

Mild Traumatic Brain Injury and Mindfulness-Based Stress Reduction: A Review

*Jared S. Link, M.S., Trevor Barker, M.S., Sophia Serpa, M.S., Maya Pinjala, M.S.,
Thomas M. Oswald, Psy.D., and Lisa K. Lashley, Psy.D.*

Abstract

The often pernicious neuropsychological effects following a mild traumatic brain injury can persist for months or even years. Symptoms associated with head injury can include headaches, orthostatic hypotension, trouble sleeping, slower processing speed, fatigue, and impairments in attention, memory, and executive functioning. These symptoms can be exacerbated as well as maintained via depression and anxiety. Collectively, this is known as persistent post-concussive syndrome. Interventions to alleviate these symptoms are lacking, expensive, and/or time-consuming. Currently, there has been a surge of interest into the neuroanatomical and neuropsychological correlates of mindfulness-based stress reduction (MBSR). Evidence suggests that an 8-week MBSR program and its variants may increase cortical gray matter in specific areas such as the hippocampus, portions of the cerebellum, right thalamus, orbital frontal cortex, and other areas. Moreover, the literature suggests that such a program has evidenced improved scores on measures of attention, memory, and executive functioning. The extant literatures pertaining to mild traumatic brain injury, persistent post-concussive syndrome, and MBSR are reviewed here. Considerations for future empirical studies to validate the plausibility of using such a program as a neurorehabilitative intervention are suggested.

Introduction

Knowledge of physiological and psychological sequelae of traumatic brain injury (TBI) has grown significantly in recent decades; however, there has been a relative dearth of research on preventative interventions for prolonged symptoms. While no brain injury affects an individual in the same way, typical symptoms of TBI tend to include memory difficulties, slow processing, fatigue, sleep difficulties, dizziness, anxiety, depression, headache, and executive functioning deficits (Binder, 1986; Mittenberg & Burton, 1994), and includes varying levels of TBI such as minor, mild, moderate, and severe. The Center for Disease Control and Prevention (CDC; 2013) estimates that approximately 1.7 million individuals acquire a TBI each year. The minor and mild types are the most prevalent, typically consisting of 75% to 90% of cases (Belanger & Vanderploeg, 2005). Moreover, Belanger and Vanderploeg (2005) estimate that 7-33% of patients continue to manifest cognitive deficits, headaches, balance problems, fatigue,

depression, anxiety, irritability, and/or memory and attention difficulties beyond three months, which may be indicative of persistent post-concussive syndrome (PPCS). However, a diagnosis of PPCS is currently controversial in the medical and legal fields due to conflicting theories on what these symptoms reflect. Some theories suggest that PPCS may reflect neurological dysfunction that is below the threshold of routine diagnostic procedures such as computed tomography (CT), magnetic resonance imaging (MRI), and electroencephalography (EEG) (Hayes & Dixon, 1994; Miller, 1996), while others suggest that these symptoms are the result of poor coping styles (Marsh & Smith, 1995), emotional reactions to adverse events (Bryant & Harvey, 1999), or expectations of symptoms occurring following a mild traumatic brain injury (mTBI) (Mittenberg et al., 1992). Despite this controversy and PPCS symptoms being present in moderate to severe TBI, these symptoms are occasionally used to define mTBI (Petchprapai & Winkelman, 2007). The continuation of these symptoms likely stymie the individual's ability to return to school or work, contributing to a loss in productivity. In fact, mild TBI (mTBI) accounts for an astonishing \$12 billion in direct and indirect costs (Faul, Xu, Wald, & Coronado, 2010). Furthermore, Faul, Xu, Wald, and Coronado (2010) suggest that since 2004 the incidence of TBI has increased by 21%. Therefore, it may be expected that the relative cost of TBI will also increase. As a result, cost-effective and brief interventions for the persistent symptoms of TBI should be a priority for clinicians and researchers.

Currently, there is a lack of a universal definition for mTBI; however, the World Health Organization's (WHO) definition is considered to be the most widely used and accepted. The definition states "mTBI is an acute brain injury resulting from mechanical energy to the head from external physical forces" (Bigler, 2008; Carroll et al., 2004). In addition, there has been a lack of consistency regarding appropriate criteria for brain injuries within frontline diagnostic manuals such as the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5; APA, 2013)* and the *International Classification of Disorders (ICD-10; WHO, 2008)*. These inconsistencies are mostly in regards to the time frame (i.e., ICD-10 requires that symptoms start within four weeks of the injury while DSM-V does not specify a time) and naming. The DSM-V includes PCS under 'Minor Neurocognitive Disorder.' Despite this, there are general common characteristics of mTBI such as a loss of consciousness (LOC), lasting 30 minutes or less, a period of posttraumatic amnesia lasting no more than 24 hours, and Glasgow Coma Scale scores of 13-15 that have been used to aid in a diagnosis of mTBI (Petchprapai & Winkelman, 2007).

The criteria set forth via the *ICD-10* for post-concussion syndrome (PCS), which is a sequela of a mTBI, is the most widely accepted, and states that the individual is required to have three or more symptoms that persist for a minimum of 4 weeks (Mittenberg, Canyock, Condit, & Patton, 2001; Nguyen & Yablon, 2002; Petchprapai & Winkelman, 2007). These symptoms include headache, memory loss, fatigue, insomnia, dizziness, anxiety, depression, concentration difficulties, irritability, and sensitivity to light and sound following mild traumatic brain injury (Binder, 1986; Gouvier, Cubic, Jones, Brantley, & Cutlip, 1992). Previously, the *DSM-IV-TR* provided criteria for post-concussion disorder as a Disorder for Further Study and included similar symptoms; however, the individual was required to display symptoms for at least three months. With the recent release of the *DSM-5*, this disorder has been subsumed into Major or Mild Neurocognitive Disorder Due to Traumatic Brain Injury, requiring only one or more symptoms of loss of consciousness, posttraumatic amnesia, disorientation and confusion, and neurological signs such as an indication of injury via neuroimaging (APA, 2013). The lack of a

general consensus as to the specific criteria for mTBI has influenced research into potential biomarkers that would allow for a more accurate diagnosis.

A study by de Kruijk, Leffers, Menheere, Meerhoff, Rutten, & Twijnstra (2002) examined post-traumatic complaints (PTC), which include the possible presence of numerous symptoms such as headache, drowsiness, neck pain, nausea, vomiting, dizziness, loss of memory, concentration problems, and early biochemical markers associated with mTBI. More specifically, the researchers investigated mTBI associated specific serum markers S-100B (an acidic calcium binding protein found in the brain) and neuron specific enolase (NSE) (an isoenzyme of enolase, located mainly in neurons but also in smooth muscle fibers and adipose tissue) in blood samples taken within six hours post-injury. All patients were questioned about the severity of their PTC at two weeks and six months post-injury. Results found that headache, dizziness, or nausea at the ER after mTBI is strongly associated with the severity of most PTC after six months. Absence of these symptoms in combination with normal serum marker concentrations within six hours after trauma seemed highly predictive of full recovery after six months.

As one of the leaders in the investigation, contributing factors, and treatment of PCS and mTBI, McCrea (2008) described several psychological theories and models that contribute to the persistence of symptoms in PCS. The Expectation as Etiology paradigm that was originally described by Mittenberg and others (1992) suggested ongoing symptomatology following a mild brain injury could be best explained by the degree to which the person misattributes common complaints to the injury. The vast majority of complaints described in this population are also indicated in other populations such as in college students, chronic pain patients, and depressed clients (McCrea, 2008). Moreover, many PCS patients underreport the frequency of experiencing these symptoms before their injury (Mittenberg, Digiulio, Perrin, & Bass, 1992). In a similar vein, the Nocebo Effect (Hahn, 1997; Iverson, Zasler, & Lange, 2006; McCrea 2008) suggests that the actual anticipation of particular illness and emotional anguish can directly influence the sickness they anticipated, and is more often than not associated with specific situational cues. Finally, like many psychological disorders, a Diathesis-Stress Model has been suggested to be involved in the development and continuation of symptoms seen in PCS (Wood, 2004; McCrea, 2008). It has been posited that the high level of individual variance in regards to motivating factors and coping skills strongly contributes to the development of PCS symptoms in some individuals versus others. Furthermore, iatrogenic factors such as clinician suggestion of being “brain damaged” despite vague symptom presentations and no clear indication that there has been any parenchymal damage have been described as contributing to PCS. Given the nonspecific symptom complaints that can be seen in a variety of populations that have benefited from mindfulness-based practices, it seems clear that those experiencing similar symptoms and have been diagnosed with mTBI and/or PCS could also benefit from these techniques.

In recent years, there has been a steady interest in the use of mind-body techniques for various medical as well as psychiatric disorders (Kabat-Zinn, 1990; Teasdale et al., 2000). These techniques include meditation, yoga, deep breathing exercises, progressive muscle relaxation, and hypnosis. Many of these techniques have yielded meaningful results. Aside from the obvious psychological benefits such as increased well-being, awareness of emotions, and nonjudgmental attitude, these techniques have begun to capture interest into the neuroanatomical, neurobiological, and neuropsychological correlates of engaging in such exercises. These techniques have been utilized by a plethora of cultures for thousands of years; however, researchers are only now beginning to tap into the relative scientific benefits of these

practices. The most widely researched mind-body program is mindfulness-based stress reduction (MBSR), which has garnered much praise for its ability to coach the participant into a more mindful and accepting attitude. Currently, the literature pertaining to the neuropsychological effects of MBSR is burgeoning; however, few studies have investigated the feasibility of its use as an intervention for individuals with mTBI. One pilot study conducted with individuals who experienced an mTBI seven months prior to the study found that a modified version of MBSR yielded improvements on quality of life and self-efficacy. In addition, the researchers found small, yet significant effects on measures of central executive aspects of working memory and attention regulation (Azuley et al., 2013).

The present review examines the relevant literature regarding the effects of a brain injury on the structures of the brain, the neuropsychological effects of brain injury, current interventions for mTBI, the efficacy of MBSR and its variants, the neuroanatomical evidence for MBSR, and the neuropsychological effects of MBSR. Despite the lack of consensus regarding the specific symptomatology of mTBI, there are broad symptoms that appear to be consistent in all definitions of mTBI. These broad symptoms consist of deficits in memory, attention, and executive functioning. It has been suggested in the MBSR literature that such a program has the tendency to improve memory, attention, and executive functioning; therefore, the purpose of this review is to assess the feasibility of using an MBSR program to alleviate the post-concussive symptoms associated with a mild traumatic brain injury. Future considerations for areas of research are discussed.

Post-Concussive Symptoms

Recovery from a concussion is typically rapid and complete for most individuals (Iverson et al., 2007). Even though complete recovery is common, a subset of individuals display symptoms for a prolonged period (as indicated above). If post-concussion symptoms persist for three to five months, a person is typically diagnosed as having PCS. If symptoms continue to persist for six months or greater, the person is diagnosed as having PPCS. From a neuropsychological viewpoint, symptoms of impaired attention, executive functioning, memory, and emotional regulation dominate the clinical picture of PPCS (Lunden et al., 2006). While these self-reported problems are commonly observed in closed head injury, there remains controversy surrounding the etiology of the symptoms. Some argue that residual effects of brain injury stem from psychological factors, while others argue that functional or structural factors contribute to residual symptoms (Meares et al, 2008; Wood, 2007).

The dominant symptoms of concussion include brief alteration in consciousness with changes in mentation and processing speed; physical symptoms of headache, dizziness, vertigo and/ or fatigue; impairments in short term memory, attention, and concentration; and increased likelihood for changes in mood and emotional regulation (Bigler, 2007). It is assumed that there is a common origin of these symptoms due to the relative frequency of them following concussion.

A complete discussion of brain anatomy and the physics of TBI are provided by Bigler (2007), and a summary of his findings and hypotheses will be presented. The physics of brain trauma and the relationship to functional anatomy of the brain has led to hypotheses about how insults impact everyday functioning. TBI can alter consciousness due to disrupted neuroanatomical connections, specifically the upper brainstem and reticular activating system. Memory can be impaired by mechanical compression of the perirhinal and entorhinal cortices, which disrupt input to the hippocampus or output from the hippocampus via the fornix and its

connection with the anterior thalamus and cingulate. Emotional regulation may be impaired when damage occurs to the medial temporal lobe and/or the basal forebrain. Migraine or headache following a traumatic injury may be due to the stretching of the internal carotid and the vasculature comprising the Circle of Willis, along with stretching or irritation of the dura and other vessels. Hormonal changes also occur due to hypothalamic-pituitary disruption. Processing speed is lowered due to insult of the integrity of white matter pathways, particularly interhemispheric axons. These structural disruptions to neurological functioning provide possible explanations for the symptoms of PPCS.

Alexander Luria's approach to brain injury included a detailed analysis of syndromes arising in individual cases of brain damage. These detailed analyses were then used to understand the role of particular brain structures in cognitive activity (Loftus, 1978). It is clear that brain injuries differ from one another significantly and, therefore, it appears that interventions aimed at decreasing symptoms of PPCS should be tailored to the deficits and symptoms accompanied by the injury. In other words, individuals with significant cognitive deficits in attention for example, would likely benefit from an MBSR intervention involving enhancement of attentional skills, while individuals with more physical symptoms such as headaches would benefit from an MBSR intervention aimed at enhancing pain tolerance. Individuals with emotional dysregulation symptoms may benefit from increasing flexibility and learning emotional regulation skills.

While structural problems may play a part in the presence of PPCS, there are also many other factors to consider. According to meta-analysis by Belanger et al. (2005), neuropsychological tests revealed short-term effects of mild traumatic brain injury (mTBI), but long-term effects were only found in cases that were in litigation or wanting compensation. The presence of litigation seems to be a major confound in research of PPCS. Another confound is the presence of other medical or psychiatric disorders. Every symptom of PCS can occur independently of a head injury, and PPCS is often misdiagnosed when depression is the true cause of symptoms (Iverson, 2007). Some investigators have explained that certain symptoms of PPCS including dizziness and vertigo are primarily explained by chronic pain, eye, ear, or internal organ damage (Suh, et al., 2006). The critical issue with many of these investigations is the general lack of consensus in regards to the appropriate treatment of the symptoms being experienced as well as the *maintaining* psychological factors and *comorbid* diagnosis such as depression, anxiety, in addition to various coping deficits that contribute to longevity of psychiatric diagnoses (Mittenberg, Digiulio, Perrin, & Bass, 1992; McCrea, 2008). As is described below, many of the factors that have been described as contributing to the continuation of symptomatology, poor quality of life, and comorbid diagnoses have been effectively treated through mindfulness techniques (Segal, Williams, & Teasdale, 2000).

In order to examine the direct effects of a head injury versus general distress associated with psychological factors, Fox et al. (1995) measured self-reported PCS symptoms in a group of 400 psychiatric outpatients. This was to determine whether the complaints were associated with having general psychological difficulties, while controlling for head trauma and being involved in a lawsuit. For almost every item, the group who had experienced a concussion had equal or greater symptom endorsement rates than those without concussion history. Of the entire sample, 77% reported anxiety, 64% had sleep problems, 55% had fatigue, 53% experienced impatience, and 42% felt disorganized. Although those with a head injury had higher rates of symptoms, the symptoms are common enough in psychiatric patients to warrant caution when diagnosing PCS, especially when there is a history of psychiatric problems. Despite this, the

authors failed to consider Mittenberg's (1992) explanation for increased prevalence of such symptoms in this population. Moreover, appropriate suggestions for intervention and prevention of symptoms were not discussed.

A study by van der Horn, Spikman, Jacobs, and van der Naalt (2012) looked at the relationship of anxiety and depression to PPCS in patients with TBI. They proposed that anxiety and depression result in a lower sense of well-being and increased problem-focused behavior, leading to more expressed complaints. These complaints are known to interfere with return to work or other activities, so it is important to have a better understanding of the relationship. The 242 patients were separated into three groups based on severity - minor, mild, or moderate-to-severe TBI. Overall, 67% experienced complaints, with the most frequent complaints being fatigue (53%), forgetfulness (50%), poor concentration (44%), drowsiness (42%), and dizziness (40%). In the group, 22% had anxiety, 18% had depression, and 12% had both. The presence of complaints correlated significantly with the presence of depression and anxiety. In patients with post-concussive complaints, or incomplete return to work, anxiety and depression were more frequent. Interestingly, these rates were high in the minor TBI group. More emotional distress was found in relation to PPCS in those with less severe injuries. This might have been due to negative perceptions, beliefs, and interpretations of their injury. Women were also found to be more likely to report emotional distress and have work-related problems. The authors attribute many of the problems to ineffective coping strategies; however, appropriate methods in which to teach coping skills were not iterated. Furthermore, the authors failed to consider the possibility of grounding techniques to aid in relieving emotional distress, which could have lowered the rate of work-related problems and complaints. The incorporation of mindfulness techniques within the work place has been shown to decrease employee stress and burnout (Fries, 2009) and increase work performance (Glomb, Duffy, Bono, & Yang, 2011). Given the consensus among investigators that those with mTBI and PCS experience work-related issues as a result of their injury and psychological sequelae that contribute, mindfulness-based practices would decrease this burden.

Current Interventions

Currently, there are few structured psychological interventions designed for mTBI. Approximately 38% of patients who have mTBI meet ICD-10 criteria for PPCS within 6-weeks post-injury, but only a small number of these patients actually seek treatment for the above symptoms (Mittenberg et al., 2001). This may be due to lack of education on available treatments, beliefs that symptoms are unrelated to the mTBI (retribution of symptoms to other causes), or even minimization of the symptoms experienced. A survey conducted by Mittenberg and Burton (1994) was distributed amongst neuropsychologists regarding the current treatment approaches for PPCS. The survey found that respondents believe anxiety and depression are important emotional factors contributing to PPCS, and approximately half of the respondents believe that selective attention, attentional bias, anxiety and depression can lead to symptom exacerbation as well maintenance of PPCS. When asked about the most commonly used interventions for PPCS, the respondents reported education, support, and reassurance to be key aspects of intervention in this population.

Taking the survey information further, Ferguson and Mittenberg (1995) developed a 12-week treatment protocol for PPCS patients that involved teaching patients how PPCS symptoms are maintained and exacerbated by negative cognitions, misattributions, and anxiety. The goal was also to teach patients a variety of coping skills, cognitive restructuring, and stress

management techniques to reduce PPCS symptoms. They found that this treatment significantly reduced the number of reported symptoms and respective severity, with mean number of symptoms reported at baseline being reduced from 9.4 (SD=1.8) to 1.8 (SD= 1.7) post-treatment. While general symptomatology was reduced, there was no follow-up investigation to determine whether these gains continued. Furthermore, the authors failed to assess how these symptoms affected other areas of their lives including work experience and performance. Without a follow-up, it is impossible to know whether the misattributions, anxiety, and maladaptive thinking are likely to come back if an additional injury is sustained or any other life event triggered a re-experiencing of residual symptoms. More recent findings have suggested that becoming aware of triggers through mindful practice can decrease the incidence of relapse or falling back into a similar mode of thinking (Segal, Williams, & Teasdale, 2000).

Miller and Mittenberg (1998) reviewed literature in the prevention and treatment of PPCS and found that in both adults and children, the symptoms of PPCS may initially have an organic, neurological basis; however, these are maintained and exacerbated by psychological factors. This finding emphasizes the need for psychological interventions aimed at reducing anxiety and depression and that involve education, reassurance, and coping skills in order to reduce symptom presentation. Clearly, those with such symptoms could have experienced small bleeds within the brain, axonal shearing, or edema as a result of their injuries; however, these neurological insults are more often caused by more severe trauma. Taking this in mind, it would be more appropriate to suggest that these individuals suffer an inability to be aware of how psychological factors play a role in the perceived symptoms. The education described by the authors revolved around brain functioning and ways of preventing future head injuries. While this information is clearly important, it does not, however, explain how certain thoughts and bodily functions and experiences can influence such symptoms. Mindfulness approaches consider these contributing factors and teach patients how to recognize such triggers. Use of these approaches would be beneficial in alleviating residual psychological symptoms.

Evans et al. (1994) conducted a survey of the most common forms of treatment for PPCS and found that post-concussive symptoms are most commonly treated with medication. The most frequently used medication being nonsteroidal anti-inflammatory analgesics (NSAID), followed by antidepressant medication such as serotonin reuptake inhibitors (SSRIs) and tricyclic antidepressants. This survey also found that physicians refer approximately 50% of their patients with this cluster of symptoms to neuropsychological testing and 40% for psychological intervention. The psychological interventions usually include education, reassurance, and reattribution of symptoms to benign causes. While many of these interventions are suggested to be the frontline methods in treating PPCS, they appear much of a band-aid for the contributing factors of the symptoms. Reassurance and reattribution of symptoms likely introduces feelings of invalidation as the patient may actually misinterpret normal bodily functions as a result of being hyper-vigilant of anything that seems out of the ordinary. Mindfulness approaches allow the patient to sit with uncomfortable bodily feelings that are frequently misinterpreted. Teaching these methods to such a population would likely reduce the number of somatic complaints and misinterpretations.

Various research studies show that education about post-concussive symptoms, how to cope with them, reassurance, and instructions on stress management as well as relaxation techniques are beneficial to individuals with brain injuries and can lead to fewer post-concussive symptoms (Kelly, 1975; Gronwall, 1986; Alves et al., 1993). Wade et al. (1997) provided patients with information on their injury, a description of post-concussive symptoms and

management, stress reduction techniques, and methods of coping with cognitive difficulties. When compared to patients that received routine care, the patients in the treatment group reported fewer post-concussive symptoms and significantly less disruption in social and occupational functioning. Recognition of symptoms that influence psychological factors of PPCS allows patients to take a step back from their typical ways of thinking and processing. Mindfulness based approaches allow patients to do just that. Furthermore, these authors described feelings of judgment towards the self when symptomatic, which furthered the belief of being incapable to do things they once were able to do. Despite the recognition of this, no author described ways in which judgment could be reduced, which is a key component of mindfulness-based techniques.

Paniak et al. (1998) compared a single session preventative treatment for PPCS with 12-week outpatient rehabilitation for PPCS. They found that post-concussive symptoms improved under both conditions and the groups did not differ significantly in the reduction of symptoms, or the severity of residual PPCS symptoms. In addition, the groups did not differ significantly in the number of days before returning to pre-injury vocational activities or in treatment satisfaction ratings. These results suggest that single session preventative care post-injury can be as effective as standard 12-week outpatient rehabilitation. More research would be needed in order to show these effects (Mittenberg & Burton, 1994; Paniak, Toller-Lobe, Durand, & Nagy, 1998). A major pitfall of these investigations is the lack of follow-up procedures to determine if there are any lasting effects. Furthermore, preventative care measures do not teach clients to recognize factors that contribute to the symptoms they experience post-injury. While standard outpatient rehabilitation may allow for this, it merely describes the symptoms. This type of intervention fails to incorporate the practice of recognizing overt signs that contribute as well as subtle signs that may have not been consciously determined to influence symptoms.

Mindfulness-Based Practices

There are numerous variants of mindfulness meditation, but perhaps the most widely recognized and researched is Jon Kabat-Zinn's mindfulness-based stress reduction program (MBSR). Mindfulness as defined by Jon Kabat-Zinn (1990) is the act of paying attention on purpose to the present moment in a nonjudgmental manner. Kabat-Zinn developed an 8-week mindfulness program that is given in a group format that was originally established for chronic pain patients. Participants typically meet weekly for 2-2.5 hours with a certified instructor as well as an entire day devoted to mindfulness practice that is held between the sixth and seventh week. During the eight-week program, participants are invited and encouraged to partake in a minimum of 45 minutes of home practice for the six remaining days. The homework includes a body scan in which participants draw attention to differing parts of the body, sitting meditation, and gentle stretching yoga that is based on Hatha yoga.

MBSR and other variants such as mindfulness-based cognitive therapy (MBCT), dialectical behavior therapy (DBT), acceptance and commitment therapy (ACT), and substance use and mood disorder relapse prevention, to name a few, have garnered significant attention in terms of their positive psychotherapeutic benefits. MBCT is a strikingly similar variant of MBSR; however, it emphasizes many aspects of cognitive-behavioral therapy such as acknowledging that "thoughts are just thoughts" and "I am not my thoughts" (Segal, Williams, & Teasdale, 2000). Segal, Williams, and Teasdale developed MBCT for individuals that are susceptible to depression relapse. The authors theoretically explain that individuals are likely to develop vulnerability towards certain negative attitudes that can have lasting effects throughout

their lives. This vulnerability is likely to lead to continuous relapses in chronically depressed persons. The authors posit further that even during remission periods, moods can be relatively negative, and depressive episodes can be initiated via milder triggering events. Furthermore, it has been suggested that this negative thinking is maintained via rumination or actively focusing on their thoughts. MBCT has also been shown to be effective in treatment of numerous conditions, including externalizing disorders (Bögels, Hoogstad, van Dun, de Schutter, & Restifo, 2008), mood disorders (Hoffman, Sawyer, Witt, & Oh, 2010), chronic pain (Kabat-Zinn, 1982), substance use (Bowen et al., 2009), sleep difficulties (Caldwell, Harrison, Adams, Quin, & Greeson, 2010), and decreased immune functioning (Davidson et al., 2003).

For example, Teasdale et al. (2000) recruited 145 participants that were in remission or recovery from three different sites in North America and the United Kingdom. Participants were categorized by time since last episode of depression (0-12 months versus 13-24 months at time of participation) and amount of previous depressive episodes (at least two versus three or more). The primary outcome for this study was the occurrence of relapse, and participants were designated to a treatment as usual (TAU) group or an MBCT group. Statistical analyses indicated that there was not a significant interaction between treatment and number of previous depressive episodes indicating that those with two episodes did not benefit very much from MBCT. In fact, more participants with two episodes in the MBCT group experienced a relapse relative to the TAU group (56% versus 31%, respectively). Additionally, those in the MBCT group who previously had three or more depressive episodes were significantly less likely to relapse relative to the TAU group (MBCT: 37% versus TAU: 66%). Teasdale and colleagues reiterated that MBCT was developed specifically for recovered depressed patients that have vulnerability for relapse and that can be activated by subjective feelings of dysphoria. This can perpetuate and maintain a cycle of negative ruminative thinking. In essence, these individuals who have had recurrent depressive episodes have sensitized their brains to react to milder triggering events, and these reactivated patterns of negative thinking can maintain and perpetuate a vicious downward spiral towards relapse, leading the authors to state that MBCT may not be appropriate for acute depression and/or those who have had less than three depressive episodes.

In a related study, Ma and Teasdale (2004) sought to replicate these original findings as well as expand the literature pertaining to the efficacy of MBCT by examining whether MBCT actually disrupted the ruminative negative thoughts that are activated via subjective dysphoria, and determine whether those with only two episodes were from a similar population as the participants with three or more episodes (i.e., commonalities in childhood experience, age of onset of first depressive episode, etc.) or from disparate populations with different psychopathologies. The design was quite similar to Teasdale et al. (2000), except this study was conducted within one treatment site rather than three, and included a never-depressed control group. Overall, 36 participants were allocated to the MBCT group and 37 to the TAU group. Participants were measured via Beck Depression Inventory (BDI), Hamilton Depression Rating Scale (HAM-D), Measure of Parenting Style (MOPS; Parker et al., 1997), the occurrence of relapse, and, if relapse occurred, whether the relapse was a significant life event. Their results replicated that of Teasdale and colleagues (2000) in that over a 60-week period, 36% of those with three or more previous episodes in the MBCT group experienced a relapse whereas 78% of those in the TAU group did. Furthermore, participants that only had two previous episodes relapsed more in the MBCT group (50%) versus the TAU group (20%), which increases evidence against use of MBCT as an intervention for those with only two previous depressive episodes. Additionally, analyses indicated that participants with three or more previous episodes

had significantly more adverse childhood experiences compared to those with only two previous episodes, which typically had a normal childhood. Moreover, those with two prior episodes experienced their first depressive episode at a significantly older age with the mean age being 37.50 years. In contrast, participants with three or more episodes were younger with the mean age of onset being 28.40 years. The authors were able to replicate the findings of Teasdale et al. (2000) and were able to provide further evidence that MBCT is an efficacious treatment for individuals with three or more depressive episodes.

Further evidence for the powerful benefits of MBSR and MBCT can be drawn from a comprehensive meta-analysis done by Baer (2003) in which she discussed the different mindfulness-based approaches and interventions that include aspects of mindfulness such as MBSR, MBCT, dialectical behavior therapy, acceptance and commitment therapy, and relapse prevention. Furthermore, Baer (2003) examined the specific skills that mindfulness may help with such as prolonged exposure to distress, changes in the perspective one has about their thoughts, ability to be “mindful” of oneself when engaging in “mindless” behaviors, increased capacity to be accepting of the full experience of everyday life without escaping or avoiding, and the fact that being mindful can lead to increased relaxation; however, inducing relaxation is not a core feature of mindfulness, it is merely an associated effect of it. The results from 15 independent post-treatment mean effect sizes yielded a mean effect of 0.74, and when these effect sizes were weighted by sample size, there was a mean effect of 0.59. Additionally, mean effect size for follow up data was assessed yielding an effect size of 0.59. This indicated that, on average, the literature that was reviewed posits that mindfulness-based approaches have generated medium-sized effects. Baer concluded that MBSR and MBCT are becoming well-established interventions in the literature and can be considered effective in influencing improvement in a wide range of mental health issues and psychological functioning.

Neuroanatomical Evidence for Benefits

Quite recently, there has been increasingly more and more research devoted to understanding the neuroanatomical changes following mindfulness practices. In one investigation that looked at long-term meditators, Luders, Toga, Lepore, and Gaser (2009) examined MRI data using voxel-based morphometry in combination with an automated parcellation approach to reveal possible links between meditation and brain structure. They also set out to assess whether there was an effect from the duration of meditation practice. The meditation group (years of practice ranging from five to 46 years) consisted of 22 meditators, while the control group consisted of 22 non-meditators. The meditation group was also split into individuals with less than 20 years, and those with more than 20 years of meditation experience to allow the researchers to examine if duration of meditation practice had an effect. Sixty-three percent of the meditators practiced deep concentration as an essential part of their meditation, 36% controlled breathing, 32% visualization, 32% attention to external and internal stimuli, 14% withdrawal of sensory perceptions, and 18% letting go of thoughts. Regions with significantly increased gray matter in meditators included the right orbito-frontal cortex and right thalamus even when age was controlled for. Increased gray matter was also found in the left temporal gyrus as well as the right hippocampus. When the threshold was removed, increased gray matter in meditators was found in the paracentral lobes in the left and right hemisphere. There were no regions where non-meditators had significantly more gray matter. The authors posited that the hippocampus has been demonstrated to generate neurons throughout life, meditation may be

improving the rate of neurogenesis and foster the preservation of these newly generate neurons, supporting the idea that meditation causes these differences.

Previous studies have not examined lower brain stem region differences from meditation. Vestergaard-Poulsen et al., (2009) suggested that since attention to breathing is a common element in meditation training in many traditions, and as meditation is known to have lasting effects on respiration control and rate, skin conductance, and oxygen consumption are all reduced, it is possible that structural changes in brain regions involved in basic autonomic regulations could be different in meditators. To examine this, the authors utilized whole-brain MRI including lower brain stem with voxel-based morphometry used to identify significant regional differences to compare 10 experienced meditators with 10 age and sex matched people with no history of meditation practice. The meditators all practiced the same style of mediation and averaged 2.2 hours of meditation a day. Elements of loving kindness and compassion were included in each session, which created a suitable environment for open awareness, which is their main practice. Results indicated increased gray matter density in meditators, but no volume differences in the medulla oblongata of meditators. The largest changes were in dorsal regions on the left and in ventral regions on the right, which are involved in relaying sensory inputs from the body and in respiratory and cardiac control. The main function of the dorsal respiratory group is the control of the basic rhythm of respiration and has been shown to mediate behavioral respiratory control in humans. This finding indicates there are lasting effects on respiration control from meditation practice.

Different studies have shown that several meditation practices are associated with increased vagal tone, which is associated with higher attentional stability during exposure to stressful stimuli. Considered in conjunction with the author's findings, it suggests a possible mechanism for the finding that regular meditation can induce increased resistance to stressful stimuli, increased attentional skills, and increased sense of calmness commonly reported by practitioners. Increased gray matter densities were also found in the left superior frontal gyrus and left inferior frontal gyrus (involved in self-relation). Further differences were found in the anterior lobe of the cerebellum bilaterally and small region in the left fusiform gyrus. No significant difference was found in gray matter density as a function of total practice hours in any region.

In a more recent investigation of the neuroanatomical changes associated with an MBSR program, Hölzel and colleagues (2011) examined participants via fMRI with no prior meditation experience, before and after an 8-week MBSR program. Eighteen participants were enrolled into the MBSR group and 17 in the control group. All participants were recruited from the Center for Mindfulness at the University of Massachusetts Medical School and consisted of physicians as well as self-referred persons. These were individuals who had not received any formal meditation practice prior to enrollment in the study. Following recruitment, all participants were scanned via fMRI two weeks prior to starting the MBSR program, and were scanned once again two weeks following completion. A priori regions of interest included the bilateral hippocampi and bilateral insulae. In addition to these regions, whole brain analyses were conducted in order to examine whether any added gray matter changes occurred. Analyses indicated increased gray matter within the left hippocampus, which plays a major role in regulation of emotion and neurogenesis. In addition, exploratory analyses indicated increased gray matter concentration in the posterior cingulate cortex, which is important in integrating self-referential information into an emotional and autobiographical context that pertains to the individual self, and the left temporo-parietal junction, an important brain region involved in social cognition and conscious

experience of the self. These areas have relevance to mindfulness in that they support varying forms of self-projection, compassion for others, and perceiving others' viewpoints.

Further evidence for increased gray matter concentration includes areas of the cerebellum such as the flocculonodular lobe as well as the vermis. It is widely known that the cerebellum, aside from its role in motor control, coordination, and muscle memory, also plays a role in regulating emotion and cognition, and can influence healthy psychological functioning. It was suggested that the morphological increases in gray matter in these varying regions may contribute to the effects of mindful meditation. Moreover, the neuroanatomical changes have spurred additional research relating to the neuropsychological effects associated with the increases in gray matter.

Neuropsychological Benefits of Mindfulness Meditation

Studies suggest that months to years of intensive and systematic meditation training can improve attention. However, the lengthy training required has made it difficult to use random assignment of participants to conditions to confirm these findings. Tang et al. (2007) examined a group randomly assigned to 5 days of meditation practice with the integrative body–mind training method (IBMT). Results showed significantly better attention and control of stress than similarly chosen control group given relaxation training. The training method comes from traditional Chinese medicine and incorporates aspects of other meditation and mindfulness training. This was presented in a standardized way by CD and guided by a skilled IBMT coach, which is highly similar to the format of MBSR. Compared with the control group, the experimental group of 40 undergraduate Chinese students given 5 days of 20-min integrative training showed greater improvement in conflict scores on the Attention Network Test, lower anxiety, depression, anger, and fatigue, and higher vigor on the Profile of Mood States scale (McNair, Lorr, & Droppleman, 1992), a significant decrease in stress-related cortisol, and an increase in immunoreactivity. These results provide a convenient method for studying the influence of meditation training by using experimental and control methods similar to those used to test drugs or other interventions. While results from these initial studies investigating the cognitive profiles of those that used meditation practices were promising, it should be noted that the authors did not use different cognitive measures that assessed different cognitive domains. Use of only one test of attention and cognitive control can lead to problems in interpretation and generalization of results. Additional measurements of sustained attention, shifting attention, working memory, and other neuropsychological constructs would have benefited the understanding of how mindfulness promotes better attentional skills.

Characterizing autobiographical memory as a hierarchy, with more general information higher, and more detailed and specific information lower in the hierarchy, people are normally able to move fluently through the hierarchy, selecting the level of specificity necessary to respond appropriately to the given context (Williams, Teasdale, Segal, & Soulsby, 2000). However, several recent studies suggest that depressed patients have considerable difficulties moving fluently through the memory hierarchy. Their memory appears to abort the search for a specific event prematurely, when only the general description stage has been reached. For example, according to Williams, Teasdale, Segal and Soulsby (2000), in response to a word cue such as kindness, such a depressed patient may respond, "My grandmother was always kind to me. She used to take me out when my father got cross." In this example, the patient is responding with a summary description, a category of events, rather than retrieving a specific event that happened at a particular place and time. Having a better understanding of memory

ability and the way in which such memory is organized is helpful in understanding depressed patients that use mindful ways of remembering. Use of instruments that assess organizational skills and mental flexibility such as the Trail Making Test and Category Test would have increased this understanding. Furthermore, using subtests on the Wechsler Memory Scale, Fourth Edition, would have increased generalizability of memory difficulties. Finally, the authors failed to incorporate the Stroop Color Word Test, which would have helped to determine the level of automaticity in this particular population.

Overgenerality of memory is commonly found in individuals experiencing depression, especially suicidal ones. This may cause the problem to worsen and make recovery take longer. Previous investigators have concluded that overgenerality of memory is a cognitive style, a long-term, trait-like phenomenon that starts early in development and makes people vulnerable to depression and PTSD in the face of trauma. It is not considered a mood-state trait, so reducing the emotional disturbance would not help. Williams et. al (2000) examined whether MBSR would help with autobiographical memory. They administered the standard Autobiographical Memory Test (AMT; Brittlebank et al., 1993) at one of the three sites involved (Bangor, Wales). This task involved giving positive, negative, and neutral cue words, one at a time, to patients and asking them to respond with a specific event from their past that the word reminded them of. It was administered before the start of the 8-week series of classes, and again during the 12-months follow-up period. They examined the specificity of the responses to determine whether or not recovered depressed patients became less generic following the treatment. The findings of this study indicate that when recovered depressed patients undergo training that includes instructions to focus more carefully on everyday events and to allow cognitions to occur without trying to avoid or suppress them, the tendency to retrieve events in a categorical style is reduced. Furthermore, consistent with earlier studies showing that this aspect of memory is not mood-state dependent, overgenerality in memory was reduced significantly in the MBCT group despite there being no change in mood scores over this interval.

In other words, the memory changes were not mood driven. Autobiographical memory is a highly specific form of memory, and the rationale for needing to examine this in the population was somewhat lacking. Making assumptions from one specific test is dangerous, as it does not allow for comparisons of performance between similar tests. It is possible that individual variance could contribute to certain findings and without comparison measures, one may erroneously conclude that a significant effect occurred. It is likely that the act of acceptance of one's self, non-judgmental view of the self or others, and paying attention to contributory factors influences gains in other cognitive domains such as attention, mental flexibility, judgment making ability, problem solving, social awareness, labeling emotions, and other constructs. The lack of additional measures and constructs was a serious limitation to this study.

In a similar article examining the effects of MBSR on autobiographical memory, Heeren, Van Broeck, and Philippot (2009) sought to replicate Williams, Teasdale, Segal, and Soulsby's (2000) findings and examined the reliability of MBCT and explored the role of executive processes in the relationship between mindfulness training and over generalized memory. Eighteen participants (15 being women) with no prior meditation training, other psychological interventions, active drug abuse, known neurological problems, or use of psychopharmacotherapy were recruited into the mindfulness group. Participants were paired individually with a control participant and matched on age, gender, and education. Again, the AMT was utilized to examine autobiographical memory. In addition to the AMT, a number of tasks that measured prepotent responses as well as behavioral flexibility and cognitive flexibility

were used. In general, their hypotheses were confirmed. Data revealed that mindfulness training increases specificity and decreases general autobiographical memory retrieval. Analyses also indicated that mindfulness training improves the capacity to inhibit prepotent responses and to switch between different cognitive sets. However, mindfulness training was not found to be associated with changes on motor inhibition and flexibility. This pattern of results supports the idea that mindfulness training might inhibit secondary elaborative process of thoughts, feelings, and sensations that arise in one's stream of consciousness and that it may be used to change habitual cognitive patterns of responding that are voluntarily chosen rather than automatic. It was also found that changes in one of the cognitive tasks, cognitive flexibility, partially mediates the impact of mindfulness training on overgeneralization of memories.

At a theoretical level, the results support the notion that executive processes are implicated in overgeneralized memory. At a clinical level, the data confirms previous studies demonstrating that overgeneralized memories can be changed by psychological interventions. Many of the assertions made by the authors were based on results from a single cognitive measure. While the AMT has been shown to be valid and reliable in other studies (Brittlebank et al., 1993; Teasdale et al., 2000), it does not allow for comparison of performance on other measures of mental inhibition, overgeneralization, mental flexibility, and memory. Thus far, there has been a general lack of consideration for individual variation in test taking attitudes, environmental conditions in which tests were taken, and state-dependent attitudes during testing. In addition, a lack of comparison measures increases the chances of Type-1 error. These considerations need to be taken into account during future investigations.

Chiesa, Calati, and Serretti (2011) reviewed numerous studies that examined neuropsychological effects of different mindfulness training techniques. The authors first discussed the different components of mindfulness indicating that the overwhelming majority of the articles reviewed referred to mindfulness as a state that highlights the importance of purposely paying attention to the present moment. A second component addressed was that to be mindful one's particular attitude should embody non-judgment and openness to the current experience. Overall, 23 studies were reviewed by the authors, all of which consisted of different mindfulness teachings such as Jon Kabat-Zinn's MBSR, MBCT, Vipassana meditation, and other miscellaneous mindfulness practices that included a variety of different techniques. The main finding gathered from the review was that different mindfulness practices can have a beneficial impact in the areas of sustained, selective, and executive attention, working memory and memory specificity (i.e., considered a marker for mental well being), and executive function. Despite these promising results, a substantial number of the studies included in this review had significant limitations in their methodologies. A major issue was the variance in time to which participants practiced the different mindfulness techniques. A majority of studies that implemented shortened versions of MBSR or included a mixture of techniques for a short duration yielded non-significant results. Additionally, there was significant heterogeneity in what some techniques highlighted as important to the concept of mindfulness. For example, some practices place higher importance on internal experience whereas some emphasize external experience. Furthermore, several studies failed to include appropriate controls, which contributed to a higher frequency of insignificant results.

In one of the few studies reviewed by Chiesa, Calati, and Serretti (2011) that was found to have promising results following a brief mindfulness training, Zeidan, Johnson, Diamond, David, and Goolkasian (2010) examined whether four sessions (20 minutes/day) of mindfulness practice could have a beneficial impact on cognition. The authors used a mindfulness training

approach that was modeled after Shamatha skills (Wallace, 2006) in which participants were instructed to concentrate on the flow of their breath (session 1) and then to include the full breath (i.e., noticing sensations as the breath comes in through the nostrils to the abdomen and back; sessions 2-4). These participants were contrasted to a control group that listened to an audiobook of JRR Tolkien's *The Hobbit*. Well-being was assessed using the Freiburg Mindfulness Inventory (Walach, Buchheld, Buttenmuller, Kleinknecht, & Schmidt, 2006), the State Anxiety Inventory (Speilberger, 1983), Center for Epidemiologic Studies Depression Scale (Radloff, 1997), and the Profile of Mood States (McNair, Looor, & Doppelman, 1971). Cognition was measured via the Controlled Oral Word Association Test (Benton, 1989), the Symbol Digit Modalities Test (Smith, 1982), and the forward and backward digit span on the Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981).

The authors reported that individuals in the mindfulness group improved on tasks of sustained attention and executive processing. Additionally, visuo-spatial processing and working memory improved after brief mindfulness training. Furthermore, compared to controls, those in the mindfulness group indicated lower fatigue and anxiety ratings after the training. The authors included a measure of level of mindfulness, which other authors described above failed to do. While a number of neuropsychological domains were included in this study, failure to include a standardized mindfulness training program likely introduced extraneous variables, which decreased internal validity. Standardization is an incredibly important part of intervention. It ensures that everyone receives the same level of top-rated care, which will result in similar outcomes. Future studies need to consider the use of a standardized mindfulness program. MBSR and MBCT are two standardized platforms that should be considered for any future study wanting to investigate the effectiveness of such a program on neuropsychological domains.

Current Investigations of Mindfulness and mTBI

A common long-term complaint after TBI is mental fatigue, which often delays return to work and affects quality of life following the injury (Borgaro et al., 2005). Johansson, Bjuhr and Ronnback (2012) developed a mindfulness-based stress reduction intervention specifically aimed at mitigating mental fatigue in brain injured and stroke patients. Participants included 29 stroke or TBI patients who complained of mental fatigue for at least one year post insult and the groups were randomly split into a treatment and a waitlist control group. Mental fatigue level was assessed by the self-assessment of mental fatigue (MFS), a 15-item multidimensional scale including affective, cognitive, and sensory symptoms of fatigue. The intervention was based on Kabat Zinn's MBSR program, including eight weekly group sessions, a daylong retreat, and home practice for 45 minutes per day guided by a CD recording. Following the intervention, the treatment group displayed a significant reduction in mental fatigue symptoms on the MFS compared with the waitlist control group. These results suggest a promising non-pharmacological treatment approach to mental fatigue; however, the authors did not address at-home treatment adherence, nor the long term effects of the intervention. Although Johansson, Bjuhr, and Ronnback (2013) found that the reduction in mental fatigue was sustained after eight additional monthly trainings of advanced MBSR in 14 of these participants, those who did not continue to the advanced program were not followed. Additionally, the authors failed to assess differences in recovery between the participants that sustained a stroke versus a TBI. Despite a common complaint of mental fatigue, the associated features of these disorders are highly variable and individualized treatment modalities must be considered.

Azulay et al. (2012) found promising results studying a sample of 22 participants diagnosed with PPCS following mTBI utilizing a modified MBSR protocol within a brain-injury rehabilitation center. The MBSR program was modified to accommodate cognitive challenges associated with mTBI and PPCS, such as reduced memory recall, disorganization, and poor attention maintenance. Treatment was expanded from eight to 10 weeks of group training, and group sizes were reduced from 25 to an average of six participants to allow for increased explanation of instructions, modeling, and processing of unique experiences. Additionally, they provided assignments in writing and a daily log to record home practice to reduce forgetfulness. Utilizing this modified procedure, participants displayed an increase in perceived quality of life and self-efficacy for managing their cognitive and emotional symptoms. Additionally participants evidenced increased visual and verbal attentional abilities. This study demonstrates the efficacy of an MBSR intervention, specifically modified to address the cognitive complaints associated with mTBI. The intervention was found to be useful in improving participants' perception of their ability to manage disruptive effects of the injury; however, overall self-reported post-concussive symptoms did not decrease. The lack of a comparative control group may have clouded the effects of the particular intervention and the specific benefits it provided.

The increasing interest in mindfulness-based techniques, as well as the results of pilot studies, show the promise of studying the efficacy of specialized MBSR interventions for the management of post-concussive symptoms. Future studies should include randomization to standardized and modified versions of MBSR treatment protocols. Expansion of pre- and post-intervention measures to include ratings of self-perceived symptoms and related neuropsychological functioning may also provide important data addressing efficacy of the intervention in this specific population.

Discussion

The purpose of this review was to pool together the relevant literatures pertaining to traumatic brain injury, persistent post-concussive syndrome, and mindfulness-based practices, in order to determine the feasibility of utilizing such a practice as a neurorehabilitative technique for mild TBI. MBSR and MBCT were focused on here due to the vast empirical data pertaining to their efficacy. After reviewing the extant literatures, it seems apparent that specific deficits of mTBI and PPCS are exacerbated and maintained via psychological factors such as depression, stress, and anxiety. Other symptoms of PPCS and mTBI include headache, memory loss, fatigue, insomnia, dizziness, concentration difficulties, irritability, and sensitivity to light and sound. The persistence of these symptoms can hinder an individual in a variety of areas such as work and interpersonal relationships, which can create even more stress and anxiety. Many of the frontline interventions for mTBI and PPCS entail psychoeducation, cognitive restructuring, reassurance, and coping skills training; however, many of these interventions have only partial success, are time consuming, and are not cost-effective. Additionally, the vast majority of these interventions do not influence neurogenesis, which is a major benefit of mindfulness-based practices. Moreover, MBSR and MBCT are both quite cost effective, and are only eight weeks, compared to already established interventions lasting 12 weeks (Ferguson & Mittenberg, 1995; Paniak et al, 1998).

It is well documented that traumatic brain injury has a significant effect on cognitive functioning. Even mTBI has substantial cognitive effects that can be exacerbated by psychological symptoms such as depression and anxiety. Many of these symptoms can remit; however, some can be ongoing and even worsen as in the case of PPCS. Individuals with PPCS

complain of difficulties in concentration, attention, memory, judgment, decision-making, problem-solving, low frustration tolerance, and anger. These symptoms can influence negative cognitions, increase stress, and cause bodily tension to increase. MBSR has been suggested to increase selective, sustained, and executive attention, working memory, autobiographical memory, memory specificity, visuo-spatial functioning, and executive functioning. Moreover, mindfulness-based practices have been shown to decrease anger, anxiety, depression, and fatigue. Despite the plethora of advantages of MBSR as measured via neuropsychological batteries, there have been no investigations into its worth as a preventative intervention for PPCS. To date, only one study has assessed the use of brief mindfulness-based practices as a possible intervention for attentional difficulties in those with severe TBI; however, there were no significant findings (McMillan et al., 2002). Possible reasons for the lack of significant findings may be attributable to the fact that the intervention only consisted of four weekly meetings, which had an unspecified duration. Additionally, the intervention consisted of eclectic mindfulness-based techniques, and did not consist of a full-fledged MBSR program led by a qualified instructor. In light of this, it may still be feasible to use an MBSR program as a preventative intervention for those with mild to moderate TBI considering the cognitive difficulties in that population are not as pervasive as in severe TBI. In addition, MBSR and its various techniques have been studied extensively, and its beneficial effects are well documented.

The anatomy of a closed traumatic brain injury has been described as the brain's center of mass continuing forward following an initial impact (Bayli et al., 2005; Bigler, 2008). The brain's posterior regions such as the brain stem are tethered to fixed bony structures, and when the anterior regions compress and move forward it causes the caudal regions to shear. This causes extensive damage to the upper brainstem, systems that mediate sleep and attention (reticular activating system), as well as areas such as the perirhinal and entorhinal cortices located in the medial temporal lobe that help to formulate and consolidate memory and control visual perception. Damage in these areas can disrupt connections with the hippocampus, anterior thalamus, and cingulate. Additionally, damage to the medial temporal lobe has been known to interfere with emotion regulation. In terms of damage to areas associated with executive functioning, the orbital frontal cortex is a common area to be affected following a TBI, which is involved in social and emotional behavior (Cicerone & Tanenbaum, 1997).

Many of these brain structures have been shown to have an increase in gray matter following an 8-week MBSR program. Specifically, there have been increases in brainstem areas, the left temporal lobe, the hippocampus, right orbital frontal cortex, and right thalamus. Other areas that have been shown to have increase in gray matter volume as indicated via brain imaging scans include left superior frontal gyrus involving self awareness and working memory; the left inferior frontal gyrus, which is involved in self-relation; posterior cingulate cortex involving emotional and autobiographical information; and areas of the cerebellum including the vestibulocerebellum and cerebellar vermis, which not only control muscle memory, movement and coordination, but are also involved in regulating emotion and cognition (Hölzel et al., 2011).

Taken together, it appears that mindfulness-based practices, specifically MBSR, affect similar brain regions that are typically damaged following a traumatic brain injury. While no brain injury is the same, these areas are often sites of damage considering Bayli et al. (2005) and Bigler (2008)'s discussion of brain injury. Despite the heterogeneity of injuries, many neurorehabilitative interventions are tailored to general areas of functioning such as attention, memory, executive functioning, et cetera. MBSR would allow for a more extensive intervention that targets not only cognitive, but also emotional and somatic symptoms. It appears that an

MBSR intervention would allow individuals with an mTBI to shift from an external to an internal locus of control and therefore increase self-efficacy. In addition, as patients improve their awareness of bodily functions, sensations and thoughts, their ability to cope with stress is enhanced. This increased ability to cope with stress can lead individuals to deal more effectively with their symptoms. The idea of practicing and maintaining attention throughout extended periods of time can lead to an increase in mental control and therefore, taken together it appears that MBSR could effectively improve an individual's cognitive, physical, and emotional status through these mechanisms. Finally, it would be important to tailor the intervention to the symptoms experienced by the individual, as symptoms of mTBI are heterogenous.

Evidence from neuroimaging investigations suggests that an 8-week MBSR program may elicit strengthening of synapses as well as neurogenesis in areas that are affected in TBI; therefore, randomly controlled trials investigating the efficacy of such a program as a preventative intervention for post concussive symptoms is warranted. Future areas of research may include whether MBSR improves cognitive abilities in individuals with mTBI, whether such an intervention would be applicable to moderate TBI, and whether an MBSR program would be efficacious in treating veterans with TBI. This latter area may be especially fruitful in alleviating post-combat stress and anxiety. Moreover, there has been a dearth of research into the specific mindfulness techniques utilized in the MBSR program. It is still unknown whether specific techniques are more efficacious than others or is it the collection of all the techniques that contribute to the beneficial effects of MBSR.

These persistent symptoms not only affect the individual but also their spouses and families. In fact, Kreutzer and colleagues (2007) posit that 25% of marriages 6-8 years post-injury end in divorce. The high incidence of divorce in individuals with TBI suggests that current interventions do little to support caregiver burden, stress, anxiety, depression, and other symptoms. Caregiver burden is often exacerbated by the extent of the family member's injury as well as the affected individual's perception of their injuries (i.e., how anxious/depressed they are; Marsh, Kersel, Havill, & Sleigh, 2002). Marsh and colleagues suggest that this burden is increased one year after the brain injury. MBSR programs have been used with different types of caregivers including those of children with chronic conditions (Minor, Carlson, Machkenzie, Zernicke, & Jones, 2006), of cancer patients (Bimie, Garland, & Carlson, 2010), of elderly individuals (Epstein-Lubow, McBee, Darling, Armeay, & Miller, 2011), and of those with dementia (Whitebird, et al., 2012), which have yielded promising and significant results. The importance of including caregivers in the recovery process cannot be stressed enough, yet many caregivers are not receiving the attention they so desperately need. To date, there have been no studies assessing the efficacy of use of an MBSR program to decrease caregiver burden and other maladaptive psychological symptoms. It would behoove clinicians and researchers to examine whether use of such a program would benefit caregivers of individuals with a TBI. Specifically, does engagement in an MBSR program decrease caregiver burden in those caring for individuals with mild, moderate, and severe TBI? What are the long-term outcomes of an MBSR program for spouses of those with TBI? Would mindfulness-based practices actually prevent caregiver burden if implemented immediately following an injury? MBSR increases one's awareness of thoughts and body sensations, which in turn increases one's ability to cope with stressors. It appears that by practicing and maintaining overall mental control, caregivers would be better suited to cope with the stressor of caring for an individual with a TBI and could therefore prevent caregiver burnout.

Conclusion

MBSR has been widely researched and has been shown to increase well-being, attention, memory, executive functioning, compassion for oneself and others, and increased ability to tolerate stressful situations. Recently, there has been a flurry of interest into the neuroanatomical benefits of MBSR, which has shown that there are increases in gray matter in different areas of the brain. Many of these areas have also been implicated in traumatic brain injury such that there is extensive damage that causes a slew of cognitive deficits as well as emotional difficulties that are collectively known as persistent post concussive syndrome. It seems plausible that an 8-week MBSR program may be a beneficial preventative intervention for post concussive symptoms; however, empirical evidence is required to validate this hypothesis.

About the Authors

Jared S. Link, M.S. is with Nova Southeastern University's College of Psychology. Correspondence concerning this article should be addressed to Jared S. Link, Nova Southeastern University, College of Psychology, 3301 College Avenue, Ft. Lauderdale, Florida, 33314-7796.
Email: jl1751@nova.edu

Trevor Barker, M.S. is with Nova Southeastern University's College of Psychology.
Email: tb1092@nova.edu

Sophia Serpa, M.S. is with Nova Southeastern University's College of Psychology.
Email: sc1814@nova.edu

Maya Pinjala, M.S. is with Nova Southeastern University's College of Psychology.
Email: mp1835@nova.edu

Thomas M. Oswald, Psy.D. is currently with the Neuropsychology Department at the Central Arkansas Veterans Hospital in Little Rock, AR.
Email: Thomas.oswald@va.gov

Lisa K. Lashley, Psy.D. is currently the Assistant Director of the Neuropsychology Assessment Center at Nova Southeastern University's College of Psychology.
Email: lkohn@nova.edu

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