own loss of consciousness, post-traumatic amnesia, alteration of consciousness, and dizziness. The use of this measure may have limited our ability to determine if individuals experienced a mild TBI, as previous research has indicated that forced-choice and paper-and-pencil measures increase post concussive symptom endorsement when compared to open-ended questionnaires (Edmed, Sullivan, Allan & Smith, 2015; Iverson, Brooks, Ashton, & Lange, 2010; Nolin, Villemure, & Heroux, 2006). On our measure, individuals were asked questions about how long it took them to "remember things" and about "dizziness", both of which may be affected by the forced choice nature of the measure (Ivins et al., 2003). To remedy this issue, future studies should consider open-end interviews, which are currently the standard for mTBI diagnosis. Two such interviews, the OSU TBI-ID (Corrigan & Bogner, 2007) and the VCU rCDI-B (Walker, et al., 2015), have demonstrated strong psychometrics and are commonly used in research and clinical practice.

Another limitation associated with TBI classification in the current study was the use of different procedures across sites. As noted above, at one site, most individuals were recruited during the course of their clinical care. Due to collection via clinical care, these individuals tended to have more recent injuries. At this site, individuals were more frequently assigned to the TBI groups when compared to other sites. This difference may be due to a variety of reasons, including site-specific differences (e.g. higher numbers of mTBI at this site in general), recruitment attempts to specifically include individuals with TBI, or improved classification of

TBI at this site due to chart review. In addition, at other sites, individuals were recruited via the larger parent study focused on post-deployment mental health, which did not require TBI reporting to be focused on deployment related or recent injuries (Brancu et al., 2017). As a result, the current study had a wide range for our time since injury variable (7 days to 40 years). Of note, individuals with more recent injuries (under 90 days) did not perform worse on any BDS item when compared to individuals who reported their most recent mTBI occurred more than 90 days ago.

The final important study limitation was that individuals were disproportionately removed from the PTSD and mTBI + PTSD group based on scores on the validity measures. This is consistent with previous research within the VA finding that individuals referred for mTBI or PTSD present with the highest rate of validity failures when compared to other mental health disorders, individuals with moderate/severe TBI, other brain injuries, and dementia (Young, Roper, & Arentsen, 2016). Furthermore, the context in which an assessment is completed significantly effects the rate of validity concerns, as individuals in forensic or clinical contexts are more likely to fail measures of validity and subsequently be removed from studies (Armistead-Jehle & Buican, 2012; McCormick et al., 2013; Jackson et al., 2017). This is relevant to the current study, as some individuals were also enrolled in a clinical protocol, which previous research using a portion of the current sample found led to increased effort failure (McCormick et al., 2013). This is most likely because individuals completing assessments outside of a research context are impacted by external motivations (Bigler, 2012). Additionally, previous studies with NSS have not included a measure of validity and as such there was a greater range of deficits on NSS and PTSD symptomatology (Greenberg et al., 2015; Gurvits et al., 1993, 1997, 2000, 2006; Ruff et al., 2012). Furthermore, although the current study removed

individuals for validity concerns, we did not use conventional cutoff scores. If conventional cutoff scores were used another 12 individuals would have been removed from the study, including seven individuals with PTSD. In the current study, there was a small but significant difference between those removed for validity concerns and those retained on the BDS total score. Thus, the current study may have removed individuals who were included in previous investigations of NSS who present with a greater number of NSS. Future studies of NSS may benefit from comparing individuals on measures of NSS who score above and below cutoff points for validity measures.

Conclusion

The current study contributes to a literature that highlights the difficulty discriminating between mTBI, PTSD, and mTBI + PTSD using neuropsychological measures, including NSS. Consistent with previous research, NSS discriminate between controls and individuals diagnosed with mTBI, PTSD, or mTBI + PTSD (Gurvits et al., 1993, 1997, 2000 & 2006; Ruff et al., 2012). In contrast to our hypotheses, though, NSS measured by the BDS were not effective at predicting between mTBI, PTSD, and mTBI+PTSD. While differences on a single NSS existed between mTBI group and PTSD group, they were dependent on how PTSD was diagnosed, sampling methods, and the use of validity testing in the current study. The results of the current study are also consistent with previous research that indicates that discrimination between mTBI and PTSD via neuropsychological measures remains difficult, especially when they are co-occurring (Dolan et al., 2012; Vasterling et al., 2017). Instead, neuropsychological assessment and NSS are more effective at identifying individuals who are experiencing a mild neurocognitive impairment or are cognitively healthy, after accounting for performance on validity measures. Thus, our results indicate that neuropsychological assessment in veterans with

PTSD and/or mTBI should adopt a framework focused on a specific question about the individual's cognitive ability, rather than differential diagnosis between these disorders.

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Appendix A

Table 10
Motor Coordination and Sequencing of Complex Motor Acts NSS on the BDS

Neurological Soft Sign	On the BDS?
Intention Tremor	No
Balance	No
Gait	No
Finger Thumb Opposition	Yes (Item 6)
Dysdiachokinesis	No
Finger to nose test	No
Fist-Edge-Palm	Yes (Item 5)
Fist-Ring test	No
Ozeretski Test	No
Go/no-go test	Yes (Item 3 & 4)
Rhythm Tapping foot	No
Rhythm Tapping Hand	Yes (Item 1 & 2)
Jaw Jerk	No
Glabella Tap	No

Note. Motor Coordination and Sequencing of Complex Motor Acts. Adapted from "Significance and meaning of neurological signs in schizophrenia: Two decades later", by I. Bombin, C. Arango, C & R.W. Buchanan (2005). *Schizophrenia Bulletin, 31*(4), p.963.

BDS Item 7 is associated with echopraxia according to Grigsby et al., (1992) and contains a component of right/left confusion, which is associated with integrative sensory functions according to Bombin et al., (2005, p. 963).

Appendix B

Data handling and issues related to the current data

The data from the current study are based on a study closure date of 02/01/2019. After this time, any changes to the data were made based on information that was available to the writer (e.g. paper files in Richmond, VA or files located on the jointly accessible share drive, via a data use agreement across sites). Given the number of variables contained in the current study, data checks were conducted for individuals who were included in the final sample.

To create the data set for the current study, a request was placed to the multi-site principal investigator for the study of neurocognition. Initially, the request included only the demographics, BDS, PAI, PCL, TBI characteristics, and WMT. Independently the writer of the current project initially coded all individuals in the TBI data set, to determine 1) if an individual had a TBI and 2) the severity of TBI. As noted in the measures section, individuals were classified as having a mild TBI if they scored consistent with mild TBI across indicators, including loss of consciousness and post-traumatic amnesia. These data were then double-checked and discrepancies were resolved with the multi-site principle investigator for the study of neurocognition. As of 02/08/2019, these classifications were predominantly finalized by the study team, though determination of certain injuries are still pending. Additionally some individuals who were hospitalized or seen through a non-research mechanism were classified based on medical record reporting. This process was completed by the local study coordinator and previous individuals who worked on the study.

In association with the Word Memory Test, individuals were determined to have good data if they completed the task. Specific individuals in the data set had scores that were found to not be possible (e.g. 82.0). This data was double checked against available records and adjusted for correctness. Additionally, two individuals had incomplete WMT data, though they had one

indicator that deemed their performance valid (immediate recall). As a result, they were retained since they had no scores below the appropriate cutoff.

For the PCL, the initial data was comprised of 395 individuals. As this data set did not encompass all individuals included in the current study, attempts were made to locate these files, either in the original paper files or via the share drive located at the VA. One individual was removed from the final sample as their PCL was not found at the time of study closure. Some individuals in this data set had individual items missing from their measures. In accordance with the policy of the overall study, these values were mean imputed using their symptom cluster average score.

Demographics were obtained from the overall, larger MIRECC study for individuals who had completed both the study of neurocognition and post-deployment mental health. These data were not available at the time of the study for all participants, as initial recruitment did not include mandatory participation in the larger study across sites. For those individuals, available data were collected by the examiner (i.e. age, education, and marital status) but this did not include history of deployment, military rank, service connection, and other VA based demographic information. The reported statistics for demographics outside of age and education include all data available to the writer of this document at the time of study closure. The writer of this document attempted to locate any missing data using paper files or jointly accessible data.

For the Personality Assessment Inventory, after the overall study was closed by the dissertation chair and writer, an error in the PAI data was found. Five individuals who were included in the study were found to have 0's for all validity indicators. This information was brought to the attention of the principle investigator who noticed that these errors were a result of

computer failure. For the purposes of the current study, these individuals were removed as individuals needed to complete the PAI for study inclusion.

Upon completion of the initial dissertation proposal on 09/08/2017 a request was made to the principal investigator for more data, including all neuropsychological measures. As this data was collected on a site-by-site basis, they were provided to the writer of this dissertation in that manner. Additionally, follow-up requests for data were made if any individual who passed the WMT and PAI was found to be missing neuropsychological assessments. Associated with the neuropsychological assessments, individuals who completed measures on the computer prior to a specific date were unable to be accessed, due to a hard drive issue that occurred early in the study. This included the CVLT and CPT. For the CVLT, some data was able to be obtained at the site where the writer resides, as paper records were accessible.

For the creation of standard scores in the current study, the writer hand-converted all neuropsychological measures to T-scores for the REY, BVMT-IR and DR, CVLT Total score, and Stroop CW Predicted. For all Wechsler tests, raw scores were converted into standard scores by research assistants/coordinators across the sites. Additionally, the writer of the current project converted all grooved pegboard and trail making tests into z-scores, in accordance with the preferred norms. Finally, measures that were completed on the computer, and had available data, were accessed and T-scores were used for these individuals. If standard scores were found to be missing and paper records were able to be accessed, this information was added to the database.

In an effort to ensure that the neuropsychological scoring, TBI classification, group membership and other information was correctly entered, the writer of the current project double checked each of these scores by hand. This included all hand-scored neuropsychological tests that the writer of this dissertation performed. Other data that was previously converted from raw

scores to standard scores by study personnel or the computer were not double-checked, as the principal investigator had previously conducted these checks. For classification of individuals into the control, mTBI, PTSD, and mTBI + PTSD group, all individual's scores were double-checked for correctness based on the most recent mTBI classification method.

Appendix C – Non-copyrighted study measures

Figure 2

Ivins et al., (2003) TBI Screen

1) Have You Ever Suffered a Head Injury*	0 = No	1 = Yes	2 = Don't Know	
2) Date of Injury	Month	Date	Year	
3) Did it require a Stay in the Hospital	No Yes			
4) What Was The Event that caused the Injury	Free Response			
5) How Long was it before you started remembering things again	0 = Less than 24 hours	1= 24 hours to 7 days	2 = More than 7 days	
6) Could you remember the actual injury**	0 = No	1 = Yes	2 = Don't Know	
7) How long was it before you started remembering new things again	0= Less than 1 hour	1= More than 1 hour but less than 24 hours	2= More than 24 hours, but less than 7 days	3= More than 7 days
8) Were you unconscious?***	0 = No		1 = Yes	
9) How Long were you unconscious	0 = 1-20 minutes	1= 21-59 minutes	2 = Over 59 minutes	
10) Were you dazed or confused right after the injury	0 = No		1 = Yes	
11) Could you remember things right after the injury	0 = No		1 = Yes	

Notes. Study measure discontinued if Item 1 was answered 0 or 2
**If answered "Yes" question 7 was administered
*** If answered "Yes" question 9 was administered, if no, then questions 10 and 11 were administered

Figure 3

PTSD Checklist- Military (Weathers, Litz, Herman, Huska & Keane, 1993)

		Frequency				
Question Number	Problem/Complaint	Not at all	A little bit	Moderately	Quite a bit	Extremely
1	Repeated disturbing memories, thoughts, or images of a stressful military experience	1	2	3	4	5
2	Repeated disturbing dreams of a stressful military experience	1	2	3	4	5
3	Suddenly acting or feeling as if a stressful military experience were happening again (as if you were reliving it)	1	2	3	4	5
4	Feeling very upset when something reminded you of a military experience	1	2	3	4	5
5	Having physical reactions (e.g. heart pounding, trouble breathing or sweating) when something reminded you of a stressful military experience	1	2	3	4	5
6	Avoid thinking about or talking about a stressful military experience or avoid having feelings related to it?	1	2	3	4	5
7	Avoid activities or talking about a stressful military	1	2	3	4	5

	experience or avoid having feelings related to it?					
8	Trouble remembering important parts of a stressful military experience	1	2	3	4	5
9	Loss of interest in things you used to enjoy	1	2	3	4	5
10	Feeling distant or cut off from other people	1	2	3	4	5
11	Feeling emotionally numb or being unable to have loving feelings for those close to you	1	2	3	4	5
12	Feeling as if your future will somehow be cut short	1	2	3	4	5
13	Trouble falling or staying asleep	1	2	3	4	5
14	Feeling irritable or having angry outburtsts	1	2	3	4	5
15	Having difficulty concentrating	1	2	3	4	5
16	Being “super alert” or watchful on guard	1	2	3	4	5
17	Feeling jumpy or easily startled	1	2	3	4	5

Appendix D

Table 11

Means, Standard Deviations, and Correlations of Important Variables for Hypothesis 1-4

Variables	TBI	PCL Total	Cluster B	Cluster C	Cluster D	BDS Total	BDS 1	BDS 2	BDS 3	BDS 4	BDS 5	BDS 6	BDS 7	BDS 8	BDS 9	Education	SC	Rank	Age	BDI Total
TBI	1																			
PCL Total	.29**	1																		
Cluster B	.27**	.85**	1																	
Cluster C	.26**	89**	.83**	1																
Cluster D	.29**	88**	.80**	.86**	1															
BDS Total	-.04	-.12	-.11	-.10	-.15*	1														
BDS 1	.08	-.05	-.02	-.04	-.07	.49**	1													
BDS 2	.05	.03	.04	.03	.02	.40**	.42**	1												
BDS 3	-.05	-.08	-.071	-.07	-.09	.44**	.11	.04	1											
BDS 4	-.08	-.19**	-.21**	-.14*	-.18**	.41**	.14*	.06	.12	1										
BDS 5	-.09	-.05	.01	-.07	-.09	.59**	.24**	.17**	.05	.16*	1									
BDS 6	.03	-.01	.01	.03	-.06	.56**	.12	.04	.19**	.15*	.30**	1								
BDS 7	.05	-.01	-.04	.001	-.01	.44**	.14*	.10	.13	.12	.16*	.17**	1							
BDS 8	-.09	-.08	-.11	-.07	-.06	.48**	.04	.01	.09	.15*	.16*	.10	.003	1						
BDS 9	-.05	-.16*	-.16*	-.14*	-.16*	.49**	.16*	.08	.17**	.20**	.17**	.25**	.14*	.17*	1					
Education	-.11	-.15*	-.13*	-.12	-.18**	-.01	.07	-.07	-.03	.05	-.04	-.10	.04	.02	.09	1				
SC	.09	.19**	.18*	.16*	.20**	-.05	-.04	-.17*	-.03	-.01	.09	-.003	.01	-.02	-.12	-.02	1			
Rank	-.03	-.18*	-.11	-.19**	-.20**	.03	.10	.03	-.03	-.01	.07	-.07	-.01	.05	.03	.47**	.04	1		
Age	-.01	-.06	-.07	-.06	-.03	-.26**	-.07	-.14*	-.18**	-.09	-.12	-.21**	-.08	-.08	-.15*	.28**	.04	.46**	1	
BDI Total	.26**	.81**	.72**	.81**	.75**	-.10	-.07	.03	-.06	-.11	-.07	-.03	.04	-.08	-.11	-.05	.15*	-.16*	-.03	1
Mean	.28	36.47	10.04	13.94	12.47	22.04	2.69	2.55	2.52	2.81	2.17	2.13	2.49	1.88	2.79	14.34	.54	5.5	36.50	11.59
SD	.45	17.00	5.33	6.92	5.79	2.77	.52	.58	.69	.42	.75	.72	.65	.90	.48	2.07	.50	3.85	9.94	9.97

Notes. TBI= Traumatic Brain Injury; PCL Total= Post-Traumatic Stress Disorder Checklist Total Score; Cluster B = Re-Experiencing Symptoms of PTSD; Cluster C = Avoidance Symptoms of PTSD; Cluster D = Hypervigilance symptoms of PTSD; BDS Total = Behavioral Dyscontrol Scale Total; BDS 1 = Behavioral Dyscontrol Scale Item 1; BDS 2 = Behavioral Dyscontrol Scale Item 2; BDS 3 = Behavioral Dyscontrol Scale Item 3; BDS 4 = Behavioral Dyscontrol Scale Item 4; BDS 5 Behavioral Dyscontrol Scale Item 5; BDS 6 = Behavioral Dyscontrol Scale Item 6; BDS 7 = Behavioral Dyscontrol Scale; BDS 8 = Behavioral Dyscontrol Scale Item 8; BDS 9 = Behavioral Dyscontrol Scale Item 9; Education = Years of Education; SC = Service Connection Yes/No; Rank = Highest Rank Achieved in the Military; Age = Age at time of testing; BDS- II =Beck Depression Inventory-II total score (BDI-II)

*p < 0.05 level (2-tailed). **. p< 0.01 level (2-tailed).

TBI and Service connection were coded "0" for no and "1 for yes"

Data presented based on available information (see appendix B for more information)

For correlations between clusters B, C, and D and the PCL total score, the corresponding symptom cluster was removed to reduce collinearity

Table 12

Regression Table for Hypothesis 2 – Model 1 (Logistic Regression, BDS Total Score, PTSD defined by Putative Diagnosis)

Predictor	*B*	S.E.	OR	95% CI for OR	
Education	-.12	.07	.89	.78	1.02
Age	-.01	.01	.99	.96	1.02
BDS Total	-.11	.05	.90*	.82	.99
Constant	4.10	1.57	60.56*		

Notes. OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS Total = Behavioral Dyscontrol Scale Total; Education = Years of education; Age = Age at Testing

Nagelkerke R^2=.05 * $p < .05$, ** $p<.01$

Table 13

Regression Table for Hypothesis 2 – Model 2 (Logistic Regression, BDS Total Score, PTSD defined by PCL ≥ 50)

Predictor	*B*	S.E. *B*	OR	95% CI for OR	
Education	-.16	.07	.86*	.75	.98
Age	-.01	.02	.99	.96	1.02
BDS Total	-.11	.05	.89*	.81	.99
Constant	4.64	1.60	103.45**		

Notes. OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS Total = Behavioral Dyscontrol Scale Total; Education = Years of education; Age = Age at Testing

Nagelkerke R^2=.06; * $p < .05$, ** $p<.01$

Table 14

Regression Table for Hypothesis 2 – Model 3 (Logistic Regression, BDS Items, PTSD defined by Putative Diagnosis)

Predictor	*B*	S.E.	OR	95% CI for OR	
Education	-.10	.07	.91	.79	1.04
Age	-.01	.02	.99	.96	1.02
BDS 1	.05	.31	1.05	.58	1.91
BDS 2	.12	.27	1.13	.67	1.89
BDS 3	-.38	.21	.69	.45	1.04
BDS 4	-.95	.37	.39**	.19	.79
BDS 5	-.08	.20	.93	.63	1.37
BDS 6	.24	.21	1.27	.84	1.92
BDS 7	.15	.22	1.16	.75	1.79
BDS 8	-.15	.16	.86	.63	1.17
BDS 9	-.47	.31	.63	.34	1.15
Constant	5.64	1.81**			

Notes. OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS 1 = Behavioral Dyscontrol Scale Item 2 1; BDS 2= Behavioral Dyscontrol Scale Item 2; BDS 3 = Behavioral Dyscontrol Scale Item 3; BDS 4 = Behavioral Dyscontrol Scale Item 4; BDS 5 = Behavioral Dyscontrol Scale Item 5; BDS 6 = Behavioral Dyscontrol Scale Item 6; BDS 7 = Behavioral Dyscontrol Scale Item 7; BDS 8 = Behavioral Dyscontrol Scale Item 8; BDS 9 = Behavioral Dyscontrol Scale Item 9; Education = Years of education; Age = Age at Testing

Nagelkerke R^2=.12; * $p < .05$, ** $p<.01$

Table 15

Regression Table for Hypothesis 2 – Model 4 (Logistic Regression, BDS Items, PTSD defined by PCL ≥50)

Predictor	*B*	S.E.	OR	95% CI for OR	
Education	-.14	.07	.87*	.79	1.04
Age	-.01	.02	.99	.96	1.02
BDS 1	.23	.31	1.25	.58	1.91
BDS 2	.14	.27	1.15	.67	1.89
BDS 3	-.38	.21	.69	.45	1.04
BDS 4	-1.03	.37	.36**	.19	.79
BDS 5	-.17	.20	.85	.63	1.37
BDS 6	.15	.21	1.16	.84	1.92
BDS 7	.17	.23	1.19	.75	1.79
BDS 8	-.17	.16	.84	.63	1.17
BDS 9	-.41	.31	.66	.34	1.15
Constant	6.00**	1.84			

Notes. OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS 1 = Behavioral Dyscontrol Scale Item 2 1; BDS 2= Behavioral Dyscontrol Scale Item 2; BDS 3 = Behavioral Dyscontrol Scale Item 3; BDS 4 = Behavioral Dyscontrol Scale Item 4; BDS 5 = Behavioral Dyscontrol Scale Item 5; BDS 6 = Behavioral Dyscontrol Scale Item 6; BDS 7 = Behavioral Dyscontrol Scale Item 7; BDS 8 = Behavioral Dyscontrol Scale Item 8; BDS 9 = Behavioral Dyscontrol Scale Item 9; Education = Years of education; Age = Age at Testing

Nagelkerke R^2=.14; * $p \leq .05$, ** $p < .01$

Table 16

Regression Table for Hypothesis 3 – Model 1 (Multinomial Logistic Regression, BDS total, PTSD defined by Putative Diagnosis)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-4.04	2.18			
	Age	.02	.02	1.02	.98	1.06
	Education	.10	.10	1.11	.91	1.34
	BDS Total Score	.15	.07	1.16*	1.01	1.33
mTBI	Intercept	-2.62	2.81			
	Age	.01	.03	1.01	.96	1.06
	Education	.03	.13	1.03	.80	1.32
	BDS Total Score	.08	.09	1.08	.91	1.29
mTBI + PTSD	Intercept	-.64	2.77	1.01		
	Age	.01	.03	.92	.96	1.06
	Education	-.08	.13	1.07	.72	1.19
	BDS Total Score	.06	.09	1.01	.90	1.26

Notes. Reference Group is PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS Total = Behavioral Dyscontrol Scale Total; Education = Years of education; Age = Age at Testing

Nagelkerke R^2=.05; * $p < .05$, ** $p<.01$

Table 17

Regression Table for Hypothesis 3 – Model 2 (Multinomial Logistic Regression, BDS total, PTSD defined by PCL ≥ 50)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-5.45*	2.33			
	Age	-5.45	2.33	1.01	.98	1.06
	Education	.01	.02	1.20	.91	1.34
	BDS Total Score	.18	.11	1.19*	1.01	1.33
mTBI	Intercept	.18	.07			
	Age	-3.17	2.83	1.01	.96	1.06
	Education	.01	.03	1.04	.80	1.32
	BDS Total Score	.04	.13	1.11	.91	1.29
mTBI + PTSD	Intercept	.10	.09			
	Age	-2.48	2.98	1.00	.96	1.06
	Education	.00	.03	1.05	.72	1.19
	BDS Total Score	.05	.14	1.08	.90	1.26

Notes. Reference Group is PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS Total = Behavioral Dyscontrol Scale Total; Education = Years of education; Age = Age at Testing

Nagelkerke R^2=.06; * $p < .05$, ** $p<.01$

Table 18

Regression Table for Hypothesis 3 – Model 3 (Multinomial Logistic Regression, BDS total, PTSD defined by Putative Diagnosis)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-5.82*	2.37			
	Age	.02	.02	1.02	.98	1.06
	Education	.06	.10	1.06	.87	1.30
	BDS 1	.33	.39	1.38	.64	2.99
	BDS 2	-.10	.37	.91	.45	1.86
	BDS 3	.40	.28	1.49	.86	2.55
	BDS 4	.90	.46	2.46*	1.01	6.02
	BDS 5	-.14	.28	.87	.50	1.52
	BDS 6	-.18	.30	.84	.47	1.49
	BDS 7	.06	.29	1.07	.60	1.89
	BDS 8	.10	.22	1.11	.72	1.71
	BDS 9	.62	.39	1.86	.87	4.00
mTBI	Intercept	-4.43	3.14			
	Age	.01	.03	1.01	.96	1.07
	Education	-.02	.13	.98	.75	1.27
	BDS 1	1.23	.61	3.41*	1.02	11.37
	BDS 2	.09	.49	1.10	.42	2.87
	BDS 3	-.17	.36	.85	.42	1.70
	BDS 4	-.20	.53	.82	.29	2.29
	BDS 5	-.48	.36	.62	.35	1.25
	BDS 6	.11	.38	1.12	.53	2.37
	BDS 7	.24	.40	1.28	.58	2.81
	BDS 8	-.09	.28	.91	.52	1.59
	BDS 9	.70	.58	2.01	.64	6.30
mTBI + PTSD	Intercept	-1.14	2.86			
	Age	.01	.03	1.01	.96	1.07
	Education	-.09	.13	.91	.70	1.18
	BDS 1	.25	.49	1.28	.49	3.34
	BDS 2	-.00	.46	1.00	.41	2.45
	BDS 3	.18	.35	1.19	.60	2.35
	BDS 4	.04	.52	1.04	.38	2.88
	BDS 5	-.20	.35	.82	.42	1.62
	BDS 6	.07	.37	1.07	.52	2.22
	BDS 7	.45	.39	1.56	.72	3.38
	BDS 8	-.09	.28	.92	.53	1.59
	BDS 9	.03	.46	1.03	.41	2.55

Notes. Reference Group is PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS 1 = Behavioral Dyscontrol Scale Item 2 1; BDS 2= Behavioral Dyscontrol Scale Item 2; BDS 3 = Behavioral Dyscontrol Scale Item 3; BDS 4 = Behavioral Dyscontrol Scale Item 4; BDS 5 = Behavioral Dyscontrol Scale Item 5; BDS 6 = Behavioral Dyscontrol Scale Item 6; BDS 7 = Behavioral Dyscontrol Scale Item 7; BDS 8 = Behavioral Dyscontrol Scale Item 8; BDS 9 = Behavioral Dyscontrol Scale Item 9; Education = Years of education; Age = Age at Testing

Nagelkerke R^2=.15; * $p < .05$, ** p<.01

Table 19

Regression Table for Hypothesis 3 – Model 4 (Multinomial Logistic Regression, BDS total, PTSD defined by PCL ≥ 50)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-6.94**	2.52			
	Age	.02	.02	1.02	.97	1.06
	Education	.16	.11	1.17	.95	1.46
	BDS 1	.04	.41	1.04	.46	2.34
	BDS 2	-.14	.38	.87	.41	1.85
	BDS 3	.41	.29	1.51	.86	2.65
	BDS 4	1.04	.46	2.83*	1.14	7.01
	BDS 5	.04	.29	1.04	.59	1.84
	BDS 6	-.00	.31	1.0	.54	1.82
	BDS 7	.04	.31	1.04	.57	1.90
	BDS 8	.15	.23	1.16	.73	1.82
	BDS 9	.52	.40	1.68	.76	3.70
mTBI	Intercept	-3.24	2.98			
	Age	.01	.03	1.01	.96	1.07
	Education	.01	.14	1.01	.78	1.32
	BDS 1	.42	.52	1.52	.55	4.23
	BDS 2	-.12	.47	.89	.36	2.22
	BDS 3	-.04	.34	.96	.49	1.88
	BDS 4	-.03	.51	.97	.36	2.61
	BDS 5	-.26	.35	.77	.39	1.52
	BDS 6	.28	.37	1.32	.64	2.72
	BDS 7	.36	.40	1.43	.66	3.11
	BDS 8	.07	.28	1.07	.62	1.86
	BDS 9	.37	.52	1.45	.52	3.99
mTBI + PTSD	Intercept	-3.38	3.14			
	Age	.00	.03	1.00	.95	1.06
	Education	.04	.14	1.04	.79	1.38
	BDS 1	.44	.57	1.55	.51	4.74
	BDS 2	.16	.51	1.17	.43	3.18
	BDS 3	.14	.37	1.15	.56	2.38
	BDS 4	.07	.54	1.07	.38	3.08
	BDS 5	-.09	.37	.92	.45	1.88
	BDS 6	.15	.39	1.16	.54	2.50
	BDS 7	.30	.42	1.35	.60	3.06
	BDS 8	-.19	.30	.83	.46	1.49
	BDS 9	-.02	.51	.99	.36	2.67

Notes. Reference Group is PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS 1 = Behavioral Dyscontrol Scale Item 2 1; BDS 2= Behavioral Dyscontrol Scale Item 2; BDS 3 = Behavioral Dyscontrol Scale Item 3; BDS 4 = Behavioral Dyscontrol Scale Item 4; BDS 5 = Behavioral Dyscontrol Scale Item 5; BDS 6 = Behavioral Dyscontrol Scale Item 6; BDS 7 = Behavioral Dyscontrol Scale Item 7; BDS 8 = Behavioral Dyscontrol Scale Item 8; BDS 9 = Behavioral Dyscontrol Scale Item 9; Education = Years of education; Age = Age at Testing

Nagelkerke R^2=.14; * $p < .05$, ** p<.01

Table 20

Regression Table for Hypothesis 4– Model 1 (Multinomial Logistic Regression, BDS Total Score and PTSD defined by Putative Diagnosis)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-3.40	2.30			
	Age	.01	.02	1.01	.97	1.05
	Education	.18	.11	1.20	.98	1.47
	BDS Total Score	.09	.07	1.09	.95	1.26
mTBI	Intercept	-1.99	2.91			
	Age	.00	.03	1.00	.95	1.06
	Education	.11	.13	1.11	.86	1.44
	BDS Total Score	.02	.09	1.02	.85	1.22
PTSD	Intercept	.64	2.77			
	Age	-.01	.03	.99	.94	1.04
	Education	.08	.13	1.09	.84	1.40
	BDS Total Score	-.06	.09	.94	.79	1.12

Notes. Reference Group is mTBI + PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS Total = Behavioral Dyscontrol Scale Total

Nagelkerke R^2=.05; * $p < .05$, ** $p<.01$

Table 21

Regression Table for Hypothesis 4– Model 2 (Regression Table for Hypothesis 4– Model 2 (Multinomial Logistic Regression, BDS Total Score and PTSD defined by PCL ≥ 50)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-2.97	2.43			
	Age	.01	.02	1.01	.97	1.06
	Education	.14	.11	1.15	.93	1.42
	BDS Total Score	.10	.08	1.10	.95	1.28
mTBI	Intercept	-.69	2.93			
	Age	.01	.03	1.01	.96	1.07
	Education	-.01	.13	1.00	.77	1.29
	BDS Total Score	.03	.09	1.03	.85	1.23
PTSD	Intercept	2.48	2.98			
	Age	-.00	.03	1.00	.95	1.06
	Education	-.05	.14	.96	.73	1.26
	BDS Total Score	-.08	.09	.92	.77	1.11

Notes. Reference Group is mTBI + PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS Total = Behavioral Dyscontrol Scale Total

Nagelkerke R^2=.06; * $p < .05$, ** $p<.01$

Table 22

Regression Table for Hypothesis 4– Model 3 (Multinomial Logistic Regression, BDS Total Score and PTSD defined by Putative Diagnosis)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-4.69	2.51			
	Age	.01	.02	1.01	.97	1.05
	Education	.16	.11	1.17	.95	1.44
	BDS 1	.08	.43	1.08	.47	2.49
	BDS 2	-.09	.38	.91	.43	1.91
	BDS 3	.22	.31	1.25	.69	2.27
	BDS 4	.86	.49	2.36	.91	6.13
	BDS 5	.06	.29	1.06	.61	1.85
	BDS 6	-.25	.30	.78	.43	1.41
	BDS 7	-.38	.34	.68	.35	1.32
	BDS 8	.19	.23	1.21	.77	1.89
	BDS 9	.59	.42	1.81	.80	4.08
mTBI	Intercept	-3.29	3.24			
	Age	-.00	.03	1.00	.95	1.05
	Education	.07	.14	1.07	.82	1.41
	BDS 1	.98	.63	2.66	.77	9.21
	BDS 2	.09	.50	1.10	.41	2.93
	BDS 3	-.34	.38	.71	.34	1.48
	BDS 4	-.24	.55	.78	.26	2.32
	BDS 5	-.29	.36	.75	.37	1.52
	BDS 6	.04	.39	1.04	.49	2.23
	BDS 7	-.20	.43	.82	.35	1.91
	BDS 8	-.01	.29	.99	.56	1.75
	BDS 9	.67	.60	1.95	.61	6.27
mTBI + PTSD	Intercept	1.14	2.86			
	Age	-.01	.03	.99	.94	1.04
	Education	.09	.13	1.10	.85	1.42
	BDS 1	-.25	.49	.78	.30	2.03
	BDS 2	.00	.46	1.00	.41	2.46
	BDS 3	-.18	.35	.84	.43	1.66
	BDS 4	-.04	.52	.96	.35	2.64
	BDS 5	.20	.35	1.22	.62	2.40
	BDS 6	-.07	.37	.93	.45	1.93
	BDS 7	-.45	.39	.64	.30	1.38
	BDS 8	.09	.28	1.09	.63	1.89
	BDS 9	-.03	.46	.97	.39	2.42

Notes. Reference Group is mTBI + PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS 1 = Behavioral Dyscontrol Scale Item 2 1; BDS 2= Behavioral Dyscontrol Scale Item 2; BDS 3 = Behavioral Dyscontrol Scale Item 3; BDS 4 = Behavioral Dyscontrol Scale Item 4; BDS 5 = Behavioral Dyscontrol Scale Item 5; BDS 6 = Behavioral Dyscontrol Scale Item 6; BDS 7 = Behavioral Dyscontrol Scale Item 7; BDS 8 = Behavioral Dyscontrol Scale Item 8; BDS 9 = Behavioral Dyscontrol Scale Item 9; Education = Years of education; Age = Age at Testing

Nagelkerke R^2=.15; * $p < .05$, ** $p<.01$

Table 23

Regression Table for Hypothesis 4– Model 4 (Multinomial Logistic Regression, BDS Individual Items and PTSD defined by PCL ≥ 50)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-3.57	2.71			
	Age	.01	.02	1.01	.97	1.06
	Education	.12	.11	1.13	.90	1.40
	BDS 1	-.40	.50	.67	.25	1.78
	BDS 2	-.30	.42	.74	.32	1.70
	BDS 3	.27	.32	1.31	.69	2.47
	BDS 4	.97	.51	2.63	.98	7.10
	BDS 5	.13	.30	1.13	.62	2.06
	BDS 6	-.15	.32	.86	.46	1.62
	BDS 7	-.26	.36	.77	.38	1.55
	BDS 8	.34	.24	1.40	.87	2.26
	BDS 9	.53	.45	1.70	.71	4.09
mTBI	Intercept	.14	3.15			
	Age	.01	.03	1.01	.96	1.07
	Education	-.03	.14	.97	.74	1.27
	BDS 1	-.02	.59	.98	.31	3.11
	BDS 2	-.28	.50	.76	.28	2.02
	BDS 3	-.18	.37	.83	.40	1.73
	BDS 4	-.10	.55	.90	.31	2.63
	BDS 5	-.17	.36	.84	.42	1.69
	BDS 6	.13	.39	1.14	.53	2.42
	BDS 7	.06	.43	1.06	.46	2.47
	BDS 8	.26	.29	1.30	.73	2.29
	BDS 9	.38	.55	1.47	.50	4.30
mTBI + PTSD	Intercept	3.38	3.14			
	Age	.00	.03	1.00	.95	1.06
	Education	-.04	.14	.96	.72	1.27
	BDS 1	-.44	.57	.64	.21	1.97
	BDS 2	-.16	.51	.85	.31	2.31
	BDS 3	-.14	.37	.87	.42	1.80
	BDS 4	-.07	.54	.93	.33	2.67
	BDS 5	.09	.37	1.09	.53	2.25
	BDS 6	-.15	.39	.86	.40	1.87
	BDS 7	-.30	.42	.74	.33	1.68
	BDS 8	.19	.30	1.21	.67	2.18
	BDS 9	.02	.51	1.02	.37	2.76

Notes. Reference Group is mTBI + PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

BDS 1 = Behavioral Dyscontrol Scale Item 2 1; BDS 2= Behavioral Dyscontrol Scale Item 2; BDS 3 = Behavioral Dyscontrol Scale Item 3; BDS 4 = Behavioral Dyscontrol Scale Item 4; BDS 5 = Behavioral Dyscontrol Scale Item 5; BDS 6 = Behavioral Dyscontrol Scale Item 6; BDS 7 = Behavioral Dyscontrol Scale Item 7; BDS 8 = Behavioral Dyscontrol Scale Item 8; BDS 9 = Behavioral Dyscontrol Scale Item 9; Education = Years of education; Age = Age at Testing

Nagelkerke R^2=.14; * $p < .05$, ** $p<.01$

Table 24

Neuropsychological Correlations

Variables	BDS	TMT A	TMT B	GP Dom	GP Non Dom	CW	CVLT Total	WCST	BVMT Total	BVMT Delay	WTAR	DS	SIM	BD	SS	LNS	REY	D'	HIT Rate	CVLT LDFR
BDS	1																			
TMT A	.12	1																		
TMT B	.21**	.44**	1																	
GP Dominant	.14*	.15*	.22**																	
GP Non Dominant	.29**	.15*	.25**	.66**	1															
CW	.23**	.26**	.29**	.14*	.15*	1														
CVLT Total	.24**	.04	.23**	.12*	.23**	.15*	1													
WCST	.11	.01	.14*	.10	.32**	.21**	.21**	1												
BVMT Total	.22**	.17**	.36**	.19**	.28**	.19**	.39**	.29**	1											
BVMT Delay	.20**	.13*	.34**	.19**	.33**	.13*	.40**	.31**	.82**	1										
WTAR	.34**	.16*	.40**	.18**	.23**	.29**	.35**	.23**	.43**	.37**	1									
DS	.20**	.43**	.44**	.26**	.31**	.35**	.13*	.13*	.22**	.20**	.27**	1								
SIM	.23**	.11	.14*	.13*	.28**	.14*	.22**	.33**	.39**	.36**	.47**	.15*	1							
BD	.30**	.24**	.35**	.33**	.41**	.31**	.25**	.30**	.49**	.48**	.36**	.35**	.44**	1						
SS	.23**	.44**	.50**	.31**	.30**	.36**	.15**	.09	.37**	.33**	.29**	.64**	.23**	.52**	1					
LNS	.31**	.20**	.34**	.11	.18**	.31**	.28**	.15*	.26**	.26**	.39**	.33**	.10	.22**	.32**	1				
REY	.09	.13	.18**	.24**	.28**	.13*	.27**	.22**	.54**	.51**	.24**	.21**	.30**	.44**	.22**	.24**	1			
D'	-.14*	-.04	-.04	.02	-.01	-.06	-.05	.11	.08	.07	-.01	-.10	-.01	.04	.00	-.12	.02	1		
HIT Rate	-.04	-.08	-.05	-.01	-.00	-.12	-.09	-.17**	.00	.01	-.04	-.05	.04	.01	-.15*	-.02	.11	-.45**	1	

CVLT LDFR	.24**	.06	.22**	.11	.18**	.20**	.70**	.16*	.38**	.40**	.26**	.08	.23**	.22**	.15*	.21**	.28**	-.01	-.11	1

Notes *$p < 0.05$. **. $p < 0.01$

BDS = Behavioral Dyscontrol Scale; *TMT A* = Trail Making Test A; *TMT B* = Trail Making Test B; *GP Dom* = Grooved Pegboard Dominant Hand; *GP Non Dom* = Grooved Pegboard Non Dominant Hand; *CW* = Stroop Color Word; C*VLT Total* = CVLT total score trials 1-5 total; *WCST* = Wisconsin Card Sorting Test Errors; *BVMT Total* = Total score BVMT trials 1-3; *BVMT Delay* = BVMT Delayed Free Recall; *WTAR* = Wechsler Test of Adult Reading; *DS* = WAIS-III Digit Symbol Coding; *SIM* = WAIS-III Similarities; *BD* = WAIS-III Block Design; *SS* = WAIS-III Symbol Search; *LNS* = WAIS-III Letter Number Sequencing; *REY* = Rey-Osterrieth Immediate Recall; D' = CPT-II Detectability; *HIT Rate* = CPT-II Hit Rate; CVLT LDFR = CVLT Long Delay Free Recall

Table 25

Regression Table for Hypothesis 5 – Model 1 (Logistic Regression, BDS Total Score, Neuropsychological predictors, PTSD defined by Putative Diagnosis) Stepwise

Predictor	*B*	S.E.	OR	95% CI for OR	
Education	-.11	.07	.90	.78	1.03
Age	-.03	.02	.97	.94	1.00
WTAR	.00	.01	1.00	.97	1.02
GP Non Dom	-.34	.13	.71*	.55	.92
BDS Total	-.07	.05	.94	.84	1.04
Constant	3.78	1.80	43.84*		

Notes. OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

WTAR = Wechsler Test of Adult Reading; GP Non Dom = Grooved Pegboard Non Dominant Hand; BDS Total = Behavioral Dyscontrol Scale Total

Nagelkerke R^2=.08 * p < .05, ** p<.01

Table 26

Regression Table for Hypothesis 5 – Model 2 (Logistic Regression, BDS Total Score, Neuropsychological predictors, PTSD defined by PCL ≥ 50)

Predictor	*B*	S.E.	OR	95% CI for OR	
Education	-.16	.07	.86*	.74	.99
Age	-.02	.02	.98	.95	1.01
WTAR	.00	.01	1.00	.97	1.02
GP Dom	-.24	.10	.78*	.64	.96
BDS Total	-.09	.05	.91	.82	1.02
Constant	4.68	1.81	107.91**		

Notes. OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

WTAR = Wechsler Test of Adult Reading; GP Dom = Grooved Pegboard Dominant Hand; BDS Total = Behavioral Dyscontrol Scale Total

Nagelkerke R^2=.09 * p < .05, ** p<.01

Table 27

Regression Table for Hypothesis 5 – Model 3 (Logistic Regression, BDS individual items, Neuropsychological predictors, PTSD defined by Putative Diagnosis)

Predictor	*B*	S.E.	OR	95% CI for OR	
Education	-.10	.07	.90	.78	1.04
Age	-.03	.02	.97	.95	1.00
WTAR	-.01	.01	.99	.97	1.01
GP Non Dom	-.32	.14	.73*	.56	.95
BDS 4	-.70	.34	.50*	.25	.97
Constant	4.57	1.80	96.66*		

Notes. OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

Education = Years of education; Age = Age at Testing; WTAR = Wechsler Test of Adult Reading; GP Non Dom = Grooved Pegboard Non Dominant Hand; BDS 4 = Behavioral Dyscontrol Scale Item 4

Nagelkerke R^2=.11 * $p < .05$, ** $p<.01$

Table 28

Regression Table for Hypothesis 5 – Model 4 (Logistic Regression, BDS individual items, Neuropsychological predictors, PTSD defined by PCL ≥ 50)

Predictor	*B*	S.E.	OR	95% CI for OR	
Education	-.15	.07	.86	.75	1.00
Age	-.02	.01	.98	.95	1.01
WTAR	-.01	.01	.99	.97	1.01
GP Dom	-.24	.10	.78*	.64	.96
BDS 4	-.90	.34	.41*	.21	.79
Constant	5.51	1.81	246.32**		

Notes. OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

Education = Years of education; Age = Age at Testing; WTAR = Wechsler Test of Adult Reading; GP Non Dom = Grooved Pegboard Dominant Hand; BDS 4 = Behavioral Dyscontrol Scale Item 4

Nagelkerke R^2=.13 * $p < .05$, ** $p<.01$

Table 29

Regression Table for Hypothesis 6 – Model 1 (Multinomial Logistic Regression, BDS total score, Neuropsychological predictors, PTSD defined by Putative Diagnosis)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-1.77	2.65			
	WTAR	-.01	.02	.99	.96	1.03
	Age	.02	.02	1.02	.98	1.07
	Education	.16	.11	1.18	.95	1.46
	BDS Total Score	.06	.08	1.06	.91	1.23
	GP Non Dom	.43	.18	1.53*	1.08	2.17
mTBI	Intercept	-.84	3.33			
	WTAR	.01	.02	1.01	.96	1.05
	Age	.02	.03	1.02	.96	1.07
	Education	.07	.14	1.08	.82	1.40
	BDS Total Score	-.04	.10	.96	.79	1.17
	GP Non Dom	.54	.25	1.72*	1.05	2.80
PTSD	Intercept	2.02	3.20			
	WTAR	-.02	.02	.98	.94	1.02
	Age	-.01	.03	.99	.94	1.05
	Education	.10	.13	1.10	.85	1.43
	BDS Total Score	-.03	.09	.97	.81	1.17
	GP Non Dom	-.01	.19	.99	.69	1.43

Notes. Reference Group is mTBI + PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

Education = Years of education; Age = Age at Testing; WTAR = Wechsler Test of Adult Reading; GP Non Dom = Grooved Pegboard Non Dominant Hand; BDS Total = Behavioral Dyscontrol Scale Total

Nagelkerke R^2=.11; * $p < .05$, ** $p<.01$

Table 30

Regression Table for Hypothesis 6 – Model 2 (Multinomial Logistic Regression, BDS total score, Neuropsychological predictors, PTSD defined by PCL ≥ 50)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-3.09	2.64			
	WTAR	.00	.02	1.00	.97	1.04
	Age	.01	.02	1.01	.97	1.06
	Education	.14	.11	1.15	.92	1.42
	BDS Total	.09	.08	1.10	.94	1.29
mTBI	Intercept	-1.81	3.22			
	WTAR	.02	.02	1.09	.98	1.06
	Age	.01	.03	1.01	.96	1.07
	Education	-.02	.14	.98	.75	1.27
	BDS Total	.00	.10	1.00	.83	1.21
PTSD	Intercept	3.82	3.28			
	WTAR	-.02	.02	.98	.94	1.02
	Age	.00	.03	1.00	.95	1.06
	Education	-.04	.14	.97	.73	1.27
	BDS Total	-.05	.10	.95	.78	1.16
	Intercept	-3.09	2.64	1.00	.97	1.04
	WTAR	.00	.02	1.01	.97	1.06
	Age	.01	.02	1.15	.92	1.42

Notes. Reference Group is mTBI + PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

Education = Years of education; Age = Age at Testing; WTAR = Wechsler Test of Adult Reading; BDS Total = Behavioral Dyscontrol Scale Total

Nagelkerke R^2=.08; * $p < .05$, ** $p<.01$

Table 31

Regression Table for Hypothesis 6 – Model 3 (Multinomial Logistic Regression, BDS Items, Neuropsychological predictors, PTSD defined by Putative Diagnosis)

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-.78	2.19			
	WTAR	-.00	.02	1.00	.96	1.03
	Age	.02	.02	1.02	.97	1.06
	Education	.16	.11	1.17	.95	1.45
	GP Non Dom	.45	.17	1.56*	1.11	2.20
mTBI	Intercept	-1.51	2.81			
	WTAR	.00	.02	1.00	.96	1.05
	Age	.02	.03	1.02	.96	1.08
	Education	.07	.14	1.07	.82	1.40
	GP Non Dom	.53	.25	1.70*	1.04	2.77
PTSD	Intercept	1.47	2.63			
	WTAR	-.03	.02	.98	.94	1.01
	Age	-.01	.03	.99	.94	1.05
	Education	.10	.13	1.10	.85	1.43
	GP Non Dom	-.02	.18	.98	.69	1.39

Notes. Reference Group is mTBI + PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

Education = Years of education; Age = Age at Testing; WTAR = Wechsler Test of Adult Reading; GP Non Dom = Non Dominant Hand Grooved Pegboard

Nagelkerke R^2=.10; * $p < .05$, ** $p<.01$

Table 32

Regression Table for Hypothesis 6 – Model 4 (Multinomial Logistic Regression, BDS Items, Neuropsychological predictors, PTSD defined by PCL ≥ 50

Comparison Group	Predictor	*B*	S.E.	OR	95% CI for OR	
Control	Intercept	-4.26	2.56			
	WTAR	.01	.02	1.01	.97	1.04
	Age	.01	.02	1.01	.97	1.06
	Education	.13	.11	1.13	.91	1.41
	BDS Item 4	1.02	.47	2.78*	1.11	6.99
mTBI	Intercept	-1.79	3.03			
	WTAR	.02	.02	1.02	.98	1.06
	Age	.01	.03	1.01	.96	1.07
	Education	-.02	.13	.98	.75	1.27
	BDS Item 4	-.01	.51	.99	.37	2.68
PTSD	Intercept	3.43	3.05			
	WTAR	-.03	.02	.98	.94	1.02
	Age	.00	.03	1.00	.95	1.06
	Education	-.03	.14	.97	.74	1.28
	BDS Item 4	-.19	.50	.83	.31	2.22

Notes. Reference Group is mTBI + PTSD

OR = Odds Ratio; S.E = Standard Error; CI: Confidence Interval

Education = Years of education; Age = Age at Testing; WTAR = Wechsler Test of Adult Reading; BDS Item 4 = Behavioral Dyscontrol Scale Item 4

Nagelkerke R^2=.10; * $p < .05$, ** $p<.01$

Table 33

Four Cluster Model with factor loadings

Cognitive Variables	Cluster Names and Factor Loadings			
	Mildly Impaired Reasoning and Memory	MCI	Mild Processing Speed Deficit	Cognitively Healthy
TMT A	.16	-.49	-.82	.36
TMT B	.27	-1.64	-.51	.42
GP Dom	.07	-.91	-.41	.32
GP Non Dom	-.15	-1.21	-.29	.43
CW	-.15	-.79	-.27	.33
CVLT Total	-.47	-1.02	.17	.35
WCST	-.46	-.90	.23	.29
BVMT Total	-.82	-1.41	.26	.54
BVMT Delay	-.80	-1.47	.31	.53
WTAR	-.34	-1.38	-.23	.52
DS	.10	-1.03	-.75	.46
SIM	-.71	-.71	-.24	.55
BD	-.63	-1.08	-.25	.59
SS	-.08	-1.11	-.69	.53
LNS	-.29	-.93	-.37	.46
REY	-.89	-.75	.09	.50
D	.08	-.33	.49	-.16
HIT RATE	-.36	.47	-.04	.07
LDFR	-.39	-1.04	.14	.33
BDS 1	.06	.03	-.79	.28
BDS 2	.06	-.23	-.38	.17
BDS 3	-.04	-.69	-.16	.22
BDS 4	.07	-.25	-.49	.22
BDS 5	.01	-.51	-.32	.23
BDS 6	-.21	-.24	-.06	.16
BDS 7	-.22	-.44	-.03	.20
BDS 8	.16	-.47	-.47	.21
BDS 9	.16	-.95	-.33	.25

Notes Scores in this table are expressed a Z score units, such that scores between 0 and +/- 0.25 are average, +/- 0.25 to 0.49 are very slightly above or below average, +/- 0.5-0.99 are slightly above or slightly below average, +/-1.0-1.49 are moderately above to moderately below average, and +/-1.50 well above or well below average

BDS 1 = Behavioral Dyscontrol Scale Item 1; BDS 2 = Behavioral Dyscontrol Scale Item 2; BDS 3 = Behavioral Dyscontrol Scale Item 3; BDS 4 = Behavioral Dyscontrol Scale Item 4; BDS 5 Behavioral Dyscontrol Scale Item 5; BDS 6 = Behavioral Dyscontrol Scale Item 6; BDS 7 = Behavioral Dyscontrol Scale; BDS 8 = Behavioral Dyscontrol Scale Item 8; BDS 9 = Behavioral Dyscontrol Scale Item 9; TMT A = Trail Making Test A; TMT B = Trail Making Test B; GP Dom = Grooved Pegboard Dominant Hand; GP Non Dom = Grooved Pegboard Non Dominant Hand; CW = Stroop Color Word; CVLT Total = CVLT total score trials 1-5 total; WCST = Wisconsin Card Sorting Test Errors; BVMT Total = Total score BVMT trials 1-3; BVMT Delay = BVMT Delayed Free Recall; WTAR = Wechsler Test of Adult Reading; DS = WAIS-III Digit Symbol Coding; SIM = WAIS-III Similarities; BD = WAIS-III Block Design; SS = WAIS-III Symbol Search; LNS = WAIS-III Letter Number Sequencing; REY = Rey-Osterrieth Immediate Recall; D' = CPT-II Detectability; HIT Rate = CPT-II Hit Rate; CVLT LDFR = CVLT Long Delay Free Recall

Table 34

Two Cluster Model with factor loadings

	Cluster Names and Factor Loadings		
Measures	Cognitively Healthy	Mild Cognitive Impairment	F
TMT A	.24	-.36	22.99*
TMT B	.34	-.52	51.50*
GP Dom	.26	-.40	27.83*
GP Non Dom	.36	-.54	56.22*
CW	.24	-.37	23.54*
CVLT Total	.33	-.49	45.90*
WCST	.26	-.39	27.10*
BVMT Total	.51	-.76	150.99*
BVMT Delay	.48	-.72	122.74*
WTAR	.43	-.65	93.07*
DS	.32	-.48	42.81*
SIM	.44	-.66	95.58*
BD	.51	-.76	151.14*
SS	.42	-.64	88.16*
LNS	.38	-.58	67.88*
REY	.45	-.68	103.59*
D	.00	.00	.00
HIT RATE	.01	-.02	.07
LDFR	.31	-.47	41.19*
BDS 1	.19	-.28	12.97*
BDS 2	.16	-.24	9.39*
BDS 3	.15	-.22	7.92*
BDS 4	.14	-.21	7.25*
BDS 5	.11	-.16	4.06*
BDS 6	.13	-.20	6.17*
BDS 7	.15	-.23	8.39*
BDS 8	.14	-.22	7.57*
BDS 9	.19	-.28	12.89*

Notes. Scores in this table are expressed a Z score units, such that scores between 0 and +/- 0.25 are average, +/- 0.25 to 0.49 are very slightly above or below average, +/- 0.5-0.99 are slightly above or slightly below average, +/- 1.0-1.49 are moderately above to moderately below average, and +/-1.50 well above or well below average

* *P<.05*

BDS 1 = Behavioral Dyscontrol Scale Item 1; BDS 2 = Behavioral Dyscontrol Scale Item 2; BDS 3 = Behavioral Dyscontrol Scale Item 3; BDS 4 = Behavioral Dyscontrol Scale Item 4; BDS 5 Behavioral Dyscontrol Scale Item 5; BDS 6 = Behavioral Dyscontrol Scale Item 6; BDS 7 = Behavioral Dyscontrol Scale; BDS 8 = Behavioral Dyscontrol Scale Item 8; BDS 9 = Behavioral Dyscontrol Scale Item 9; TMT A = Trail Making Test A; TMT B = Trail Making Test B; GP Dom = Grooved Pegboard Dominant Hand; GP Non Dom = Grooved Pegboard Non Dominant Hand; CW = Stroop Color Word; CVLT Total = CVLT total score trials 1-5 total; WCST = Wisconsin Card Sorting Test Errors; BVMT Total = Total score BVMT trials 1-3; BVMT Delay = BVMT Delayed Free Recall; WTAR = Wechsler Test of Adult Reading; DS = WAIS-III Digit Symbol Coding; SIM = WAIS-III Similarities; BD = WAIS-III Block Design; SS = WAIS-III Symbol Search; LNS = WAIS-III Letter Number Sequencing; REY = Rey-Osterrieth Immediate Recall; D' = CPT-II Detectability; HIT Rate = CPT-II Hit Rate; CVLT LDFR = CVLT Long Delay Free Recall

Appendix E

Results of Hypothesis 1 through 6 using N=226 based on previously established Validity Criteria

Correlations

A correlation matrix was created to compare the relationship between the primary study variables, including the PCL (and associated clusters), BDS Total Score, individual BDS items, TBI classification, and demographic variables used in the models. Correlations of primary study variables can be found in Table 6. There was an inverse association between the BDS and age (r=-.26, p <.001) indicating that greater neurologic dysfunction was found among older veterans. Further, the presence of a history of TBI was not associated with the BDS Total Score (r= -.03, p=.695) or any individual item on the BDS. The BDS Total Score was negatively correlated with the PCL, with the direction indicating greater neurological dysfunction was associated with more symptoms of PTSD, though this relationship fell short of significance (r= -.09, p =.165). While there was not a significant relationship between the BDS Total Score and the PCL, the go/no-go task (BDS 4 (r =-.17, p = .012) and an item related to insight (BDS 9 (r =-.15, p = .020) were both significantly associated with PTSD symptoms.

Hypothesis Testing

Hypothesis one. To address hypothesis one, that hyperarousal symptoms of PTSD will show a greater association with the BDS than the avoidance or numbing symptoms, correlations between these variables were examined. None of the PTSD symptom clusters were significant correlated with the BDS Total Score (cluster B (re-experiencing), r =-.09, p =.185, cluster C (avoidance), r =-.06, p =.411, cluster D (hyperarousal), r=-.12, p =.068). The association between Cluster D (hyperarousal) and both Clusters B (re-experiencing: *Fisher's z* = 0.32, p =.375) and C (avoidance: *Fisher's z* =-0.64, p =.261) do not significantly differ from one

another. Moreover, while the associations between cluster D and the BDS was the largest, this is a small effect by conventional standards (Sullivan & Feinn, 2012). Therefore, hypothesis one is not supported; the BDS Total Score does not exhibit greater association with hyperarousal symptoms than with any other symptom cluster of the PCL.

Hypothesis two. To address hypothesis two, that control subjects will perform better on the BDS than individuals with a mTBI, PTSD, or mTBI+PTSD group classification, indicating less neurologic dysfunction, logistic regression was used. The dependent variable of this analysis was the binary group classification with PTSD defined by putative diagnosis or PCL ≥50 ("0" = control; "1" = illness). In the first step of the model, age and education were added to control for their influence on the BDS. The BDS total score was not a significant predictor of group membership using putative diagnosis ($\chi^2(1) = 2.45$, b= -0.8, p = .117, OR: .91 [95%CI: .82,1.01]) or a PCL cutoff of 50 ($\chi2(1) = 2.94$, b= -.09 p = .087, OR: .92 [95%CI: .83,1.02]). Thus, when the BDS total score does not predict group membership when using either a PCL cutoff of 50 or putative diagnosis.

To address concerns about the poor internal consistency of the BDS scale and highlight the unique variance associated with individual NSS, a subsequent pair of analyses using individual BDS items as the predictors of group membership was conducted. For both models, age and education were entered in the first step to control for their impact on the BDS. In the second step, the BDS individual predictors were entered simultaneously. The addition of the BDS individual items to the model did not significantly improve prediction over and above the effect of age and education (Block $\chi^2(9) = 13.43$, p = .144) when PTSD group membership was defined by putative diagnosis. While the overall model was not significant, BDS Item 4 (a go/no-go task) emerged as a significant predictor of group membership ($\chi2(1) = 5.35$, b= -.86 p = .021).

For every one-point increase on item 4 of the BDS, individuals were less likely (OR = 0.42) to be in the illness group (95% CI: [.20, .88]). When the PTSD group was defined by a putative diagnosis, the overall model, including years of education, age, and the total BDS score, correctly classified 64.2% of individuals, predicting 26.4% of the illness group correctly and 87.8% of the control group. These results indicate that, when PTSD group membership was defined using either method, only a go/no-go task (item 4) of the BDS discriminated between individuals in the control and illness group over and above the effect of age and education.

The addition of the BDS individual items were not a significant predictor over and above the effect of age and education, (Block $\chi^2(9) = 12.69$, $p = .18$). Within this model, BDS item 4 (a go/no-go task) ($\chi^2(1) = 4.33$, $b = -.77$, $p = .037$; 95% CI: [.23, .95]) emerged as significant predictors of illness group membership. On BDS Item 4 (go/no go task), a one-point increase (less neurologic dysfunction) was associated with a lower (OR = 0.46) likelihood of being in the illness group. When the PTSD group was defined by a putative diagnosis, the overall model, including years of education, age, and the total BDS score, correctly classified 61.9% of individuals, predicting 28.6% of the illness group correctly and 84.4% of the control group. Thus, as the score on item 4 of the BDS increases (decreased NSS), there is a lower likelihood of being in the illness group.

Hypothesis three. To address hypothesis three, that individuals in the PTSD group will perform worse on the BDS than will individuals with mTBI, a multinomial logistic regression was conducted. Age and education were entered as demographic controls to account for their impact on BDS scores. In the second step, the BDS Total Score was entered. The BDS Total Score was not a significant discriminating variable between individuals in the PTSD or mTBI group using putative diagnosis to define the PTSD group ($\chi^2(1) = 0.42$, $b = .06$, $p = .518$; 95% CI:

[.89, 1.28]). In a second model, when individuals items of the BDS were entered instead of the BDS Total Score, the BDS individual items were not a discriminating predictor of overall group membership over and above the effect of education and age ($\Delta\chi^2(27) = 31.27$, $p = .260$). When examined across groups, only BDS Item 1 (dominant hand initiated alternating rhythm tapping) $\chi^2(1) = 5.51$, $b = 1.51$, $p = .019$; 95% CI: [1.28,15.96], discriminated between the mTBI and PTSD group. These results indicated that for every one-point increase on item 1 of the BDS, individuals were 4.52 times more likely to be in the TBI group than the PTSD group. In addition, item 4 of the BDS (go/no-go task) was associated with a difference between the PTSD group and control group (item 4 $\chi^2(1) = 3.93$, $b = .95$, $p = .047$; 95% CI: [1.01, 6.60]). For every one point increase on Item 4 of the BDS (indicating better go/no-go performance), individuals were 2.58 times more likely to be in the control group. Additionally, the mTBI group scored worse on two go/no-go tasks when compared to the control group (Item 3: $\chi^2(1) = 3.96$, $b = .63$, $p = .047$; 95% CI: [1.01, 3.52]; Item 4 $\chi^2(1) = 3.42$, $b = 1.23$, $p = .012$; 95% CI: [1.31, 8.95]). Thus, for every one point increase on Item3 and Item 4 of the BDS (indicating better go/no-go performance), individuals were 1.89 and 3.42 times more likely to be in the control group than the mTBI group, respectively. The model including total score correctly predicted 58.4% of individuals into their correct groups (with no individuals correctly classified into the PTSD, mTBI, or PTSD + mTBI group), while the model including individual items correctly predicted 58.0% of individuals, with 3.0% into the PTSD Group and 6.7% into the mTBI group. Thus, BDS Item 1 discriminated between the mTBI and PTSD group, finding that the mTBI group performed better on Item 1 when compared to the PTSD group.

A second model was created using the PCL $\geq$ 50 to define PTSD group membership. In the first step, age and education were entered as demographic controls to account for their impact

on BDS scores. In the second step, the BDS Total Score was entered. The BDS Total Score was not a significant discriminating variable between individuals in the PTSD or mTBI group ($\chi^2(1) = 1.05$, $b = 0.10$, $p = .305$; 95% CI [.91,1.35]). Additionally, when individual items of the BDS were entered into step two instead of the BDS Total Score, no items emerged as significant predictors between the PTSD and mTBI group over and above the effect of age and education ($\Delta\chi^2(27) = 26.01$, $p = .518$). Although there was no difference between the PTSD and mTBI groups on the BDS items, the PTSD group scored worse on the BDS Total Score when compared to the control group ($\chi^2(1) = 4.14$, $b = .16$, $p = .042$; 95% CI [1.01,1.36]), such that for every point increase on the BDS (fewer NSS), individuals were 1.17 times more likely to be in the control group. Furthermore, BDS item 4 (a go/no-go task) discriminated between the PTSD and control group ($\chi^2(1) = 5.31$, $b = 1.12$ $p = .021$; 95% CI [1.18, 8.01]), indicating that for every one point increase on BDS item 4 individuals were 3.08 times more likely to be in the control group than the PTSD Group. Additionally, the mTBI group scored worse on a go/no-go task (item 4) when compared to the control group ($\chi^2(1) = 6.16$, $b=1.17$, $p = .013$; 95% CI: [1.28, 8.16]). Thus, for every one point increase on Item 4 of the BDS (indicating better go/no-go performance), individuals were 3.23 times more likely to be in the control group than the mTBI group. Consistent with the inability of the BDS to predict overall group differences, individual items correctly predicted 0% of individuals correctly in the mTBI and 6.9% into the PTSD group, while the total score only predicted 5.7% of PTSD group membership.

Hypothesis four. To address hypothesis four, that veterans diagnosed with comorbid PTSD + mTBI will perform worse on the BDS when compared to healthy controls, or single illness group classification (mTBI or PTSD) and correctly predict group membership, four multinomial logistic regressions were run. In step one of all regressions, age and education were

entered to control for their effect on the BDS. In step two, the BDS Total Score was entered for the first two models and individual items were entered for the second set. In the first model, using putative diagnosis to define PTSD group membership, the results of the multinomial logistic regression indicated that there were no significant differences between the mTBI+PTSD group and any other group (defined by putative diagnosis) on the total BDS (Control $\chi^2(1) = .44$, $b = .05$ $p = .507$; mTBI $\chi^2(1) = .04$, $b = -.02$ $p = .841$; PTSD $\chi^2(1) = .73$, $b = -.08$, $p = .392$). When individual items of the BDS were entered instead of BDS Total Score, no items of the BDS discriminated between the mTBI+PTSD group and the mTBI group and the PTSD only group.

Results with the BDS Total Score were replicated with the PTSD group defined by a PCL of >50 (Control χ^2 (1) = .42, $b = .53$ $p = .516$; mTBI χ^2 (1) = .03, $b = -.02$ $p = .871$; PTSD $\chi^2(1) = 1.05$, $b = -.10$ $p = .305$). When defined by a PCL $\geq$ 50 no single item of the BDS discriminated individuals in the mTBI + PTSD group from any other group. Thus, on the BDS, there were no significant differences across the mTBI only, PTSD only, and mTBI + PTSD group on either the BDS Total Score or individual items.

Hypothesis Testing: Neuropsychological Measures and BDS (Hypothesis 5 and 6)

To address hypothesis five and six, that the BDS Total Score and individual items will predict group membership when entered into a model with other neuropsychological tests, four logistic regressions (for hypothesis five) and four multinomial logistic regressions (for hypothesis six) were run, to replicate hypothesis two and four with the addition of neuropsychological tests. Given the volume of neuropsychological tests administered in the current battery and requirements for power in the current study, a forward stepwise approach was used to determine the predictive ability of the neuropsychological tests. When using neuropsychological assessments, raw scores were converted to standard scores for the purposes

of the analyses. Additionally, age, education, and the Wechsler Test of adult reading were entered into the model to control for their impact on neuropsychological assessments.

Hypothesis 5. To address hypothesis five, that the BDS will discriminate between the illness and control group above and beyond other neuropsychological measures, two logistic regressions were conducted. For each model, age, education, and the WTAR Standard score were forced into the first block of the logistic regression to control for these demographic variables. In the second step the neuropsychological assessment measures were entered stepwise. In the third block the BDS Total Score was forced into the equation. These models indicated that the BDS Total Score did not predict group membership over and above the effect of age, education, and significant neuropsychological measures using putative PTSD diagnosis ($\chi^2(1) = .98$, $b = -.06$ $p = .322$; 95% CI [.84, 1.06]) or PCL $\geq$ 50 criteria to define the PTSD group, ($\chi^2(1) = 1.98$, $b = -.08$ $p = .159$; 95% CI [.83, 1.03]). Thus, the BDS Total Score did not predict group membership over and above the effect of age, education, and neuropsychological measures. In a second set of models, only BDS item 4 improved prediction over and above the effect of significant neuropsychological predictors ($\chi^2(1) = 4.22$, $b = -.72$ $p = .040$; 95% CI [.25, 97]), such that for every one-point increase on BDS item 4, individuals were .49 times as likely to be in the illness group. A similar effect was found when using PCL $\geq$ 50 to define the illness group ($\chi^2(1) = 6.69$, $b = -.90$ $p = .01$; 95% CI [.21, 80]), such that for every one-point increase on BDS item 4, individuals were .41 times as likely to be in the illness group.

When using Putative Diagnosis, Non-Dominant Grooved Peg Board predicted illness group membership when BDS total score was forced into the model: $\chi^2(1) = 4.03$, $b = -.29$ $p = .045$; OR: .75, 95% CI [.57, .99]. This effect was no longer significant when using individual BDS items $\chi^2(1) = 3.08$, $b = -.26$ $p = .079$; OR: .77, 95% CI [.58, 1.03]. When using a PCL $\geq$ 50

to define PTSD diagnosis, no neuropsychological predictors emerged. When using individual items of the BDS and Dominant Grooved Pegboard, 63.3% of individuals were classified correctly using Putative Diagnosis (control: 84.4 vs illness: 31.9) and 61.1% using PCL ≥ 50 (Control: 86.3 vs Illness 20.7). Thus, the BDS did not predict group membership between the illness and control groups over and above the effect of neuropsychological measures.

Hypothesis 6. To address hypothesis six, two multinomial logistic regressions were conducted using the BDS Total Score. The models were created using a forward stepwise approach, as due to the nature of multinomial logistic regression, all items could not be entered simultaneously without a significant loss in statistical power. For each model, age, education, and the WTAR Standard score were forced into the first block of the multinomial logistic regression to control for these demographic variables. The neuropsychological assessment measures were entered in a stepwise manner in the second step. The BDS Total Score was forced into the equation in the third. When the BDS Total Score was entered the model, it was not a significant predictor when PTSD group membership was defined by putative diagnosis ($\chi^2(3) = 1.92$, $p = .590$) or PCL ≥ 50 ($\chi^2(3) = 3.01$, $p = .390$). Thus, the BDS Total Score does not predict mTBI+ PTSD group membership over and above the effect of neuropsychological assessments.

Hypothesis 6b: Neuropsychological Predictors. When using a PCL cutoff of >50 to define PTSD groups, WAIS-III similarities emerged as a significant predictor of group membership when BDS total score was included in the model ($\chi^2(3) = 9.22$, $p = .027$). There were no significant differences between the mTBI + PTSD group and any other group, though this effect approached significance with the mTBI group ($\chi^2(1) = 3.82$, b=.25, $p = .051$, 95% CI [1.00, 1.64]). Additionally, the mTBI group performed better on the similarities task when compared to the control group ($\chi^2(1) = 6.24$, b=.24, $p = .012$, 95% CI [1.05, 1.52]), such that for

every one point increase, individuals were 1.27 times more likely to be in the mTBI group. When using a putative diagnosis to define the PTSD groups, Grooved Pegboard Non-Dominant Hand was a significant predictor ($\chi^2(3) = 8.09$, $p = .04$). There was a significant difference between the mTBI + PTSD group when compared to the control group ($\chi^2(1) = 4.41$, b=.43, $p = .036$, 95% CI [1.03, 2.31]), such that for every one point *z*-score increase on the Non-Dominant Hand Grooved Peg Board, individuals were 1.54 times more likely to be in the control group. Additionally, this effect existed when the mTBI+ PTSD group was compared to the mTBI group ($\chi^2(1) = 4.58$, b=.59, $p = .03$, 95% CI [1.05, 3.11]), indicating that for every one-point increase in *z*-score, individuals were 1.81 times more likely to be in the mTBI group.

In a second set of regressions, focused on individual items of the BDS, a different procedure was used, due to the decrease in power when entering all nine items of the BDS simultaneously into a multinomial logistic regression. For these two models, age, education, and the WTAR Standard score were forced into the first block of the multinomial logistic regression to control for these demographic variables. In the second step the neuropsychological assessment measures were entered in a stepwise manner as were BDS items using a forward stepwise procedure. When using a PCL cutoff of 50 to define PTSD groups, only BDS item 4 emerged as a significant predictor in the model ($\chi^2(3) = 10.71$, $p = .013$) but did not discriminate between the illness groups (mTBI group ($\chi^2(1) = -.44$, b=-.37 $p = .507$, 95% CI [.23, 2.06]; PTSD group ($\chi^2(1) = .37$, b=-.33 $p = .544$, 95% CI [.25,2.09]). When compared to controls, the mTBI only group ($\chi^2(1) = 6.93$, b=-1.20 $p < .01$, *OR:* .30, 95% CI [.12,.74]) and PTSD only group ($\chi^2(1) = 6.61$, b=-1.16 $p = .010$, *OR:* .31, 95% CI [.13,.71]), both performed worse on BDS item 4. When using putative diagnosis to define the groups, BDS item 4 also emerged as a significant predictor, though it did not discriminate between the illness groups (mTBI group ($\chi^2(1) = -.52$,

b=-.39 *p* = .520, 95% CI [.23, 1.97]; PTSD only group ($\chi^2(1)$ =.1, *b*=-.19 *p* = .720, 95% CI [.30,2.32]). When compared to controls, the mTBI ($\chi^2(1)$ = 6.55, *b*=-1.19 *p* = .010, *OR:* .30, 95% CI [.12,.76]) and PTSD only group, ($\chi^2(1)$ =4.93, *b*=-.99 *p* =.026, *OR:* .37, 95% CI [.16,.89]), both performed worse on BDS item 4. Thus, worse performance on BDS Item 4 was associated with differences between the mTBI only and PTSD only group when compared to controls but was not associated with differences between individuals diagnosed with mTBI and/or PTSD.

Hypothesis 6B: Neuropsychological Predictors. Using a PCL ≥ 50, WAIS-III similarities discriminated between mTBI + PTSD group and the mTBI group ($\chi^2(1)$ = 3.96, *b*=.25 *p* =.047, *OR:* 1.29, 95% CI [.23, 2.06]). Specifically, for every one point increase on similarities, individuals were 1.29 times more likely to be in the mTBI group than the mTBI + PTSD group. When putative diagnosis was used to determine PTSD group membership, the mTBI + PTSD group did not differ from any groups on WAIS-III Similarities (Control: ($\chi^2(1)$ = .2.65, *b*=.80 *p* = .104, 95% CI [.85, 5.81]; mTBI ($\chi^2(1)$ = .86, *b*=.11, *p* = .35, 95% CI [.88, 1.43]); PTSD ($\chi^2(1)$ = .3.30, *b*=-.23 *p* = .069, 95% CI [.63, 1.02]). When examining differences between the illness groups, the only difference that emerged was between the mTBI only and PTSD only group such that when using PCL ≥ 50 (mTBI: ($\chi^2(1)$ = 7.29, *b*=.35 *p* < .01, 95% CI [1.1, 1.82]), or putative diagnosis (mTBI: ($\chi^2(1)$ = 7.13, *b*=.34 *p* < .01, 95% CI [1.1, 1.80]) such that for every one point increase on WAIS-III similarities individuals were 1.41 times more likely to be in the mTBI only group than the PTSD only group

Across all multinomial models, overall prediction was below 65% across the groups. Although predictive ability varied by model, prediction of the control group remained above 95% for all models. Conversely, group membership was only correctly predicted at 11.4%

(mTBI group) and 13.8% (PTSD group) when PTSD was defined by PCL>50 and individual items were entered. Thus even with the addition of step wise neuropsychological predictors, the ability to correctly classify individuals into the mTBI, PTSD, and mTBI+PTSD group remained below chance (25%) across all models.

Cluster Analysis

As noted in the above analyses, the BDS Total Score and individual items tended to poorly predict individual's membership in the four groups of interest. Based on this finding, a cluster analysis was used to determine what groups exist within the data based on the BDS and neuropsychological assessments. A *k-means* analysis was conducted on the BDS individual items and the neuropsychological assessments listed in Table 2 to determine what groups in the data would be produced should a 4-cluster or 2-cluster solution be selected. A 4-cluster solution was selected to attempt to mirror the *a priori* groups of control, mTBI, PTSD, and mTBI + PTSD. A 2-cluster solution was conducted in an attempt to mirror the *a priori* groups of control and illness.

Of the individuals with valid scores, 226 participants had complete data. Their neuropsychological assessment scores and BDS individual item scores were converted to *z*-scores and analyzed using a *k*-means cluster analysis. For our 4 cluster solution, convergence was reached in 7 iterations. Univariate ANOVAs indicated that the clustered groups differed significantly on most classifying variables (all *p*s < .05). The *n* for each cluster varied from 24 to 117. Please see Appendix D, Table 32 for individuals scores across measures included in the cluster analysis. Naming of the groups was determined by examining the z scores across the items and subjectively identifying their patterns. Based on their scores across classifying variables Cluster 1 (*n* =24) was most consistent with Impaired Fine Motor and Processing Speed,

as in general, individuals scored slightly below average to moderately below average on fine motor and processing speed tasks, including the Grooved Pegboard Tasks, Digit Span, Symbol Search, and BDS Item 1. Additionally, they scored in the slightly below average range on BDS items 2,3,4,5, and 9. Cluster 2 (n = 117) was termed Cognitively Healthy as they tended, as they tended to perform in the average to slightly above average range on all tasks. Cluster 3 (n =52) was termed mild neurocognitive decline with intact BDS as they scored in the slightly below average range across multiple tasks with scores in the average range on the BDS. Cluster 4 (n =33) was termed Mild Neurocognitive Impairment as they tended to score in very slightly below average range to moderately below average range across most neurocognitive predictors. The four cluster solution evidenced poor agreement when compared to the *a priori* defined groups (0 = "control", 1 = "mTBI", 2 = "PTSD", 3 = "mTBI + PTSD using putative diagnosis (*Cramer's V* = 0.15, p = 0.108), and PCL > 50 (*Cramer's V* = 0.15, p = 0.083).

A cluster analysis was conducted next on the BDS Individual items and neuropsychological assessments scale to determine what groups in the data would be produced with a two-cluster solution. This method was selected in an effort to mirror the two *a priori* groups of "control" and "illness", given the relatively poor fit of a four-cluster solution. Of the individuals with valid scores, 226 participants had complete data. Convergence was reached in 8 iterations. Univariate ANOVAs indicated that the clustered groups differed significantly on all but three classifying variables (CPT Detectability, CPT HIT Rate, and BDS Item 8). The final cluster centers together with the number of participants in each cluster are shown in Appendix.

Cluster 1 (N = 90) was termed Mild Cognitive Impairment as they appeared to be very slightly below average to slightly below average compared to other individuals in the sample across all significant predictors of group membership (-.10 to -.74). Participants in Cluster 2

(*N*=136) named Cognitively Healthy appeared to be very slightly above average to slightly below average across all significant predictors when compared to the overall sample (.09 to .49) within the current study. When compared to the *a priori* defined groups (0 = "control", 1 = "illness"), the two cluster solution evidenced poor agreement with the *a priori* groups, as about two-thirds of individuals fell into the Cognitively Healthy group. Moreover, there was not a significant of association between the *a priori* groups and the *k-means* cluster groups, when using the two (PCL > 50: *Cramer's V* = 0.44, *p* =0.511 & Putative Diagnosis: *Cramer's V* = 0.69, *p* =0.297) cluster solution. The association using a two-cluster solution and the *a priori* determined four groups was significant independent of PTSD group membership method (Putative Diagnosis: *Cramer's V* = 0.22, *p* = 0.014; PCL ≥ 50: *Cramer's V*= 0.20, *p* = 0.031). When examined further though, results are inconsistent with the hypothesized breakdown of groups, as in general, illness groups tended to fall into the cognitively healthy group, with the exception of the PTSD group. Thus, when using a cluster analysis of individuals in the current study, allowing the neuropsychological data and the BDS individual items to identify groups contained within the sample, there is poor agreement between the pre-determined groups and those that exist within the data.

Vita

David Rothman was born in New Brunswick, New Jersey and was raised in Cherry Hill, New Jersey. He graduated from Cherry Hill High School East in 2009. He received his Bachelors of Arts from the College of New Jersey in December of 2012. He received his Master of Science in Psychology from Virginia Commonwealth University in 2015. He is currently completing his clinical psychology internship at the Hunter Holmes McGuire Veterans Affairs Medical Center.