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Pictures by Julia Castleberry, 2014

Processing distortions have cumulative deleterious effects on the postural control system diminishing the brain's ability to rapidly and automatically integrate postural information while maintaining higher cognitive function and musculoskeletal reaction time. Pre-existing summative nervous system overload, such as altered movement patterns, disruption of cervical proprioception, or musculoskeletal pain, may increase the risk for concussion-like symptoms, revealed through deficits in postural stability, ocular tracking, cognitive reasoning, and motor patterning.

Brent Harper

Mission Statement: To provide an electronic open source forum for the presentation of research, theories, interventions, and ideas related to the practice of Physical Therapy.

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Of

The Journal of Physical Therapy Practice (JPTP)

The JPTP is a multi-disciplinary open source journal which provides a collaborative environment to explore ideas and research to enhance clinical practice.

Health care is an ever changing and challenging world in which clients relay on health care professionals to guide their recovery**.**

Our first issue centers on the topic of concussion. Historically, health care and research has focused on the treatment of concussion. Literature review indicates that concussion prevention and assessment methods are currently being formulated and evaluated for sport related injuries.

This issue contains an article and commentary discussing the risk of concussions within a global preventative theoretical framework as well as brings to the forefront the risk of concussion in the geriatric population.

We hope you enjoy reading the journal, and we encourage you to participate by submitting your commentary, article, and research. Our next issue is schedule for publication in December 2014.

We look forward to reading your submissions.

Best regards,

Julia Castleberry and Brent Harper

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Consider the Many Facets of Concussion.

A Theoretical Paradigm of Central Cognitive Mechanisms Linking Concussion and Whiplash Associated Disorder: Part One

Abstract

Sports-related concussion, a category of mild traumatic brain injury (mTBI), is a serious issue, especially for younger athletes. Incidence ranges from 1.7 to 3.8 million, making it a public health issue and fundamental to health promotion and injury prevention. High school male football and female soccer athletes have the highest incidences. Acceleration and deceleration in concussion and whiplash injuries cause soft tissue damage, neck pain, cognitive, vestibular, and oculomotor symptoms; specifically headaches, dizziness, upper extremity impairments, visual disturbances, difficulty concentrating, reading and comprehension, and remembering and processing information. Abnormal eye movement is an initial marker for decreased brain function. There is a link between athletes with a musculoskeletal injury and those with a concussion: both exhibit cognitive deficits, suggesting concussive symptoms may arise from more complex mechanisms than direct brain trauma and altered brain metabolism. It is possible the explanation resides in the afferent and efferent neuro-feedback loops. Disrupted afferent and efferent neuro-feedback loops alter cervical proprioception creating a barrage of somatosensory input, manifesting the shared symptoms. Persistent wind-up of somatosensory noxious input produces altered motor control patterning leading to cortical reorganization, which can develop into sensitization centrally. Pain causes and strengthens movement compensations through reflex patterns, primarily gamma loop and central inhibitory mechanisms. Processing distortions have cumulative deleterious effects on the postural control system diminishing the brain's ability to rapidly and automatically integrate postural information while maintaining higher cognitive function and musculoskeletal reaction time. Pre-existing summative nervous system overload, such as altered movement patterns, disruption of cervical proprioception, or musculoskeletal pain, may increase the risk for concussion-like symptoms, revealed through deficits in postural stability, ocular tracking, cognitive reasoning, and motor patterning. These are measured by balance or movement assessments, eye reflexes, smooth pursuit testing, neurocognitive tests, and functional movement screens.

Keywords: Concussion, Motor Control, Eye Movements, Posture

A Theoretical Paradigm of Central Cognitive Mechanisms Linking Concussion and Whiplash Associated Disorder: Part One

Brent A. Harper, PT, PhD, D.Sc, DPT, OCS, FAAOMPT

The two primary mechanisms of injury for concussion are direct and in-direct forces. Direct concussions occur when the head impacts another object. This is typically seen in head collisions as in American football and soccer. In contrast, in-direct concussion involves no direct head impact, but is caused by a transfer of forces to the head, such as occurs during whiplash (Meaney & Smith, 2011). Rapid sideline identification of concussion has obtained greater attention because of the potential for serious primary and secondary sequelae. Unfortunately, symptomatic athletes may not recognize or may fail to disclose symptoms; other concussed athletes may exhibit non-typical deficits in various body systems. These atypical symptoms may be identified using a broader set of assessments, which may double as useful screens to identify compensatory patterns potentially indicative of increased concussion risk. This article hypothesizes that in-direct concussions may be initiated when a continuous barrage of afferent sensory information overloads the brain, which attempts to align the input with expected sensory information causing a sensory mismatch. Using multiple assessments measuring multiple body systems, it may be possible to detect atypical, indirect concussions and to identify those with preventable increased risk factors for concussion.

According to the most recent Zurich concussion consensus statement (McCrory et al., 2013), various postural stability tests ranging from the high-tech NeuroCom to clinical balance assessments such as the Balance Error Scoring System (BESS) are valid and reliable tools for the evaluation of post-concussive athletes. The consensus states, “postural stability testing provides a useful tool for objectively assessing the motor domain of neurological functioning, and should be considered as a reliable and valid addition to the assessment of athletes suffering from concussion, particularly where the symptoms or signs indicate a balance component” (McCrory et al., 2013, p. 252). Furthermore, it supports the use of the many neuropsychological (NP) assessments available—most notably the neurocognitive test called ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing) to assess cognition, screen for concussion, and for remove from play (RFP) and return to play (RTP) decisions. However, the Zurich concussion statement does not support widespread routine NP baseline testing; rather, the panel stated there is insufficient current scientific evidence to impose mandatory NP testing. The panel minimally addressed vision and eye-tracking assessments (i.e. King-Devick Test), indicating the possibility that eye-tracking screens may be useful additions to the sideline assessment of concussion with the caveat that current research is minimal and that the required additional equipment may be impractical (McCrory et al., 2013).

Even when several valid screening tools, such as balance assessments and neurocognitive testing, are combined, athletes remain at risk or undiagnosed with or without obvious symptoms. There is a gap in the literature identifying the most reliable combination of screening tools to detect those at risk for concussion and those with concussion but asymptomatic of the standard signs. This paper proposes a theoretic link based on shared concussion-like symptomology between in-direct concussion, in which the impact to the body results in acceleration and deceleration force transfer to the head, and whiplash-associated disorder (WAD), in which acceleration and deceleration forces are transferred to the cervical neuromuscular structures resulting in soft tissue injuries. Both conditions tend to have converging and summative aberrant afferent neural signaling due to tissue disruptions in the cervical spine, vestibular, ocular, and trigeminal nuclei. This presents as a centralized phenomenon requiring consistent normalization of afferent signaling to provide a reversal of the neuroplastic changes. The purpose of this two-part article is to provide a foundation to (1) discuss the similarities between in-direct concussion and WAD, (2) identify which assessments might indicate those at risk for concussion (pre-concussive screening), (3) identify a potential concussion sideline screening set to optimize RFP and RTP, and (4) manage post-concussion syndrome (PCS). This article discusses the incidence of concussions, identifies at risk populations, describes potential preventative metric markers, and introduces an alternative theoretical construct regarding the potential mechanisms behind in-direct concussions and concussion-like symptoms.

Sports-related concussion, categorized within the broader diagnosis of mild traumatic brain injury (mTBI), is a serious (Kristjansson & Treleaven, 2009) issue, especially for younger athletes. The Centers for Disease Control and Prevention (CDC) estimated the annual incidence of traumatic brain injuries between 1.7 to 3.8 million each year from 2002 to 2006 (Faul, Xu, Wald, & Coronado, 2010). However, the CDC data is based on emergency room data and fails to capture individuals who initially sought care from a primary care provider or specialist (Sahler & Greenwald, 2012). The CDC labeled concussion as a “hidden epidemic.” If unrecognized or untreated, it can evolve into something more serious and potentially devastating (Kevin M Guskiewicz & Broglio, 2011). A history of one or multiple concussions may lead to prolonged functional impairments or devastating long-term sequelae. Returning to play prior to recovery increases an athlete’s risk for second-impact syndrome, in which excessive cerebral swelling and brain herniation cause catastrophic brain injury or death (Boden, Tacchetti, Cantu, Knowles, & Mueller, 2007; K M Guskiewicz, Weaver, Padua, & Garrett, 2000; Meaney & Smith, 2011).

Sport-related concussion is a highly sensitive topic in sports and sports medicine (Halstead, Walter, & Council on Sports Medicine and Fitness, 2010; Meehan & Bachur, 2009) due to the political and economic nature of competitive sports. In July 2011, Virginia enacted legislation requiring schools to develop concussion identification and management guidelines for student-athletes. The law includes three primary mandates: (1) the institution must retain on file annually updated documentation that parent/guardian and student-athletes have reviewed concussion educational material, (2) any student-athlete suspected of sustaining a concussion must immediately be removed from the activity, and (3) will not be allowed to return to play that same day, but only allowed to return to sports after evaluation and written clearance by a licensed health care provider ("Youth Sports Concussion Safety Laws," n.d.).

Sport-related concussion is serious (Meehan & Bachur, 2009), especially for younger athletes, whose brains are still in the process of developing physically and cognitively (Halstead et al., 2010). Published incidence reports vary, in part because older estimates only include concussions associated with loss of consciousness. These older estimates may have been further confounded by underreporting, by a lack of definitive diagnostic tools for identifying concussion without loss of consciousness, and by an absence of a concussion standard surveillance guideline. As more individuals become involved with sports and as community education and awareness of concussion grows, the published incidence may rise as concussions are more readily identified (Halstead et al., 2010).

Multiple factors including competitive level, sport, age, and gender influence the annual incidence and rate of concussion. As a percentage of all injuries for high school athletics, the overall incidence of concussion rose from 5.5% in late 1999 to 8.9% in 2005 (Gessel, Fields, Collins, Dick, & Comstock, 2007) to 13.2% for the reporting period of 2008 to 2010 (Marar, McIlvain, Fields, & Comstock, 2012). The majority of those reported concussions (65.4% to 66.6%) occurred during games and 33.4% to 34.6% occurred during practices (Gessel et al., 2007; Marar et al., 2012). The upward trend of incidence may be due to increased awareness (Gessel et al., 2007) and may be linked to new legislation ("Youth Sports Concussion Safety Laws," n.d.) which requires athletes, parents, and coaches to receive concussion education annually. This increased awareness has encouraged changes in the management of full-vs-partial-contact during practice sessions in an attempt to decreased exposure to head impacts (Gessel et al., 2007). The highest incidence of concussion per sport for high school athletes occurs in American football for males (40.5% to 47.1%) and soccer for females (8.2% to 21.5%) (Gessel et al., 2007; Marar et al., 2012).

The athletic exposure (AE) rate has been calculated by epidemiological survey studies to provide an estimated rate of concussion. As of 2010, the average AE rate for high school athletic games and practice, combined, with AE defined as one athlete participating in one practice or competition situation, is 2.3 to 2.5 concussions per 10,000 AEs. Analyzed separately, the rate of a concussion in games more than doubles, ranging from 5.3 to 6.4 concussions per 10,000 AEs, and the rate of concussion during practice drops to 1.1 per 10,000 AEs (Gessel et al., 2007; Marar et al., 2012). When comparing the proportion of concussions per total number of injuries sustained during athletic events, it appears as though collegiate athletes suffer fewer concussions than high school athletes. However, when concussion data is isolated and matched, it becomes apparent that collegiate athletes actually have a higher rate of concussion than their high school counterparts. This is because collegiate athletes also have a higher rate of injury, overall, skewing the appearance of the data when collegiate ratio of concussion to overall musculoskeletal injuries is compared directly with the high school ratio (Gessel et al., 2007).

Abrahams et al (2014) performed a systematic review of the current literature to identify which of the previously postulated preventable concussion risk factors maintained statistical validity as risk factors predisposing an athlete to a concussive event. According to their data, a previous history of a concussion across sports tripled the risk of suffering another concussion. A male athlete with both a history of concussion and participation in American football was three to six times more likely to suffer a concussion (Abrahams et al., 2014). A reluctance to report concussive injuries has been shown in high school football, with 47.3% admitting to experiencing concussion symptoms without reporting the injury (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004).

When comparing gender, the overall risk of concussion was 1.5 to 2.5 times higher for females than for males, regardless of the level of competition (Abrahams et al., 2014). The authors suggest this indicates that in sports with comparable rules and physical play, females are at greater risk. This study also confirmed the data of previous studies, that there is a higher risk of suffering a concussion during a game than during practice. Other previously postulated risk factors – genetics (apolipoprotein E gene marker), aggressive behavior during participation, the amount of time played during the game, environmental factors, and protective equipment – were not found to increase or decrease the risk of concussion. This review of current literature supported only three risk factors for suffering a concussion: a prior history of concussion, participation during games, and female gender (Abrahams et al., 2014).

As previously identified, gender is a significant risk factor for concussion (Abrahams et al., 2014). Researchers theorize that females have a higher risk due to decreased muscular development of the upper quarter, decreased neck strength, and smaller head mass, resulting in increased head acceleration during impacts (Tierney et al., 2005, 2008). However, the literature has not definitively corroborated these theories. Culturally, there may be an increased tendency to treat females more protectively (Gessel et al., 2007) and women may be more willing than men to report concussion injuries (Dick, 2009). A recent study by O'Kane et al (2014) looked at 351 elite female soccer players 11 to 14 years of age from 2008 to 2012. This study collected the number of athletic exposure hours (AEH) during practice and games. It identified 59 concussions, 86.4% occurred during games making the athlete 22.9 times likelier to suffer a concussion during a game. Of those 59 concussions, 54.3% involved contact with another person and 30.5% occurred when heading the ball. The study reported a cumulative incidence of concussion as 13.0% per season with a concussion rate of 12 to 13 per 10,000 AEH. Surprisingly, 58.6% reported playing soccer with concussion symptoms (O'Kane et al., 2014). As female athletics become more competitive and potentially lucrative, as seen by increases in collegiate scholarships and professional opportunities, there may be a fear that removal from play (Gessel et al., 2007) may limit these opportunities. This higher than previously reported incidence may be due to a more precise measure of exposure built in to AEH, indicating that those who play more minutes have a higher risk, versus the previously used AE.

As stated above, O'Kane et al (2014) gave a concussion incidence rate for adolescent female soccer athletes to be 12 to 13 concussions per 10,000 AEH. A comparable AEH study by Guskiewicz et al (2000) estimated the concussion incidence rate for male American high school football athletes to be 10.3 per 10,000 AEH. In this study (K M Guskiewicz et al., 2000), AEH for male collegiate football athletes varied depending on the level of competition, with division I athletes at 4.9 per 10,000 AEH and division II and III athletes at 6.9 per 10,000 AEH.

One purpose in the development of AE and AEH risk ratios was to identify the situations in which players are most likely to experience head impacts. One device designed to measure head impact forces is the Head Impact Telemetry™ System (HIT™), which utilizes accelerometers placed inside American football helmets to identify the location and magnitude of real-time impacts. The tool is used to detect athletes at risk for concussion by measuring the biomechanical variables of rotational and linear acceleration and the number of sub-concussive impacts recorded. High risk is indicated if the athlete is exposed to rotation acceleration forces greater than 5,500 rad/s and linear acceleration greater than 96 G (Broglio et al., 2010; Broglio, Eckner, Surma, & Kutcher, 2011).

Rowson and Duma (2013) applied kinematic parameters, considered indicative of inertial response of the brain, to predict the risk of brain injury. This injury metric establishes the probability of suffering a concussion by evaluating linear and rotational head acceleration forces. They postulated that linear acceleration-based brain injury is due to a transient intracranial pressure gradient and that rotational acceleration-based brain injury is a response secondary to tissue strain. This mathematical model reviewed the HIT™ and NFL data sets, factoring in incidence rates to account for underreporting, to suggest a concussion incidence rate of 38.8 concussions per 10,000 head impacts (Rowson & Duma, 2013).

Young et al (2013) applied acceleration force theory to youth male American football athletes to determine the number of impacts and level of force that place this group at risk. They collected head impact data on 19 male youth football players ages 7-8 years of age for two years using HIT™ data. They found that 60% of impacts occurred in practices and the remaining 40% occurred in games, the average head impacts per season was 161 ± 111 (96 ± 65 practice and 65 ± 54 in games), while the rotational acceleration median impacts for the season was 686 ± 169 rad/^{s2} and the lateral acceleration was 16 ± 2 G. This practice to game ratio directly contrasted those found by previous studies (Broglio et al., 2010, 2011; Rowson & Duma, 2013). The authors suggested the apparent discrepancy was due to increased practice time, which was twice that spent in games. When the confounding variable of time was removed, the authors found their data agreed with previous studies in that per game impacts averaged 11 ± 11 and per practice impacts averaged 9 ± 6. Only 11 impacts had linear accelerations at 80 G or greater and no concussions were diagnosed during this reporting period. This study is important because it indicates that Pop Warner American football athletes seem to experience a similar magnitude of head impacts as high school and collegiate athletes. Furthermore, they found that there is an increase in number of impacts with prior playing experience (Young et al., 2013).

A study by Cobb et al (2013) examined HIT™ head impact exposure data from 50 male youth American football players for one season between the ages of 9 and 12. A total of 11,978 impacts were measured. Individuals averaged 240 ± 147 seasonal impacts with an average of 10.6 ± 5.2 per session out of 21.8 ± 5.7 sessions. Median linear accelerations were 18 ± 2 G and rotational accelerations were 856 ± 135 rad/s^2. The 95th percentile impacts sustained were linear accelerations of 43 ± 7 G and rotational accelerations were 2034 ± 361 rad/s^2. The average player experienced 240 impacts during the season, more than the 107 impacts for 7-8 year olds and 565 for high school players. Only 36 head impacts (0.3%) were greater than 80 G's meaning the average player sustained 0.7 ± 1.2 impacts greater than 80 G. There were four athletes who sustained a diagnosed concussion with a range of linear accelerations from 26 to 64 G and rotational accelerations from 1552 to 4548 rad/s^2. Although the number of total impacts were not statistically significant for those diagnosed with concussion and a diagnosis of concussion had no statistical correlation with any data set, the authors recommended minimizing exposure to head impacts (Cobb et al., 2013).

Urban et al (2013) collected head impact information from 39 male athletes between the ages 14 to 18 during a single season of high school American football using HIT™ data. The median linear head acceleration value was 21.9 G and the median rotational head acceleration was 973 rad/s^2. The linear acceleration of 21.9 G is higher than the collegiate level of 18 G, which suggests that higher severity of impacts occurs at the high school level. Forty-five percent of impacts occurred to the front of the helmet, which was consistent between practices and games; however, historically, the primary cause of concussions is rotational acceleration forces, typically from side impacts. During the 14 games there were 16,502 impacts, 76 (0.46%) of which were above the linear acceleration value of 98 G's, which has been associated with concussion (Urban et al., 2013).

Collectively, the authors of these studies (Broglio et al., 2010, 2011; Cobb et al., 2013; Rowson & Duma, 2013; Urban et al., 2013; Young et al., 2013) recommended a limitation of the number of head impact exposures in order to decrease the risk of concussion. Put into practice, these recommendations have resulted in decreased full-contact time during practices and yet the incidence of concussion continues to rise. General cut-off values for linear and rotational acceleration forces have been determined based on the data of multiple studies (Broglio et al., 2010, 2011; Cobb et al., 2013; Rowson & Duma, 2013; Urban et al., 2013; Young et al., 2013). However, some athletes continue to suffer concussions with head impact acceleration scores below the cut-off values and other athletes with high impact acceleration scores do not display symptoms of concussion. Therefore, there must be risk factors other than the number of head impacts and acceleration forces experienced yet to be identified.

These studies dealing with AE, AEH, and head impact linear and rotational acceleration forces relate to a direct concussion mechanism of injury. The data produced by the studies

(Broglio et al., 2010, 2011; Cobb et al., 2013; Rowson & Duma, 2013; Urban et al., 2013; Young et al., 2013) has been used to develop general cut-off scores for both linear and rotational acceleration forces. Intuitively, if one hits one's head hard enough, it will most likely result in a brain injury. However, an analysis of the data demonstrates that not all incidences of concussion occur above the delineated cut-off scores. In fact, high forces do not always result in a concussive event and, alternately, concussions do occur during impacts with innocuous force scores. Repetitive or cumulative sub-concussive head impact acceleration forces may have a deleterious, summative effect, but it is not likely these summative forces function in the same manner as direct head impact forces. Perhaps individuals who have suffered multiple in-direct sub-concussive forces are more vulnerable to lower linear and rotational acceleration forces due to the altered function of multiple body systems.

In-direct sub-concussive forces may affect multiple systems. The in-direct concussion theory proposed is centered on the nervous systems processing of continuous afferent stimuli from the vestibular, cervical spine (proprioception), somatosensory, and visual systems. *Figure 1* depicts the central integration of afferent information stimulating the postural control system.

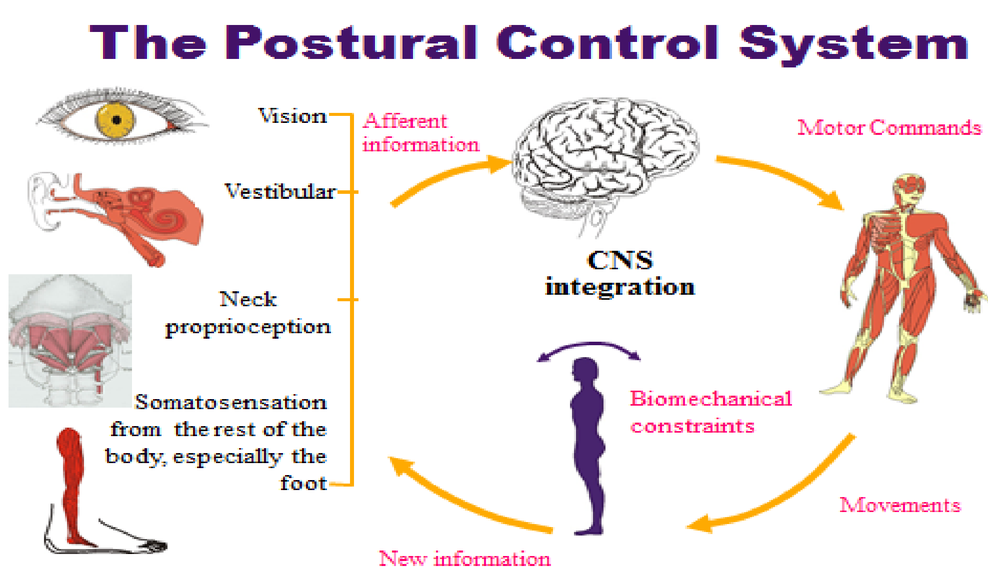

FIGURE 1. The Postural Control System. This figure describes the information input flow from the body as important stimuli for the postural control system. Adapted from ``Sensorimotor function and dizziness in neck pain: implications for assessment and management," by E. Kristjansson and J. Treleaven,(2009). *The Journal of Orthopaedic and Sports Physical Therapy, 39*(5), 364–377. Copyrighted in 2009 by E. Kristjansson and J. Treleaven. Figure was reprinted with permission.

Compensations may occur in the subcortical and cortical regions of the brain as it attempts to make sense of aberrant afferent input. The symptoms of dizziness and unsteadiness (impaired balance) may be due to a "sensory mismatch" of neural input converging from visual and somatosensory subsystems and alterations of the expected sensory patterns (afferent sensory information) (Kristjansson & Treleaven, 2009). This sensory mismatch creates a secondary disturbance to the postural control system (Falla, Jull, & Hodges, 2004; Jull, Kristjansson, & Dall'Alba, 2004; Kristjansson & Treleaven, 2009; Montfoort et al., 2006; Treleaven, Jull, & Lowchoy, 2005; Treleaven, Jull, & LowChoy, 2006). Therefore, if these systems are compensating, resulting in processing errors, there should be pre-existing deficits in musculoskeletal movement patterns and/or expressions of concussion-like symptoms that do not usually prompt concussion screening without history of a direct head impact.

In their research, Schneider et al (2013) focused on preseason concussion risk variables for 13-14 year old male ice hockey athletes. They identified three preseason predictive risk factors: the presence of neck pain, current complaint of headaches, and sensorimotor balance control deficits. Adolescent males with any two of the three risk factors during preseason screening were 2.4 to 3.65 times more likely to suffer a concussion during the competitive season. This is the first study that focused on identifying preventative concussion risk factors. The results suggest that in-direct concussions have more systems influencing the concussion-like symptoms than direct head impact concussion with the more recognized mechanisms of brain metabolic starvation and brain specific neuronal death. In-direct concussions may be affected by a sensory mismatch of nervous system integration, interpretation, and response to various neural inputs including vision, vestibular, somatosensory, and proprioceptive afferent information. There may be a summative effect of sub-concussive forces that alters neural input from various systems since this study's three predictive variables are related to proprioception, cognitive function, and balance. Perhaps those at greater risk for concussion can be identified using varied screening metrics to assess postural stability (balance), neuropsychological cognitive ability, and functional eye movements.

As previously discussed, traumatic brain injury (TBI) and concussions are caused by direct head contact forces or by in-direct inertial forces. Direct contact force loading, the head striking an object, typically causes focal brain lesions, the symptoms of which are directly observable in severely brain injured individuals but largely absent in mild traumatic brain injury (mTBI/concussion). During in-direct inertial forces, however, the head does not directly strike an object. Instead, the inertial forces, which include linear and rotational accelerations, are transmitted from other body regions on which the initial impact occurred to the head in the form of an impulse wave of acceleration/deceleration. These inertial impulses, especially rotational acceleration forces, create shearing forces, which tend to cause brain deformation. Meaney and Smith (2011) purport that the majority of concussions are caused by shearing secondary to inertial forces.

Common pathological features of TBI from direct head impacts involve diffuse axonal injury (DAI) to the subcortical white matter. Histological presentation of DAI is difficult to detect with traditional computer tomography (CT) and magnetic resonance imaging (MRI) scans but involves microscopic lesions, axonal degeneration, axonal swelling, or myelin loss. mTBI, such as in-direct concussion, may also involve DAI; thus DAI can occur with or without a direct blow to the head, such as in whiplash-associated disorder (WAD). Anterior white matter tracks tend to be vulnerable to shearing forces. Diffusion tensor imaging (DTI), an experimental MRI tool used to quantify intrinsic microstructure and micro-dynamic tissue features, examines fractional anisotropy (FA), an indicator of white matter microstructural integrity, to detect DAI and other microstructural changes in white matter associated with mTBI (Maruta et al., 2010). White matter damage leads to deficiencies in predictive timing, attention deficits, decreased balance, and impaired coordination of movement patterns. This inability to correctly time or anticipate sensory events leads to a temporal mismatch between the brain's expectations and the actual sensory input. This neural input disparity may impair brain function, causing symptoms of dizziness, sensory hypersensitivity, and tinnitus. (Maruta et al., 2010)

Abnormal eye movement is an initial marker for impaired brain function (Alsalaheen et al., 2013; Hovda et al., 1995; McCrory et al., 2013; O'Kane et al., 2014; Schneider et al., 2013; Tsao, Danneels, & Hodges, 2011). Based on the concept that overlapping regions of the brain govern eye movement and attention and on the above sensory mismatch theory, Maruta et al (2010) studied eye-movements as a potential screening tool for mTBI and found that errors in visual-tracking gaze did, in fact, occur in individuals with mTBI. Furthermore, Maruta et al (2010) found eye movement errors increased with increasing mTBI severity. They suggested that errors in visual-tracking gaze might be an effective screen to identify individuals with mTBI and to assess its severity (Maruta et al., 2010). If eye movement is a metric of cognitive attention function and tends to correlate to white matter integrity to the neural pathways known to carry out cognitive function, perhaps it can be used as a screen to identify those vulnerable to suffering an in-direct concussive event.

According to a study by Misra and Coombes (2014), the human brain processes movement, or motor control, and pain in an overlapping sensorimotor region in the cingulate cortex medial wall, specifically in the anterior midcingulate cortex (aMCC) and the supplementary motor area (SMA). This overlap occurs whether pain and motor control are individually or simultaneously stimulated. This demonstrates the integration of motor function and pain processing. Pain influences movement choices and changes the way we move. How we move changes our pain experience. Even the anticipated perception of pain may result in movement aberrations (Bank, Peper, Marinus, Beek, & van Hilten, 2013; Falla et al., 2004; Hodges & Tucker, 2011; Zedka, Prochazka, Knight, Gillard, & Gauthier, 1999). The neural basis underlying the motor-pain relationship is not well understood, however, it can be theorized that if there is sensory mismatch in pain perception and the brain's expectation of movement, it may result in concussion-like symptoms, such as headache, neck pain, and impaired motor function, such as decreased balance. Thus, this study adds credence to the mismatched sensorimotor neural input theory.

In summary, you cannot prevent all concussions; especially those that arise from a direct head impact. However, a majority of concussions are not associated with observable direct head impact indicating there may be other factors involved causing in-direct concussive events. These in-direct concussions cause shearing of brain tissues from acceleration and deceleration forces: a similar mechanism for both concussion and whiplash injuries that causes soft tissue damage, neck pain, cognitive, vestibular, and oculomotor symptoms (Gimse, Tjell, Bjørgen, & Saunte, 1996; H. Heikkilä & Aström, 1996; H. V. Heikkilä & Wenngren, 1998; Hildingsson, Wenngren, Bring, & Toolanen, 1989; Hildingsson, Wenngren, & Toolanen, 1993; Revel, Minguet, Gregoy, Vaillant, & Manuel, 1994; Roll, Velay, & Roll, 1991). Musculoskeletal injuries and concussion exhibit cognitive deficits, suggesting symptoms arise from more complex mechanisms than direct brain trauma and altered metabolism (Hutchison, Comper, Mainwaring, & Richards, 2011; Swanik, Covassin, Stearne, & Schatz, 2007). Disrupted afferent and efferent neuro-feedback loops alter cervical proprioception creating a barrage of somatosensory input mismatched to brain expectations, manifesting in the shared symptoms. Pain (Falla et al., 2004; Hodges & Tucker, 2011; Jull et al., 2004; Schneider et al., 2013) causes and strengthens movement compensations through reflex patterns. Processing distortions may have cumulative deleterious effects on the postural control system (Kevin M. Guskiewicz, Ross, & Marshall, 2001; Muir, Berg, Chesworth, Klar, & Speechley, 2010; Smith, Ulmer, & Wong, 2012) due to the overlapping brain region, diminishing the brain's ability to rapidly and automatically integrate postural information while maintaining higher cognitive function and musculoskeletal reaction time. Pre-existing summative nervous system overload, such as altered movement patterns, disruption of cervical proprioception, or musculoskeletal pain, may increase the risk for concussion-like symptoms, revealed through deficits in postural stability (Kevin M. Guskiewicz et al., 2001; Muir et al., 2010; Smith et al., 2012), ocular tracking, cognitive reasoning, and motor patterning. These are measured by balance or movement assessments (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Docherty, Valovich McLeod, & Shultz, 2006; Garrison, Arnold, Macko, & Conway, 2013; Kiesel, Plisky, & Voight, 2007; Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004), eye reflexes (Alsalaheen et al., 2013; Gimse et al., 1996; H. Heikkilä & Aström, 1996; H. V. Heikkilä & Wenngren, 1998; Heitger, Anderson, & Jones, 2002; Hildingsson et al., 1989, 1993; Revel et al., 1994; Roll et al., 1991), smooth pursuit testing (Alsalaheen et al., 2013; Gimse et al., 1996; H. Heikkilä & Aström, 1996; H. V. Heikkilä & Wenngren, 1998; Heitger et al., 2002; Hildingsson et al., 1989, 1993; Revel et al., 1994; Roll et al., 1991), neurocognitive tests (Iverson, Lovell, & Collins, 2003, 2005; Schatz, Pardini, Lovell, Collins, & Podell, 2006), and functional movements screens (Chorba et al., 2010; Garrison et al., 2013; Kiesel et al., 2007).

The follow-up article will look at the similarities between in-direct concussion and WAD and will provide additional evidence supporting the theoretical link. Furthermore, it will propose a combination of various metrics to assess multiple systems with the intent of identifying those at increased risk of suffering an in-direct concussion. The article will discuss how this preventative screening may allow at risk athletes to be prescribed exercises with the intent of normalizing the aberrant neural processing, thus decreasing their susceptibility to summative concussive trauma. Currently, studies focus on direct concussions with typical symptoms. However, it appears that many concussions seem to be caused by sub-concussive linear and rotational acceleration forces. New research should examine the in-direct mechanisms and the cumulative effect increasing the risk of suffering a concussion from a seemingly innocuous event.

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Appreciate the complexity and beauty of the human body in motion.

Julia Castleberry

Article Commentary

Concussion, Beyond Athletes

Julia Castleberry MS PT, DPT, CLT, GCS

Falls are the leading cause of injury related deaths and trauma emergency visits associated with the older adult population (Stevens and Phelan, 2013). According to the Centers for Disease Control and Prevention, falls are the leading cause of fatal and non-fatal injuries in the elderly population and account for approximately $30 billion in costs. Among community-dwelling older adults, fall related injury is one of the 20 most expensive medical conditions (Stevens et al, 2006). Fall related causes for older adults include muscle weakness, abnormal gait patterns, diminished balance reactions, impaired vision and cognition (Alexandre, Meria, Rico, & Mizuta, 2012). Falls can ultimately lead to long-term disabilities including reduced mobility, loss of independence, and diminished quality of life (Stevens & Phelan, 2013).

A fall is defined as an unexpected event in which a person suddenly rests on the ground (WHO, 2012). Factors accounting for an increased risk of falls include but are not limited to: gait impairments, balance deficits, muscle weakness, low physical activity, history of falls, visual impairments, fear of falling, cognitive impairment, depression, number and types of medications, malnutrition, arthritis, home hazards and footwear (Waters et al, 2011). The American Geriatric Society recommends annual medical screening of older adults for falls that includes but is not limited to: muscle weakness, recent fall history, gait and balance deficits, the use of assistive devices (such as a walker), sensory deficits, impaired vision, medication, and fear of falling (Vivrette, 2011).

How many concussions are the results of falls? A lack of research statistics related to fall associated concussion rates raises the question of the need for screening adults and older adults for concussion after a fall or injury such as a motor vehicle accident. Review of literature did not reveal standardized assessments or recovery guidelines for adults and older adults with suspected or diagnosis of concussion. As health care professionals actively engaged in rehabilitative efforts, how do we determine the extent of cognitive and functional impairments and deficits? Our current assessment toolbox contains such tests as the Timed Get Up and Go (TUG) for fall assessment (Shumway-Cook et al, 2001) and Folstein Mini-Mental Examination (MSS) may not be adequate in determining the extent of dysfunction related to concussion.

I encourage health care professionals to take up the challenge of looking beyond athletics for patients at risk for concussion. Often I am asked if my patient is ready to return home. Are we looking beyond our discipline specific tasks to the greater issue of returning home independently, driving, working, and all the facets of successful aging? How can we ensure the health and safety of our adult and older adult patients? Practice guidelines and standards are utilized to facilitate the rehabilitative process and quality of services. Currently there are guidelines for return to play for young athletes. *Figure 1* is the return to play protocol outlined by the Center for Disease Control and Prevention's (CDC) concussion Heads Up fact sheet guidelines.

Return to Play Protocol
After a 7-10 day rest period and with 24 hour symptom monitoring
Step 0 The athlete is to have complete cognitive and physical rest. Move to next step when no symptoms for a minimum of 24 hours.
Step 1 Light Aerobic Exercises allowed with the goal of increasing the athlete's heart rate.
Step 2 Moderate Exercise allowed with limited range of head and body movement. Examples: stationary biking, moderate jogging, moderate intensity weight lifting
Step 3 Non-Contact Exercises allowed with the goal of increased intensity but no contact.
Step 4 Practice of activity or sport to slowly reintegrate movements with full contact allowed.
Step 5 Return to full play and activities. Return to Competition.

Figure 1 outlines the return to play protocol adapted from the Center for Disease Control and Prevention's concussion *Heads Up* guidelines based on the 2008 International Concussion Consensus Guidelines.

Where are the protocols for concussion identification and recovery for adults and older adults? Are we assessing for cognitive, visual, perceptual, motor planning and processing, as well as movement and mobility impairments and deficits? Has there been a change in participation of activities of daily living?

This is a call to investigate adult and older adult concussion risks, assessments, prevention and treatment interventions. Join the initiative advocating for successful aging. It will affect each of us.

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We are at risk for falls at any age.

Concussion prevention and assessment measures are needed for all ages.

Julia Castleberry

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