IMPLICATIONS FOR BIOMECHANISTS: RESEARCH NEEDED TO HELP ADDRESS MILD TRAUMATIC BRAIN INJURY

Joshua McGeown[1]

[1]Sports Performance Research Institute New Zealand, Auckland University of Technology, Auckland, New Zealand

Sports-related mild traumatic brain injury (mTBI) is a growing area of concern to the public, media, clinicians, and researchers. There are still a wide array of unanswered questions within the mTBI literature. A number of these questions could potentially be answered using biomechanical techniques to understand how the brain responds to impacts, how characteristics of impacts may influence individuals uniquely, and how impacts may influence recovery outcomes. The purpose of this paper is to highlight gaps in the mTBI literature that are relevant to biomechanists, and to propose how the application of biomechanics may help answer these questions in the future.

KEYWORDS: mild traumatic brain injury, assessment, rehabilitation, return to play

INTRODUCTION: A traumatic brain injury (TBI) is an injury that occurs after a sudden physical trauma induced by a mechanical force that damages the brain (Kent, 2016). The severity of TBI can range from a mild concussion, to an extreme coma, or death (Kent, 2016). Mild traumatic brain injury (mTBI) accounts for 70-90% of TBI hospital admissions (Cassidy et al., 2004). Concussion and mTBI are sometimes used interchangeably within the literature and clinical practice; when in fact, concussion is a subset of mTBI. Therefore all concussions are mTBIs, but not all mTBIs are necessarily concussions (Centres for Disease Prevention, 2014; McCrory et al., 2017). An mTBI is an injury to the brain caused by linear and angular biomechanical forces directly or indirectly applied to the head, neck, or body; these forces result in the brain colliding with the inside of the skull. The stresses caused by the linear and angular forces of an mTBI may result in stretching and shearing of the neuronal cell membranes and axons and trigger a complex pathophysiological process which disrupts normal brain function (McCrory et al., 2017). This mechanical deformation of neurons leads to a disruption of the brain’s ionic equilibrium and metabolism (Farkas, Lifshitz, & Povlishock, 2006). This pattern of metabolic dysfunction following neuron deformation is referred to as the neurometabolic cascade of mTBI and manifests clinically as symptoms reported by the patient, and signs observed by clinicians (Giza & Hovda, 2001, 2014). In New Zealand, approximately 21% of all reported TBIs were sustained while playing sport or during physical activity (Theadom et al., 2014). Of these sport-related TBIs 98% were considered mTBIs, and 51% of these mTBIs were sustained by youth under the age of 18 years old (Theadom et al., 2014). Symptoms of mTBI can generally be stratified into three subgroups consisting of: cognitive, somatic, or affective symptoms (Herring et al., 2011). These symptoms cluster together in unique combinations and present as disturbances in normal day to day functions including: regulation of mood and emotions; driving a vehicle; maintenance of focus while concentrating on tasks; control of balance and gait; and regulation of heart rate and blood flow during physical exertion. Following mTBI, approximately 70% of individuals will experience spontaneous resolution of their symptoms within 10-14 days after the initial mechanical injury took place (McCrory et al., 2013). Conversely, other evidence indicates that 20-40% of individuals sustaining mTBI may continue to experience persistent symptoms for weeks, months, or years after the initial injury (Belanger, Barwick, Kip, Kretzmer, & Vanderploeg, 2013; Theadom et al., 2016). As a result, mTBI has garnered increased attention by the public, media, clinicians, and researchers in recent years, particularly in the case of contact sports. While the mTBI literature has been rapidly growing over the last two decades, many questions surrounding mTBI are still unanswered. The purpose of this paper is to highlight gaps in the mTBI literature that are relevant to biomechanists, and to propose how the application of biomechanics may help answer these questions in the future.

GAPS IN THE LITERATURE: Despite the attention surrounding mTBI, there are still substantial gaps in the literature regarding objective clinical assessment of mTBI, how to determine when an individual is considered recovered, the influence of impact magnitudes and temporal proximity to one another, and what, if any, differences exist between youth and adults, males and females in regards to recovery outcomes post-mTBI.

The assessment of mTBI symptoms presents a significant challenge for clinicians managing these types of injuries. Unlike soft tissue or boney injuries, mTBI is an invisible injury; meaning there is no obvious bruising, swelling, or deformity after sustaining an mTBI. Historically, this means that the identification, assessment, and diagnosis of mTBI relies heavily on individuals reporting their injury to appropriate medical professionals. To date, clinical assessment of mTBI consists of subjective symptom measurement tools, and performance-based baseline measures of neuropsychological performance and static postural control (Broglio & Puetz, 2008). Medical professionals are recommended to use the fifth version of the Sports Concussion Assessment Tool (SCAT-5) to evaluate athletes suspected to have sustained an acute mTBI (Echemendia et al., 2017; McCrory et al., 2017). The SCAT-5 has been demonstrated to be a useful tool in the initial assessment of acute mTBI; although, with the exception of tracking changes in symptoms, ceiling effects for several testing components limit the utility of the SCAT-5 to measure recovery following mTBI (Echemendia et al., 2017). Another limitation of the SCAT-5 is that the tool relies on an athlete's ability to recognise symptoms, and to truthfully report their symptoms to the appropriate medical professionals. In regards to sport-related mTBI, athletes are known to underreport incidence of sport-related mTBI and to try and minimise severity of symptoms (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). This presents a unique problem, wherein athletes who are suspected to have sustained a sport-related mTBI, and are motivated to avoid missing competition, can manipulate the outcomes of their mTBI assessment. Therefore, there is a need for clinical assessment tools to objectively measure assess the presence of the original injury.

There is currently limited evidence to clearly indicate why some individuals experience rapid and spontaneous recovery following mTBI (10-14 days), while others suffer with persistent symptoms. Additionally, does the resolution of symptoms indicate recovery, or do subtle disturbances in normal neurological function continue to persist after symptom resolution? What is the most realistic and affordable means to evaluate this potential disturbances in a clinical setting? Clinicians managing patients with mTBI are now recommended to incorporate a treadmill stress test as part of their assessment to determine what level of physical exertion causes symptom exacerbation (Leddy, Baker, Kozlowski, Bisson, & Willer, 2011). The incorporation of this treadmill protocol into clinical practice presents an opportunity to incorporate methods of assessing postural control during gait cycle after sport-related mTBI and throughout the recovery process. Could a device worn during treadmill testing containing accelerometers detect potential deficits in postural control following mTBI, and track changes in postural control throughout recovery? Would this potential clinical means to objectively measure post-mTBI postural control be useful to clinicians to make treatment and return to play decisions for injured athletes? Should the amount of time it takes an athlete who has sustained mTBI to recover be defined by the number of days until symptom resolution, or the amount of time until all normal functions have been restored? Should athletes be allowed to begin return to play protocols if they are symptom free, but still demonstrate characteristics of impaired neurological function?

Evidence suggests that repeated mTBI, and the proximity of injuries to one another in time, may negatively influence recovery outcomes (Giza & Hovda, 2014; McCrory et al., 2017). High risk activities such as military service; and/or contact sports like rugby may expose an individual to a heightened risk of multiple mTBI, in turn increasing risk of prolonged recovery. Presently, it is not well understood why multiple mTBIs appear to negatively influence recovery outcomes. Is the damage to neuronal tissue following mTBI analogous to musculoskeletal injuries, wherein the damage to the tissue weakens the structural integrity of the tissue resulting in decreased resiliency to future injury? Further, if there is decreased

resiliency of neuronal tissue after mTBI, would the administration of effective rehabilitation strategies restore normal integrity and resiliency? Is the magnitude of impact necessary to initiate mTBI lower for individuals with a history of >10 mTBIs than the magnitude that might cause mTBI for individuals with no history of mTBI? If there is a difference in magnitude of force that results in mTBI between those with and without history of mTBI, would the threshold of an individual with >10 mTBIs who never sustains another mTBI return to the level of an individual with no history of mTBI, or would it remain permanently changed? Recently, the idea of sub-concussive impacts has been proposed; that is, impacts with lower magnitude that do not cause mTBI but that still may have implications on neurological function and potential risk for future mTBIs (Mainwaring, Ferdinand Pennock, Mylabathula, & Alavie, 2018). Would sustaining 100 sub-concussive impacts (i.e. heading a soccer ball) be the same, better, or worse than sustaining one impact with enough magnitude to cause mTBI? Additionally, reports indicate that adolescents, females, and individuals with fewer years of education have been reported to have a higher number of reported symptoms and longer times to recovery than those observed in adults, males, or individuals with more years of education (Baker et al., 2016; Dougan, Horswill, & Geffen, 2014). Can these differences in recovery outcomes be due to unique responses in neuronal tissue of youth and females compared to adults and males in response to forces causing mTBI?
The growing public concern surrounding mTBI calls for proficient methods to model, measure, and manage this injury to ensure the safety of athletes and non-athletes alike. The gaps highlighted provide noteworthy opportunities for biomechanists to contribute to expanding the current knowledge available within the literature.

ROLE OF BIOMECHANISTS: Biomechanical methodologies to evaluate postural control during the gait cycle can be applied to gain a better understanding of how to objectively assess mTBI throughout the recovery process. Approaches used in measurement and modelling of postural control during gait in healthy and injured individuals could be applied to mTBI to develop and integrate affordable and portable instrumented tools into current clinical practice to provide clinicians with objective data to inform mTBI management. Improvements in objective clinical assessment would also answer whether functional disruptions continue to persist even when the patient reports they are asymptomatic. By refining objective clinical assessment of mTBI clinicians will be able to more accurately determine the effectiveness of treatment protocols, and when to clear an athlete to return to sport. Furthermore, analysis of impact force profiles resulting in mTBI may reveal how magnitude and frequency of impacts influence the brain under varying conditions. Investigations are currently underway using specialised sensors embedded within helmets and mouthguards in contact sports such as rugby, American football, and ice hockey to gather impact data during training and competition. To date, however, the ideal design of these impact sensors is unknown, therefore further improvements in the design of impact sensors and development of software to analyse sensor signals is needed. Once the collection and analysis of ecologically valid impact data is optimised, computerised models could be developed to determine unique characteristics between impacts that cause mTBI versus sub-impacts, differences between adults and children as well as males and females, and influence of a history of multiple mTBIs on mTBI susceptibility.

CONCLUSION: There is a need to enhance current understanding of how to objectively assess sport-related mTBI, determine when an athlete is recovered and ready to return to play, and if the initial forces resulting in mTBI can be used to understand differences in mTBI susceptibility and recovery. These prominent gaps within current mTBI literature present biomechanists with the opportunity to make impactful contributions to a high profile area of research.

REFERENCES

Baker, J. G., Leddy, J. J., Darling, S. R., Shucard, J., Makdissi, M., & Willer, B. S. (2016). Gender differences in recovery from sports-related concussion in adolescents. *Clin Pediatr (Phila), 55*(8), 771-775. doi:10.1177/0009922815606417

Belanger, H. G., Barwick, F. H., Kip, K. E., Kretzmer, T., & Vanderploeg, R. D. (2013). Postconcussive symptom complaints and potentially malleable positive predictors. *Clin Neuropsychol, 27*(3), 343-355. doi:10.1080/13854046.2013.774438

Broglio, S. P., & Puetz, T. W. (2008). The effect of sport concussion on neurocognitive function, self-report symptoms and postural control : a meta-analysis. *Sports Med, 38*(1), 53-67.

Cassidy, J. D., Carroll, L. J., Peloso, P. M., Borg, J., von Holst, H., Holm, L., . . . Injury, W. H. O. C. C. T. F. o. M. T. B. (2004). Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. *J Rehabil Med*(43 Suppl), 28-60.

Centres for Disease Prevention. (2014). Injury prevention & control: Traumatic brain injury. Retrieved from http://www.cdc.gov/traumaticbraininjury/

Dougan, B. K., Horswill, M. S., & Geffen, G. M. (2014). Athletes' age, sex, and years of education moderate the acute neuropsychological impact of sports-related concussion: a meta-analysis. *J Int Neuropsychol Soc, 20*(1), 64-80. doi:10.1017/S1355617712001464

Echemendia, R. J., Meeuwisse, W., McCrory, P., Davis, G. A., Putukian, M., Leddy, J., . . . Herring, S. (2017). The Sport Concussion Assessment Tool 5th Edition (SCAT5): Background and rationale. *Br J Sports Med, 51*(11), 848-850. doi:10.1136/bjsports-2017-097506

Farkas, O., Lifshitz, J., & Povlishock, J. T. (2006). Mechanoporation induced by diffuse traumatic brain injury: an irreversible or reversible response to injury? *J Neurosci, 26*(12), 3130-3140. doi:10.1523/JNEUROSCI.5119-05.2006

Giza, C. C., & Hovda, D. A. (2001). The neurometabolic cascade of concussion. *J Athl Train, 36*(3), 228-235.

Giza, C. C., & Hovda, D. A. (2014). The new neurometabolic cascade of concussion. *Neurosurgery, 75 Suppl 4*, S24-33. doi:10.1227/NEU.0000000000000505

Herring, S. A., Cantu, R. C., Guskiewicz, K. M., Putukian, M., Kibler, W. B., Bergfeld, J. A., . . . American College of Sports, M. (2011). Concussion (mild traumatic brain injury) and the team physician: a consensus statement--2011 update. *Med Sci Sports Exerc, 43*(12), 2412-2422. doi:10.1249/MSS.0b013e3182342e64

Kent, M. (Ed.) (2016) The Oxford Dictionary of Sports Science & Medicine (Third ed.). Online: Oxford University Press.

Leddy, J. J., Baker, J. G., Kozlowski, K., Bisson, L., & Willer, B. (2011). Reliability of a graded exercise test for assessing recovery from concussion. *Clin J Sport Med, 21*(2), 89-94. doi:10.1097/JSM.0b013e3181fdc721

Mainwaring, L., Ferdinand Pennock K.M., Mylabathula, S., Alavie, B.Z. (2018) Subconcussive head impacts in sport: A systematic review of the evidence. *Int J Psychophysiol, S0167-8760*(18), 30012-6. doi:https://doi.org/10.1016/j.ijpsycho.2018.01.007.

McCrea, M., Hammeke, T., Olsen, G., Leo, P., & Guskiewicz, K. (2004). Unreported concussion in high school football players: implications for prevention. *Clin J Sport Med, 14*(1), 13-17.

McCrory, P., Meeuwisse, W., Dvorak, J., Aubry, M., Bailes, J., Broglio, S., . . . Vos, P. E. (2017). Consensus statement on concussion in sport-the 5(th) international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med, 51*(11), 838-847. doi:10.1136/bjsports-2017-097699

McCrory, P., Meeuwisse, W. H., Aubry, M., Cantu, B., Dvorak, J., Echemendia, R. J., . . . Turner, M. (2013). Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med, 47*(5), 250-258. doi:10.1136/bjsports-2013-092313

Theadom, A., Parag, V., Dowell, T., McPherson, K., Starkey, N., Barker-Collo, S., . . . Group, B. R. (2016). Persistent problems 1 year after mild traumatic brain injury: a longitudinal population study in New Zealand. *Br J Gen Pract, 66*(642), e16-23. doi:10.3399/bjgp16X683161

Theadom, A., Starkey, N. J., Dowell, T., Hume, P. A., Kahan, M., McPherson, K., . . . Group, B. R. (2014). Sports-related brain injury in the general population: an epidemiological study. *J Sci Med Sport, 17*(6), 591-596. doi:10.1016/j.jsams.2014.02.001

Acknowledgements: Thanks are given for the AUT Vice Chancellors' PhD scholarship.