GAIT BALANCE CONTROL DEFICIENCY IN VETERANS WITH CHRONIC MILD TRAUMATIC BRAIN INJURY

by

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While mild traumatic brain injury (mTBI), or concussion, is typically associated with athletics, head trauma is widespread in the battlefield and combat training. Individuals with acute mTBI typically demonstrate many physiological and cognitive symptoms, including imbalance during walking. Many Veterans with mTBI were reported to continue suffering chronically from subjective symptoms. It is reasonable to expect they may also continue to exhibit impairment in gait balance control, especially when attention is divided. Therefore, the purpose of this study was to examine gait imbalance in Veterans with chronic mTBI. Eight healthy Veterans (1F; 33.9±3.8 years old) and eight Veteran subjects diagnosed with chronic mTBI (1F; 32.3±6.5 years old) had their gait balance examined while walking barefoot in two conditions. The first condition required each Veteran walking with an undivided attention (single-task, ST). The second condition had each subject concurrently completing a continuous auditory Stroop test, which consisted of the individual listening to different auditory stimuli and attempting to correctly identify the pitch while walking (dual-task, DT). A 10-camera motion analysis system was used to collect whole body movement during both walking conditions. Mediolateral (ML) center of mass (COM) displacement as well as peak mediolateral and anterior-posterior COM velocities were recorded during each gait cycle. Compared to healthy controls, Veterans with chronic mTBI symptoms walked with a significantly greater ML COM displacement in both ST and DT conditions. Compared to the ST condition, healthy individuals demonstrated a slower ML COM sway velocity when faced with the DT situation, while individuals with chronic symptoms showed an increase in ML COM velocity. These results indicate that Veteran subjects with chronic mTBI demonstrated gait imbalances compared to a healthy Veteran cohort. This information can be used to understand the physiological effects of chronic mTBI and to develop policy for the protection of mental health of military personnel.

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Introduction

A great deal of recent attention in popular culture has focused on concussions, which is considered a form of *traumatic brain injury* (TBI). It is most commonly associated to both youth and professional sports, where estimated millions of cases of TBI occur annually in the United States alone.[1] Several case studies have helped this pathology gain traction. For instance, Daniel Te'o-Nesheim's story as an ex-NFL player who suffered a descent into madness a result of chronic traumatic encephalopathy (CTE), a disease related to sustaining multiple TBIs that is accompanied by paranoia, disorientation, memory insufficiency, and emotional instability. These symptoms factored in to an unfortunate overdose early in his life. While an extreme example, Te-o-Nesheim's story highlights the importance of a better understanding of TBIs and the necessary changes needed in improving care.

The prevalence of TBI is high in the United States with an estimated 1.7 million cases seen in emergency rooms annually.[1] It is further approximated that about 70-90% of these cases can be classified as *mild traumatic brain injury* (mTBI).[2] This category of brain injury is associated with somatic, psychological, and cognitive symptoms that include headaches, fatigue, dizziness, anxiety, impaired memory, and a loss of consciousness under thirty seconds.[3] In the immediate period where patients suffer from these symptoms following injury, patients are often diagnosed with *acute mTBI*. Most of these symptoms are resolved within three months for most individuals, but some patients can remain symptomatic over eight months post-injury. At this point, the individual will be diagnosed with *chronic mTBI*.

Note: Italicized terms are listed and defined in Glossary

What is Chronic mTBI?

It has been reported that at least 15% of individuals with mTBI see a physician about long-term cognitive impairments.[2] However, recent research has found that 58% of mTBI patients suffer from persistent cognitive impairment and that 75% suffer from chronic physical pain, suggesting chronic mTBI is more common than originally estimated.[3,4] Further research into some of these chronic mTBI symptoms has been conducted. For instance, to find a dependable biological indication of chronic mTBI, the scientific community is continuously investigating consistent physical brain damage or abnormalities. One study took *diffuse tensor MRI* images (DTI) of patients with chronic mTBI at least eight months post-injury to inspect for deficiencies or hemorrhages.[5] They found significantly lower *fractional anisotropy* (FA) in the corpus callosum and internal capsules of patients with chronic mTBI. FA is a form of cerebral white matter, which consists of neurons with myelin sheaths that are more efficient at electric signal conduction. White matter is an important component of memory and cognitive ability, and this demonstrates a biological abnormality that may be affecting chronic symptoms.

Chronic mTBI also has lasting cognitive and emotional symptoms. One meta-analysis conducted in 2017 found that 58% of children and adults in 49 studies carried deficiencies in executive function, learning and memory, attention and processing speed, among others.[3] Persistent emotional effects are also notable, as patients with chronic mTBI have been found to have significantly high rates of anxiety (29.4%) and depression (52.9%).[6] They may also suffer from mood and sleep disturbances, exasperating these effects.[4]

Chronic mTBI in the Military

In the United States military, the prevalence of brain injuries is also very high. The number of annual reported TBI cases is around 33,000 cases, with 350,000 total diagnoses reported between 2000-2016.[2,7] Studies noted that 82.5% of these cases were classified as mTBIs and extrapolated that in most of these cases individuals could experience symptoms over a year past the time of injury.[2] Not only are mTBIs the most common form of injury for military personnel, but they are also one of the fastest increasing, with a 283% rise in between 2000 and 2011.[2]

In addition to the high prevalence of mTBI in the military setting, service personnel face unique challenges and stressors that complicate the pathology. Several studies have noted how certain aspects of military culture may affect attitude towards mTBIs. Four main values that have been discussed in this regard include personal courage, unwillingness to fail, self-sacrifice, and commitment to the cause.[8] These values are developed in order to build the perseverance to be successful and loyalty to the military cause. However, these same qualities may contribute to dismissing the adverse effects of mTBI. Those with chronic mTBI could therefore ignoring longitudinal symptoms and be lacking effective care.

It is also noted that a prominent aspect of the military circuit is sleep deprivation and fragmentation. Sleep deprivation can be filtered into several different categories, but the primary condition is chronic partial sleep deprivation, in which the individual gets less than six hours of sleep for two weeks. Testing has found this practice to result in similar memory and cognitive deficits as one night of total sleep deprivation.[9] This can have two main effects. Firstly, this factor can complicate an accurate diagnosis for military personnel, as cognitive testing will be unable to distinguish the whether the source of any deficiency stems from pathological sources or from sleep inadequacies. Second, these sleep inadequacies combined with mTBI may lead to increased fatigue severity, further decreasing quality of life.

Another concern is centralized around the high prevalence of *post-traumatic stress disorder* (PTSD) among the military population. The literature currently points to a two-way relationship between PTSD and chronic mTBI.[11] It is reported that 58% of individuals with chronic mTBI suffer from chronic pain, and that these numbers are increase with additive effect with the co-presence of PTSD. It is also noted that depression, PTSD, and sleep disturbances increase the chance of the mTBI symptoms persisting after the acute time period. On the other hand, it is noted that military individuals who suffered from mTBI had 30% more likelihood to suffer from PTSD. They also found a linear relationship in the severity of symptoms of TBI and PTSD.[10] Although no mechanism has been discovered, the data point to a likely relationship between the two. PTSD is uniquely prevalent in the veteran population, so this relationship is important to uncover for these individuals, as they are at risk for a higher degree of suffering.

With the high prevalence and level of complications, veterans who have sustained chronic mTBI have a more challenging experience when returning to civilian life after service. Interview studies have uncovered two primary patterns of thought amongst these veterans.[11] The first pattern was characterized by “the perception of a need to fade one’s military identity”. The second involved a need to maintain the integrity of their previous military identity in civilian society. Veterans with chronic mTBI felt that the symptoms and complications of mTBI exasperated the cognitive dissonance that accompanies the assimilation into a civilian lifestyle from their military one. These experiences demonstrate that military personnel face additional stressors with chronic mTBI that further degrade their quality of life.

Gait Balance Control Deficiency in Patients with mTBI

Patients with acute mTBI have been found to exhibit gait and balance impairments. Examining the whole-body center of mass (COM) movement would provide the most direct quantification of an individual's dynamic balance control.[12] Variables derived from COM kinematics can demonstrate if a more conservative gait pattern is used or if there are imbalances during dynamic walking. Recent literature further indicates that a more sensitive way to detect gait imbalance is to introduce a concurrent cognitive task while walking.[13] This dual-task (DT) condition will divert the individual's explicit attention from mechanical movements, a gait behavior more similar to real-life scenarios. This condition will provide more ecologically valid data to form a conclusion about gait impairment.

The literature identifies that the presence of acute mTBI influences gait performance immediately following the injury.[14] Recent gait studies investigating young adults sustained an acute mTBI demonstrated that a significant gait impairment exists when tested under a dual-task paradigm. One of the most representative variables to demonstrate these effects is increased mediolateral (ML) sway of their whole-body COM relative to matched control subjects, supported by studies that found that elderly patients that had complaints of imbalance that were navigating increasingly taller obstacles had a proportionally higher *ML COM displacement* when walking.[15] Studies also demonstrated that individuals with acute mTBI specifically suffer from a slower walking velocity, more conservative gait, and abnormal pelvic turning.[16,17]

Even though the persistence of chronic mTBI makes up a large percentage of those who sustain an mTBI, there is very little research done on the gait deficiencies of this population. The small amount of research released indicates that subjects with chronic mTBI may have gait deficiencies similar to the population with acute mTBI. With their prevalence of chronic mTBI and heightened risk for comorbidities, a better understanding on gait balance control of Veterans with chronic mTBI is important for several reasons. First, walking imbalance can lead to further concussive events or injuries, which can have compounding effects on symptoms.[18] Second, with the lack of knowledge on standardized signs and symptoms of chronic mTBI, understanding of gait deficiencies can be a useful clinical tool for diagnosis or tracking recovery. It can be a more objective determinant to diagnose chronic mTBI, remain non-invasive, and can quantify longitudinal recovery. Third, a better understanding of long-term effects of chronic mTBI can lead to better care and education, which can lead to decreased prevalence of chronic mTBI and increasing overall health of the population.

Research Question

The purpose of this study was to examine gait imbalance in Veterans with chronic mTBI. We hypothesized that Veterans with chronic mTBI will exhibit notable gait balance impairment compared to their healthy counterparts. Previous studies have shown that individuals with acute mTBI demonstrated deficiencies in gait balance control. Additionally, it has been reported that patients with chronic mTBI suffered from persisting symptoms that are biological, cognitive, and physical.

Since it has been shown that Veterans with chronic mTBI continue to suffer from some of these symptoms, it is reasonable to believe they may also continue to exhibit impairment in their gait balance control, especially under a dual-task walking condition.

Methods

Subjects

Two groups of Veterans were recruited for this experiment: eight Veterans with chronic symptoms following mTBI and eight healthy Veterans. Veterans with chronic mTBI (1F; 32.3 ± 6.5 years old) reported symptoms at least three months following an mTBI and were recruited from the Portland Veteran Affairs Research Center. They were screened for symptoms using the Rivermead Post-Concussion Symptom Test (Appendix B). Healthy veterans were recruited via the University of Oregon Student Veteran Center. They were individually matched to Veterans with chronic mTBI by age and sex. Healthy subjects were screened via the Post-Concussion Symptom Scale (Appendix A) to ensure they had not recently suffered any head injuries and that they were free of any mTBI-type symptoms.

Subjects were excluded who:

- Any individual not between the ages of 20 and 40 years old.
- Any individuals diagnosed with either moderate or severe TBI
- Any lower extremity injury that would prevent normal walking motion
- Any significant cognitive impairment, such as permanent memory loss or an attention deficit issue

All subjects gave their informed consent to participate in this experiment. Additionally, University of Oregon Institutional Review Board approval was received for this protocol.

Protocol

Subjects completed two practice trials of auditory Stroop test, followed by four baseline trials, all in a seated position. The Stroop test consisted of the subject listening to four distinct auditory stimuli: the recorded words “high” or “low”, each spoken in either a high pitch or low pitch.[13] Subjects were instructed to correctly identify the pitch of the word, regardless of the meaning. Three continuous stimuli separated by one second were presented during each trial through a wireless headset utilizing Superlab software (Cedrus, San Pedro, CA).

Next, subjects were instructed to walk on level ground barefoot at a self-selected, comfortable pace along a 12m hardwood walkway (Figure 1). Two practice walking trials were performed followed by sixteen recorded walking trials, eight of which involved walking only (Single-Task Condition), and eight while walking and performing the auditory Stroop test (Dual-Task Condition), and the order of testing condition was randomized (Figure 2). For the dual-task condition, subjects were given no instructions to prioritize either walking or the cognitive task.

Figure 1 Flat, hardwood walkway for subjects to walk across, then to circle back to starting position. IR camera setup is also seen around the walkway.

Figure 2 Demonstration of a subject participating in a walking trial. The headset delivers the auditory Stroop test to the subject in eight DT walking trials.

Whole body motion analysis was performed using a set of 23 reflective markers[19] with 10 cameras (Motion Analysis Corp., Rohnert Park, CA). Marker data were sampled at 60Hz and low-pass filtered using a fourth-order Butterworth filter with a cutoff frequency set at 8Hz. Whole body *center of mass* (COM) was calculated as the weighted sum of 13 linked rigid body segments using Winter's anthropometric data[20]. Total COM mediolateral displacement, peak mediolateral velocity, and peak anterior-posterior velocity were recorded during a single gait cycle[19] (Figure 3 and 4). Stroop test accuracy, step length, step width, and gait velocity were also collected.

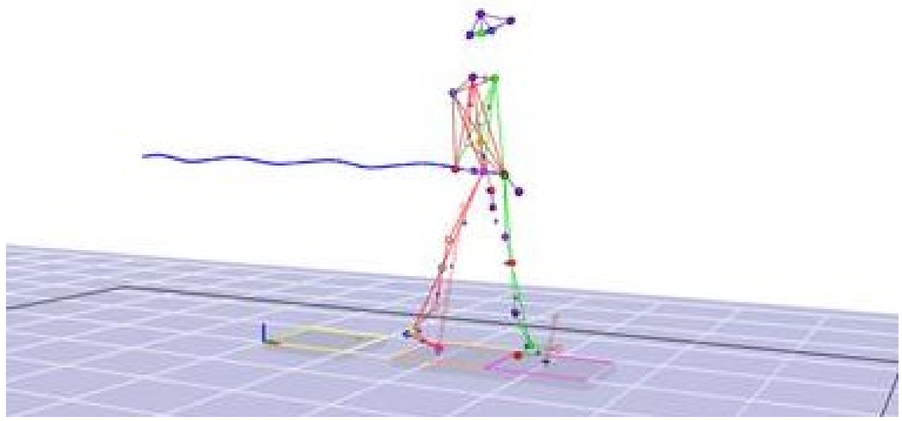

Figure 3 Representation of the full body rendering from three-dimensional motion camera reflective marker positions. Each point represents a marker point, with the blue line to the posterior of the figure tracking the movement of the COM.

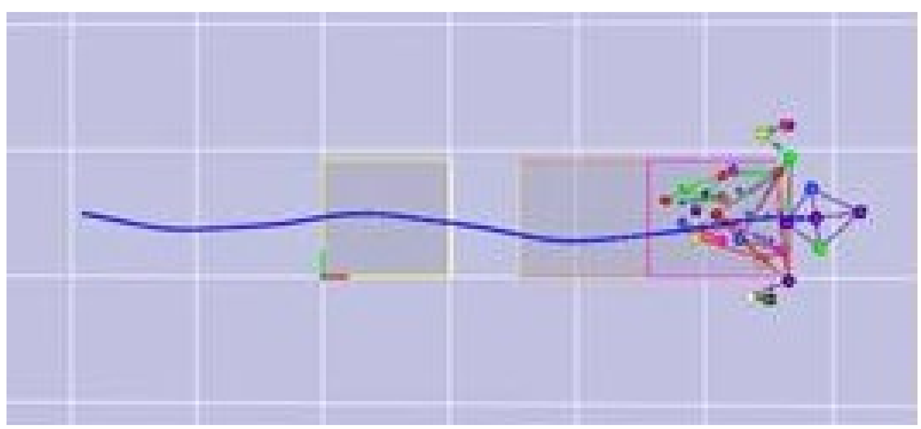

Figure 4 An overhead view of the presentation in Figure 1. The trajectory of the blue path represents the whole-body COM in the transverse plane and demonstrates the ML COM displacement that is being measured.

Statistical Analysis

A two-way, independent samples t-test was applied to test for group demographic differences, including age, height, and weight. There were two independent variables: group (Veterans with chronic mTBI and the control) and condition (single-task or dual-task walking procedure). A repeated measure, two-way ANOVA was run for gait temporal distance and center of mass stability data. An alpha-value of $\alpha = 0.05$ was chosen as the threshold to demonstrate significance in the data. Follow up pairwise comparisons using the *Bonferroni correction* controlled for family wise type 1 error due to multiple independent variables.

Results

Eight subjects were a part of each cohort of Veterans, with both groups having seven males and one female. No statistically significant difference was found between groups for age, height, or weight, as seen in Table 1. Veterans with chronic mTBI showed moderate symptoms on the Rivermead Post-Concussion Symptom Test with a symptom score of 53.1%, while the control cohort demonstrated a low symptom score on the Post-Concussion Symptom Scale with a symptom score of 4%.

As shown in Table 2, there were no significant group differences in gait velocity, step length, or step width. Compared to healthy controls, subjects with chronic symptoms walked with a significantly greater ML COM displacement in both ST and DT (main effect of group, p = .018; Fig. 5). Follow-pairwise comparisons identified significant difference between the two groups in the DT condition (p = 0.007). An interaction effect was identified for the peak ML COM velocity (p = .012; Fig. 6), indicating the ML COM velocity of both groups was affected by performing a concurrent cognitive task. Compared to the ST condition, healthy individuals demonstrated a slower ML COM velocity when faced with the DT situation while individuals with chronic symptoms showed an increase in ML COM velocity.

Table 1 Demographic Data for Veterans with Chronic mTBI and the healthy Veterans, presented as mean ± standard deviation.

Group	Sex	Age (yrs)	Height (cm)	Weight (kg)
Chronic mTBI	1F/7M	32.5±8.5	177.9±9.7	86.2±25.7
Healthy	1F/7M	33.3±3.7	173.6±8.7	78.1±8.5

Table 2 Temporal distance data for Veterans with chronic mTBI and healthy Veterans in both single-task and dual-task conditions, presented as mean ± standard deviation.

Group	Condition	Gait Velocity (m/s)	Step Length (cm)	Step Width (cm)
mTBI	ST	1.21±0.12	66.7±6.5	8.6±4.1
Healthy		1.30±0.10	68.8±3.3	10.6±3.3
mTBI	DT	1.19±0.13	64.8±7.9	8.5±3.0
Healthy		1.29±0.08	68.9±3.1	10.2±3.3

Figure 5 ML COM displacement in both the ST and DT conditions for both Control and Veterans with chronic mTBI groups. * denotes a significant difference ($p = 0.007$).

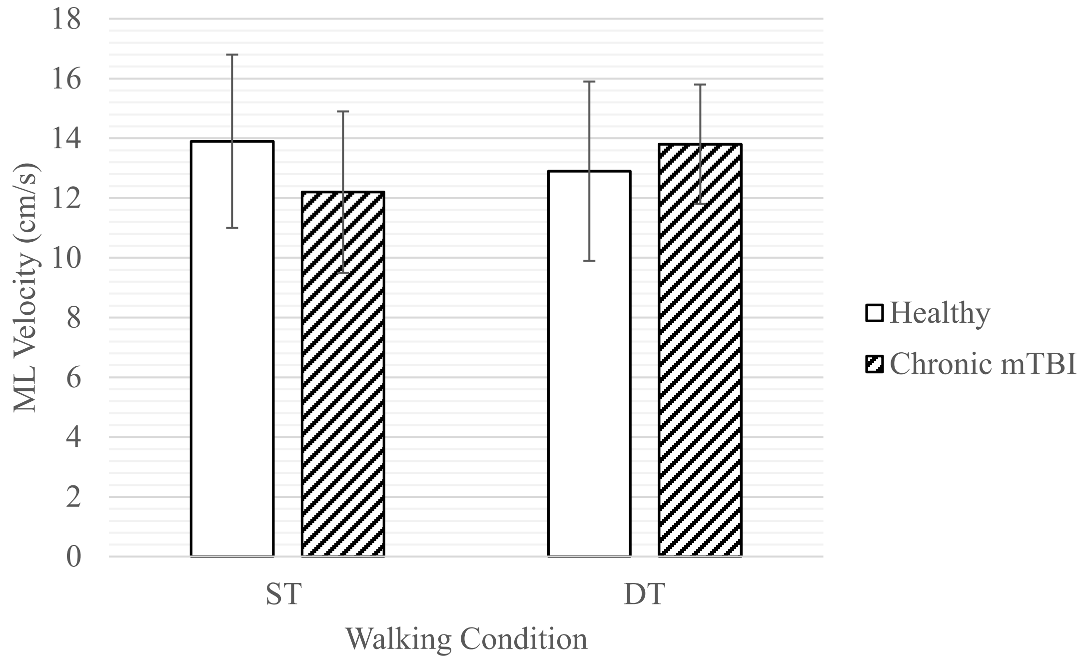

Figure 6 ML COM velocity in both the ST and DT conditions for both Control and Veterans with chronic mTBI groups.

Discussion

Previous literature has reported gait imbalance in young adults with acute mTBI. However, there was limited research on the effect of chronic mTBI on gait balance control. This study demonstrates that there are differences in gait balance control between healthy Veterans and Veterans with chronic mTBI. Specifically, the results point to differential ML COM velocity and ML COM displacement between the two groups that is similar to the impairment reported for individuals with acute mTBI.

There have been several studies that have assessed the importance of a concurrent cognitive task while completing the walking circuit. They note that both control and injured subjects will provide explicit attention to their gait movements when walking is the sole task. While concurrently performing a cognitive task, such as the implemented auditory Stroop test, would force an individual to allocate attentional resources to both motor movement and cognitive thought processes. The literature has indicated that this replicates a more realistic walking scenario from activities of daily living and provided a more sensitive detection of gait imbalance for individuals with mTBI.

Our results demonstrated that the ML COM displacement for Veterans with chronic mTBI was significantly larger in the DT condition when compared to healthy Veterans. Previous studies have investigated the practicality of ML COM displacement as a measure of gait balance. One study in particular found that elderly patients that had complaints of imbalance that were navigating increasingly taller obstacles had a proportionally higher ML COM displacement when walking.[15] They concluded that this measure is a sensitive predictor of gait imbalance.

This study also found that Veterans with chronic mTBI demonstrated a faster ML COM velocity in the ST condition, but a slower ML COM velocity in the DT condition. Healthy individuals demonstrated a slower ML COM sway velocity, suggesting they adopted a conservative balance control strategy, possibly as a result of allocating additional attentional resources in the more complex situation. Conversely in the DT condition individuals with chronic symptoms showed an increase in peak ML COM velocity suggesting their ability to control ML COM momentum may be diminished. This may be due to a reduced attentional capacity, rendering them incapable of accommodating the demands of multiple concurrent tasks.

Several studies have been conducted to investigate the gait abnormalities of populations that have acute mTBI. A 2018 meta-analysis on 38 such studies found that in a dual-task simple gait condition, similar to our dual-task protocol, the acute mTBI population suffered from decreased gait velocity and generally had increased ML COM displacement and velocity.[21] These findings suggested that individuals with acute mTBI demonstrate a significantly greater gait sway and compensated by walking slower. Results from this study suggested that Veterans with chronic mTBI may have similar gait imbalances as acutely injured individuals, as both ML COM displacement and velocity were significantly higher in the dual-task condition. Gait velocity was slower for Veterans with chronic mTBI in both conditions for our study, however, these data were not significantly different from the control population. This suggests that the subjects with chronic mTBI may be more acclimated to dealing with the increased COM sway.

The literature on neurometabolic cascades that play a role in chronic mTBI is still emerging. So far it has shown that several issues that contribute to the symptoms of acute mTBI can plausibly exist in chronic mTBI, such as chronic axonal dysfunction and toxin accumulation.[22] It is therefore possible that these similar physiological deficiencies may be causing similar COM instability issues for both acute and chronic conditions. It is necessary for further simultaneous research on both physiological and biomechanical chronic mTBI symptoms in order to gain a better understanding of these injuries.

These findings have several practical applications. Firstly, with the high prevalence of chronic mTBI, especially in the military, policy changes are likely necessary to protect at-risk individuals. Knowledge of the gait deficiencies and heighted risk for further injury with chronic mTBI can directly promote health policy that can care for these individuals. Secondly, gait testing can be utilized clinically since gait measurements can provide a valuable tool to test for chronic symptoms and to assess a patient's progress. Third, further research on the interaction between gait deficiencies and other symptoms can unlock mechanisms of chronic mTBI, leading to better understanding and care.

Although most of our findings align with the previous literature, our study was limited by small sample size and high variance for gait metrics within the chronic mTBI cohort. However, these limitations are typical challenges when working with brain injuries and/or Veterans. Additionally, brain injuries are suffered differently by each individual, contributing to the variance in the data.

Conclusion

There is evidence to suggest that individuals suffering from chronic mTBI symptoms are having persistent gait imbalance issues. Veterans with chronic mTBI demonstrated increased ML COM displacement and velocity than the control cohort. This information can be important for developing health policy and preventing further injury.

Glossary

Terms in the order they appear in the paper.

TBI: Traumatic brain injury. Often defined as brain dysfunction caused by an outside force, usually by a violent blow to the head.

mTBI: Mild traumatic brain injury. Analogous to concussion, this form of TBI is often categorized with symptoms such as headaches, fatigue, depression, anxiety and irritability, as well as impaired cognitive function.

Acute mTBI: A recently suffered mild traumatic brain injury, often within three months of the time of injury.

Chronic mTBI: A mild traumatic brain injury that leaves symptoms after approximately eight months.

Diffuse tensor MRI: A neuroimaging technique which can be used to estimate the location and direction of the brain's white matter tracts.

Fractional anisotropy: A type of white matter in the brain. White matter is often connected to higher brain functions and learning.

Post-traumatic stress disorder: Mental disturbances related to coping with experience of traumatic events.

COM: Center of Mass. The point on the body where the weighted relative position of the distributed mass sums to zero. In biomechanics, this point best defines the movement of the subject.

Mediolateral center of mass displacement (ML COM displacement): The “side to side” sway of the body’s center of mass from median to lateral.

Mediolateral center of mass velocity: The speed of the ML COM displacement

Bonferroni correction: Used when multiple independent statistical tests are being run simultaneously. It prevents a type 1 error, or “false hit”, by dividing the standard alpha value by the number of hypotheses being tested.

Appendices

Appendix A

Name: ____________________ Age/DOB: _____________ Date of Injury:___________

Post Concussion Symptom Scale

No symptoms"0"-------Moderate "3"---------Severe"6"

Time after Concussion

SYMPTOMS	Days/Hrs ________	Days/Hrs ________	Days/Hrs ________
Headache	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Nausea	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Vomiting	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Balance problems	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Dizziness	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Fatigue	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Trouble falling to sleep	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Excessive sleep	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Loss of sleep	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Drowsiness	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Light sensitivity	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Noise sensitivity	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Irritability	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Sadness	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Nervousness	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
More emotional	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Numbness	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Feeling "slow"	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Feeling "foggy"	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Difficulty concentrating	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Difficulty remembering	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
Visual problems	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0 1 2 3 4 5 6
TOTAL SCORE	_____	_____	_____

Use of the Post-Concussion Symptom Scale: The athlete should fill out the form, on his or her own, in order to give a subjective value for each symptom. This form can be used with each encounter to track the athlete's progress towards the resolution of symptoms. Many athletes may have some of these reported symptoms at a baseline, such as concentration difficulties in the patient with attention-deficit disorder or sadness in an athlete with underlying depression, and must be taken into consideration when interpreting the score. Athletes do not have to be at a total score of zero to return to play if they already have had some symptoms prior to their concussion.

Appendix B

The Rivermead Post-Concussion Symptoms Questionnaire*

After a head injury or accident some people experience symptoms which can cause worry or nuisance. We would like to know if you now suffer from any of the symptoms given below. As many of these symptoms occur normally, we would like you to compare yourself now with before the accident. For each one, please circle the number closest to your answer.

0 = Not experienced at all
1 = No more of a problem
2 = A mild problem
3 = A moderate problem
4 = A severe problem

Compared with before the accident, do you now (i.e., over the last 24 hours) suffer from:

Headaches	0	1	2	3	4
Feelings of Dizziness	0	1	2	3	4
Nausea and/or Vomiting	0	1	2	3	4
Noise Sensitivity, easily upset by loud noise	0	1	2	3	4
Sleep Disturbance	0	1	2	3	4
Fatigue, tiring more easily	0	1	2	3	4
Being Irritable, easily angered	0	1	2	3	4
Feeling Depressed or Tearful	0	1	2	3	4
Feeling Frustrated or Impatient	0	1	2	3	4
Forgetfulness, poor memory	0	1	2	3	4
Poor Concentration	0	1	2	3	4
Taking Longer to Think	0	1	2	3	4
Blurred Vision	0	1	2	3	4
Light Sensitivity, Easily upset by bright light	0	1	2	3	4
Double Vision	0	1	2	3	4
Restlessness	0	1	2	3	4

Are you experiencing any other difficulties?

1. ______________________________	0	1	2	3	4
2. ______________________________	0	1	2	3	4

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