Eye Movement Analysis

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Current state of concussion in sport globally and internationally

It is estimated that there are 42 million concussions world-wide[1] every year and these are reported. In the US alone over an 8 year period over 320, 000 US service personnel screened positive for a concussion[2] and it is estimated that 3.8 million sports related concussions each year[3]. This figure is very likely an extreme underestimate due to lack of reporting or lack of presentation by sufferers to doctors or emergency departments. A concussion or closed head injury (CHI) regardless of its severity is a Traumatic Brain Injury (TBI) and the emerging public awareness of concussion in sport is a rapidly growing health concern.

A sports related concussion typically follows from a direct or indirect blow to the head while after contact the individual remains in an awakened state and thus are often classified as mild or mild TBIs. Nonetheless, concussion in sport is not a benign occurrence and concussed patients suffer from a range of symptoms including headaches, fatigue, irritability, light sensitivities, confusion, and difficulties in sleep, memory & speech[4].

The challenge in sports related concussions is that the signs and symptoms can be subtle and transient and even CT scans of mTBI patients often present as normal. Yet these subtle implications significantly increase the vulnerability of further injury to a highly likely outcome. Figures show that concussed individuals are 3 times more likely to experience another concussion in the same athletic season[10]. What is more alarming is that the force of head impact to cause a subsequent concussion in is often much less than the force required to result in an concussion for someone who has never been concussed[11,12].

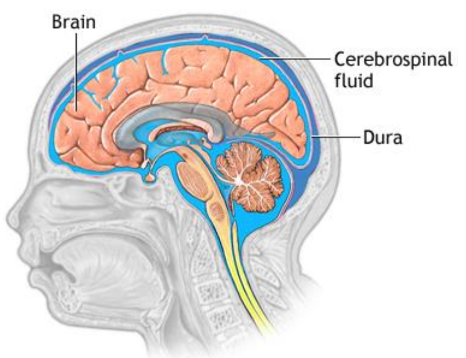
Following a mTBI up to 20%–30% of patients may also go to develop post-concussion syndrome (PCS). PCS is present when there is incomplete recovery and persistence of post-concussional symptoms that continues to be debilitating for the patient. Akin to the concussional symptoms, PCS symptoms include ***somatic*** (e.g. headaches, dizziness), ***cognitive*** (e.g. poor concentration, memory planning) and ***behavioural/emotional*** (e.g. irritability, mood swings) symptoms, the composition of which can differ between individuals [7, 8, 9,18].

Assessing and treatment for the impact of head trauma is of top priority across all sport related codes. Within the literature, there is much disparity on the accuracy, reliability and sensitivity of the existing measures of concussion particularly with reference to the long-term more subtle changes in the cognitive functioning of athletes following concussion. Several studies have indicated no association in the self-report measures of concussion history and computerised neuropsychological tests[15]. Every developing country around the world is experiencing a rapid pressure in their health care systems; access to services is becoming more difficult due to waitlists and cost. Further in the face of rising participation in sport and exercise globally the incidence of head related injury is only going to rise.

With the growing evidence for the potential insensitivity of existing assessments of concussion implications, there is a new paradigm emerging in the literature surrounding objective visual biomarkers present in concussion[16]. What follows is a brief overview for the opportunity for visual – motor assessment tools as a valid, reliable screening tool that is emerging as an accepted as a highly objective, robust and accurate measurement tool. Existing measures are also mentioned in short prior.

Current Assessment & Treatment of Concussion

The brain in normal conditions is surrounded by a tough fibrous 'casing' called ***the dura*** that allows it to be suspended or 'floating' in a liquid called the ***cerebrospinal fluid*** . It is well understood that following blunt force trauma to the head, the brain 'sloshes' in the direction towards the location of impact and then essentially 'bounces' off the interior of the skull and either returns back to its normal position or has a subsequent 'rebound bounce' off the opposite side of the skull before returning to normal. Clearly, it is this shear force and impact against the skull that causes damage across the brain. To fully appreciate the full damage caused as a result of concussion there are several exams that are performed such as the Glasgow Coma Scale (GCS), the Sport Concussion Assessment Tool (SCAT), the King – Devick (KDT) and many other symptom checklists. More in depth, longer to administer, more costly examinations that require highly trained specialist that are often ordered to obtain information on brain trauma include magnetic resonance imaging (MRI), computerised topography scans (CT-Scan) and positron emission technology scans (PET).



The GCS[14] provides a practical method for assessment of impairment following head trauma. The scale was first developed in the mid 1970's and has become a well-used tool in the assessment of observable visual, verbal & motor implications following head trauma. The scale provides a numerical assessment which for concussion is generally in the range or 13 – 15 and classified as a mild traumatic brain injury[15]. While used extensively, there are issues arising when two different individuals assess the same patient with a decrease in its reliability[20].

The **SCAT** is currently in its 3rd Edition is an internationally recognised assessment of concussion. The test can be used with athletes aged 13 years and older. There is a child version of the test for use with athletes below 13. It is designed to be used by medical professionals. The SCAT3 includes a battery of other tests as part of the overall assessment. These include a GCS score, a Maddocks score (orientation), a SAC score and a full range of symptoms. The challenge with some of these subtests is that it is noteworthy that standard orientation questions have been shown to be unreliable in the sporting situation[6].

King-Devick (K-D test) The K-D Test can be administered on the sidelines by coaches, parents,[1] athletic trainers or other medical professionals to subjects as young as 5 years old[21]. The K-D Test is based on the measurement of the speed of rapid number naming, i.e. reading aloud a series of single digit numbers from left to right and line to line. K-D Test purports to detect impairments of eye movements, attention, language, and other correlates of suboptimal brain function[22]. The K-D Test was initially developed for the evaluation of reading related eye movements[23].

When a head injury occurs sometimes, patients are referred for brain imaging (i.e. MRI, CT, PET etc). However, the existence of brain injury from mild head injury is often beneath the measurement capability of conventional CT or MRI scans. On the other hand, more the advances in brain imaging techniques, such as functional MRI, diffusion tensor imaging, MR spectroscopy are much more promising at detecting functional, structural or perfusion changes in the brain. The downside again of these techniques is that they are costly and not routinely available in a clinical setting.

The majority of symptoms typically resolve in 7 – 10 days where there is a minimum of 24 hours without any symptoms at which time the patient may return to cognitive and physical activity[5, 6]. Nonetheless there is a reasonably large proportion (30%) of sufferers where symptoms persist post-concussion and meet the diagnosis of post-concussion syndrome. Unfortunately, despite the utility of the existing scales such as the GCS, SCAT3 or KD, they are unable to predict the development of ongoing symptoms [25, 26]. Likewise, biochemical markers have failed to produce positive outcomes for symptom identification with any specificity or sensitivity24 and neuropsychological assessment due to factors negatively affecting the testing outcomes such as intelligence, age, socio – economic status remain unsatisfactory [25-30]. Even if a return to play is cleared in the absence of symptoms, the evidence indicates that a history of concussion increases up to a factor of 6 for the likelihood of another concussion [31-33] and athletes who suffer multiple concussions ***have a 5 fold*** prevalence of mild cognitive impairment a conversion rate of 10-20% annually into dementia as those without a concussion[34]. These findings are pointing towards potential structural damage occurring deeper within the brain as a result of brain impact.

A 2007 study by Viano et al. indicated that following the impact to the head that would result in concussion the resulting damage is not within the higher locations of the brain, that is the cortex, rather in the deeper core structures particularly the brain stem. It is the brain stem that provides the main motor and sensory innervation to the face, next etc via the cranial nerves. While this study was primarily identifying structural implications and not functional implications, it is well established in the scientific literature that structural damage in brain tissue corresponds with functional implications. Due the disparity in the evidence of existing neurocognitive test batteries, neuro imaging being incapable of identifying the more subtle changes associated with mTBI academics have been working to establish methods of assessing more precisely the implications of mTBI. These findings have identified that oculomotor assessment following mTBI is a valid and reliable tool for initial assessment and ongoing tracking of mTBI.

From horse to motor car – oculomotor assessment in mTBI/ Concussion – an eye tracking application

Oculomotor assessment is the examination of eye movements during very specific patterns. Formal eye tracking was first developed in 1950s to better follow the eye movements more precisely. Research not long followed through the 1960's to track the movement of the eyes. The eyes have been of interest to scientists and researchers from all fields, including physiology, neuroscience, neurology, ophthalmology and several branches of psychology such as cognitive psychology, clinical psychology, sport psychology and experimental psychology. Reviews by Rayner (1978 and 1998) discuss the varying uses of eye tracking technology and studies conducted.

With the rapid advancement of technology the bridge between theory and practice has been built. The academic literature on eye tracking and assessment of brain function is growing rapidly. The commercialisation of these findings is not. Many of the required assessments of eye movements and the related cognitive/ neurological activities are established in peer reviewed respectable journals (see table 1, page 4) . The opportunity to commercialise these findings into valuable useful tools in several different areas is very attractive.

Research Paradigms for Assessing Higher Cognitive Functions while Testing Saccades and Smooth Pursuit

Eye Movement Type	Higher Cognitive Function Tested	Paradigms Involving Eye Movements	How the Research Paradigms are Performed
Saccades	Attention	Gap Saccade Test	Subject fixates on one target which then extinguishes and the subject orients to a peripheral target after a variable period
		Visually Cued Saccades	Subject fixates on a central target and then a cue indicates the possible location of an upcoming target, then a congruent or incongruent target to the cue appears and saccades generated
	Executive Function	Antisaccades	Subject is asked to look away from the target presented
		Memory-guided Saccades	Subject focuses on a central target and then a peripheral target briefly appears; after a variable delay the subject is asked to fixate by memory on where the peripheral target was located
	Memory	Memory-guided Sequences	The subject is presented with targets on a screen and then asked to memorize the sequence in which they are illuminated, and then on cue, they are to make saccades in the memorized order
Smooth Pursuit	Memory	Smooth pursuit of a predictive target	Subject tracks an object on a known trajectory, for example, a circle, and the object may at times be transiently extinguished on its course
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Table 1) Cognitive Function Tests with various eye movements.

The current leaders in eye tracking technology are SR Research (Canada), Tobii (Sweden) and SensoMotoric Instruments (Germany). Each of these companies has pushed each other in the development of technology hardware and software with greater reliability, validity and accessibility of eye tracking data collection – likewise the power in computer processing has made rapid eye image and gaze vector processing a realistic option for non – specialists as the products and services become available.

Further the wireless and cloud based computing networks globally available allow for large databases of information to be stored, analysed at rapid speeds and accessed pretty much anywhere on the planet. No longer is hardware, software or location at barrier to use.

Future Directions

7 out 12 of the cranial nerves (II – Optic, III – Oculomotor, IV - Trochlear, V – Trigeminal, VI – Abducens, VII – Facial, VIII – Vestibulocochlear) are involved in the vision or the eyes. The eyes are a window to the inner workings for the brain and can provide an enormous amount of information regarding the state of neurological functions. While the focus in the this paper has been primarily focussed on the implications for blunt force trauma to the head; concussion or mTBI – uncoordinated or irregular eye movements will likely provide further diagnostic and treatment monitoring opportunities across several neuro-degenerative diseases. These include diseases such as Huntington, Alzheimer, and Parkinson. Further, research is suggesting that eye movement irregularities are also present in certain mental health conditions such as depression therefore assessment can likely be extended into this space. Finally, using eye movement training as a rehabilitative process is showing promise in for varying conditions such as stroke but could also then extend into other conditions such as the mental health conditions; thus moving from assessment to treatment is a natural progression.

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