ICSC01 Head Injuries
Section 1 – Sports Concussion
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Video Lesson: 21:12

My name is Brett Jarosz. I am a practicing sports chiropractor in Melbourne, Australia. Also have a role as a casual academic at RMIT University in the discipline of chiropractic. I am a member of the FICS Education Commission, as well as being part of the leadership team for functional neuro orthopedic rehabilitation, as well as doing some lecturing for the Carrick Institute of Clinical Neuroscience and Rehabilitation.

Today's little presentation we are going to do here is on the topic of sports concussion. We are going to have a quick little overview, and I want to emphasize that word **"overview"** here. **This topic is a very large topic that the information continues to grow at an almost exponential rate.** What we want to try and do here today is do a quick bias towards some of the neuropathology in the concussive injury, as well as some of the assessments that we can do clinically, and we are going to bias that towards the vestibular and ocular mode of screening. Without further ado, let us move into some of these details.

You may be familiar with looking at that concept of coup and contrecoup type of injury. But one of the things we want to just look at here today is when we look at the nervous system and what is involved with a concussive mechanism, so if we look at just the details here, there is different types of head motions that can occur with concussion. If we think about the fact the skull is on the neck with seven vertebrae, and the fact that those vertebrae can move in all those various degrees of freedom, we have rotation that can occur, we have lateral bending that can occur, flexion, extension, etc. When we look at the actual concussive mechanism, there is two broad categories of forces. There is the contact and the inertial forces that can occur during the

concussions, and the primary cause of concussive injuries is the inertial acceleration loading experienced by the brain. I almost wanted to say think of more of it the brain and the brain stem, and if we just use those topics of nervous system rather than just saying the brain. Because we do have a picture of the brain hitting inside the skull. But what we want to start looking at now with the research that we are seeing is not only just the brain hitting inside the skull, but more of the rotation and the shearing forces that are occurring, in particular through the midline structures of the nervous system.

Now you saw that word there before, "acceleration." and so if you also think of like an acceleration/deceleration injury, we often think of the word "whiplash." That is occurring to the cervical spine, that whiplash mechanism. But we can also think of an acceleration/deceleration injury to the nervous system, and we can relate that to be a concussive type of injury. We have an acceleration/deceleration injury to the neck, to the orthopedic structures of the neck, that we start to consider as a whiplash type of injury, and we also have that acceleration/deceleration injury that can occur to the nervous system. We can relate that as a concussive type of injury.

There is a linear and a rotational acceleration that occurs with every concussion, and the brain tissue deforms more readily in response to the shear forces compared to other biological tissue. What is very unique, if you ever get a chance to get a brain that has not been embalmed, just in a cadaver, and we get a brain, that brain will adapt and change to its environment. The shape of the brain that we all have in our mind is because of the shape of the skull. But if you put a brain in a flat dish or a ball, that brain within minutes will start to adapt to the shape of that ball. The brain tissue can undergo those types of responses very, very quickly and the shear responses that can occur to the nervous system through that concussive mechanism.

I want you to picture a piece of towel. And you wet that towel, and then you are going to wring the towel out, and you are going to try and get the water out of the towel. When you think of where that water comes out of the towel, it comes out from the middle of the towel, and I want you to have that picture of the midline areas of the brain. I have got a couple of slides coming up soon to show that pathway that is involved in these concussive mechanisms.

What is important to remember in this acceleration injury to the nervous system is if you were able to constrain the head motion so that the skull and the head did not rotate, it is difficult to produce traumatic unconsciousness. That is very important. Whereas if you allow the head and the skull to rotate on the neck, that substantially increases the likelihood of an unconscious episode. These key things here that we wanted to think about is the fact that the neck allows our skull and our head to rotate is one of these key things that is involved in how people can get those concussive unconscious episodes, where we can lose that consciousness transiently or for even a few minutes, and in severe cases, obviously, for longer periods of time.

If we look here now at that neuropathology and the neurobiology of a traumatic brain injury or concussion, there is two main categories. There is the focal damage and the diffuse injury. When we look at focal injury, start to think about the idea of maybe having a direct contact to the head. So if we think of combat sports where we are getting knees and fists and elbows, etc, colliding with the skull, I could have a focal injury there, where I have a fracture or I cut the scalp or the face, or of course, I could have direct bleeding underneath that focal injury there, and we want to just picture that focal injury as more of that direct severe impact onto the brain, onto the skull.

Whereas we think of a diffuse injury, we want to think of the diffuse injury, and you look at that picture there with the skull showing that sort of rotation. We can see that rotation through the midline, and we want to think about the axons there. We want to look at the fact we have got our cell bodies, and then we have got our axons, and those axons, we can remember, think of the corticospinal pathway, we have got a pathway going from the cortex, that motor strip, all the way down the spinal cord. If this is, say as an example, going to go to dorsiflexion of your ankle, think about how long that axon is going from the cortex all the way down to L4, L5 in the spinal cord. Long, long axon.

So diffuse injuries caused by stretching and tearing of the brain tissue and we do not need a focal injury for that, so we do not need the skull fracture or the direct impact to cause that service. It is that shearing, that rotation injury, and this is seen in the cases of mild traumatic brain injury or concussion. The main form of diffuse injury is called diffuse axonal injury, and again, that is due to that acceleration/deceleration force that leads to the shearing of the axons. So again, we use those words acceleration/deceleration, we think of the injury that is occurring to the neck. We have got the orthopedic injury to the cervical spine, but we have also got the shearing of these tissues through the nervous system because of that acceleration/deceleration injury. Then if we look at the pathway, the midline pathway here that we have been referencing, is this cortico-reticulospinal pathway. The pathway going from the cortex into the reticular system within that brain stem. So when we look at the cortico-reticular pathway, it is beginning primarily from the premotor cortex frontal lobe, and then it terminates in the pontomedullary reticular formation, so obviously the pons and the medulla, the mid and the lower aspects of the brain stem and that reticular formation. When we start to look at that cortico-reticular spinal pathway, that is involved in the control of muscles of the extremities and the axial muscles. I have got a slide coming up for you next to show you also a lot of the other things that the reticular systems involved with.

But this particular research here by Lee et al showed that injury of that pathway when people had had a concussion, mild traumatic brain injury, these patients showed proximal weakness, so weakness of the shoulders and of the hips. When they did this particular study, they were indicating the importance of evaluating this cortico-reticular pathway. If we look at the image on the right of the slide there, we can see on the left that is showing a sort of the normal pathway. Whereas when we go to those three images on the right there, we can see thinning. Or we can see parts of the pathway being cut off, or we can see part of the pathways disappearing here. That pathway from the cortex to that reticular formation within the brain stem is one of these key pathways being involved in that concussion, those axons, that shearing due to that acceleration/deceleration injury.

If we look at the reticular formation, and you have a look at what structures are within that reticular formation and what those structures control, they control somatic motor control. We just talked about that, about how that cortico-reticular pathways involved primarily in these proximal muscles. The reticular formation in the brain stem's involved tone, balance, and posture, and, as I said, in particular those proximal muscles showed by that last bit of research.

But what is also important is your eye and ear signals to your cerebellum are also being involved with that reticular formation. The motor nuclei for your gaze centers, so the ability for you to move your eyes left, right, up and down, to track objects, to find objects in space with your eyes, those come from the reticular formation. Cardiovascular control, your autonomic nervous system centers, your vital centers, are based in there. Pain modulation, a lot of us are familiar with our opioid mediated analgesic system, our serotonergic descending pain in the inhibitory system, that comes from that reticular formation. There are other functions as well, such as sleep and consciousness. These things are also from that reticular formation. So, when we look at what is going on in there, this becomes important, because what we are going to look at here today is that assessment of those ocular motor and vestibular centers. But keeping in mind, some other key things that are also occurring in concussion is dysautonomia, or dysfunction of the autonomic nervous system. Issues with people's balance. Issues with people's necks. Issues with people's cognitive states. What we want to try and do when we think about concussion is we want to try and keep the neuroscience in mind when you are assessing sport-related concussion. I want you to keep in mind what is going on through that brain stem and that reticular formation, and understanding that balance, eye movements, autonomic nervous system. Start thinking about the symptoms that people are presenting with when they are talking about suffering a concussion, and start to think that back to the reticular formation in that brain stem and how those midline pathways are being sheared through that acceleration/deceleration mechanism.

If we then take a look at the **Berlin Consensus Statement that was published in May (2018)** this year in the British Journal of Sports Medicine by Paul McCrory et al, and what the concussion in sport group talked about is the 11 "Rs" in sport-related concussion management. Basically, you followed a logical flow to your management, which is

- Recognize the concussion,
- Remove the athlete from the field of play, R
- e-evaluate, or of course, just evaluate, the re- obviously follows in with the Rs. Rest where appropriate.
- Rehabilitation.
- Referring to appropriate practitioners, where appropriate for particular further assessments, or if it is outside of your knowledge base and skill.
- Then we have got the Recovery

- Returning to sport, Reconsider, Residual effects and sequelae, and Risk reduction.

What we want to look at here today is we just want to look at the third point, re-evaluate, and that re-evaluation, when we look at what the consensus statement showed is our examinations should encompass a comprehensive history and detailed neurological exam, a thorough assessment of mental status, cognitive functioning, sleep-wake disturbance, ocular function, vestibular function, gait, and balance. I just want to take that particular point there and recognize that you may not see athletes or a concussion on the field, or may not be there at the point of injury, and instead these athletes may be contacting you in your office as the first point of call following that injury.

When we look at that assessment, there is a lot in that concussion assessment. If we take a look at that neuropsychological assessment, that was previously described as the cornerstone. If we think of impact, injury, or mini mental status exams, and all these various forms of nerve psychological assessments, that should not be the sole basis of any management decisions. Should not be the sole basis of course about making a diagnosis of concussion. All athletes should have a clinical neurological assessment which includes your mental status and cognition, but should also include oculomotor function, gross sensorimotor, coordination, gait, vestibular function, and balance, as we alluded to on the previous slide.

What we just want to look at here now is a brief screening straight from the literature of how we can start to look at some vestibular function and ocular function in that assessment of concussion. If we take this clinical assessment, and we are going to use this work here by Mucha et al from 2014, a Vestibular Ocular Motor Screening for Concussion. Now what this assessment involves is getting the baseline symptoms of your patient, recording what their headache is out of 10, with 10 being severe and 0 being no symptoms. We are going to do headache, dizziness, nausea, and fogginess. We are just going to ask the patient about those symptoms, if they have got them, and to rate them out of 10.

Then what we are going to do is we are going to perform these particular tests. Smooth Pursuits, Saccades, Convergence, or accommodation, the Vestibular Ocular Reflex, and a Visual Motion Sensitivity Test, also sometimes referred to info from a laboratory testing is called SHIMP, or Suppression Head Impulse Procedure. When we look at the VOMS assessment, that Vestibular Ocular Motor Screening, here is a chart that we can enter. We are going to record headache, dizziness, nausea and fogginess symptoms on a 0 to 10 scale prior to performing the tests, and then what you will do is you will perform the tests and ask them, "how is your headache, dizziness, nausea, or fogginess out of 10" after you perform each of the tests, and we can record that in this particular table here.

Let us start by looking at the smooth pursuits part of this test. What we do is we have the patient sitting in front of us, and the practitioner can hold a finger or a pen or a target that that patient's going to focus their eyes on. We are going to have that target approximately three feet away from the patient, or basically having the patient have their arm up in front, and you are going to be at least arm's distance away from the patient. Then you as the examiner are going to slowly move that target, whether it is your finger, whether it is a pen. You are going to move it smoothly left to right, in a range of about 1 and 1/2 feet to the right and 1 and 1/2 feet to the left of the midline. And that target is going to basically move. It is going to take you a second to get from the midline to the right, and then a second to get back to the middle, and then another second to get to the left. It should take you two seconds to get from right all the way across to left. What you will do is you will get two repetitions. You are going to go to the right, to the left, to the right, to the left, and then you will do the same thing vertically. You will go up, down, up, down. As you do those movements, you as the practitioner are watching the patient's eyes to see if they have any jerky eye movements. The eyes should be following your fingers smoothly. If you see any jerky eye movements, saccadic eye movements, or, of course, if you see a blatant palsy, where you do not see the eye abduct or adduct or elevate or depress, we make that observation. Then we, of course, record any symptoms-- out of 10, headache, dizziness, nausea, and fogginess. I have got horizontal pursuits, and I have got vertical pursuits. Two seconds to move horizontally left to right, two seconds to move vertically up and down, with two repetitions.

After I have recorded my findings and my symptoms from the pursuits, I then move on to the saccades. Same principle. I have got my targets, which can be my thumbs, could be my fingers. And I set those up at least arm's distance away from the patients, or about three feet. I set my two targets about 1 and 1/2 foot to the right, 1 and 1/2 feet to the left of the midline. If we look at the picture there on the top right, we can see that 1 and 1/2 to the right and to the left, 1 and 1/2 feet to the right and to the left, and then what we are going to do is ask the patient to look from one finger to the other, so from one target to the other, as quick as possible. They do 10 repetitions. Again, at the end of the 10 repetitions, you are recording any headache, dizziness, nausea, and fogginess symptoms out of 10 - 0 being no symptoms to 10 being severe.

When they are doing the saccade test, you are observing to see are they accurate. Do their eyes look directly to the target? Do they look directly to your finger? Or do they stop short? Or do they overshoot, and then come back to your finger? We are also looking to see are there more than two movements to get to your fingers. If they were looking to the right, can they look to your finger in one movement accurately? Or do they take three movements to get to your finger? We want to look for any of those abnormalities in their eye movements. Once again, do both eyes move conjugately? So does the right and the left eye move together? Or is one eye moving delayed? Or is one eye moving and the other one not? We want to observe for those gross palsies, disconjugate movements, as well as those saccadic errors.

Recording the symptoms again after the test. So again, 10 repetitions looking left and right. We then would move our fingers so that they are in a vertical plane, again, 1 and 1/2 feet above the midline, 1 and 1/2 foot below the midline, and, again, we ask the patient to look up and down, 10 repetitions as quickly as possible. Record the symptoms of the headache, dizziness, nausea, and fogginess at the end of the test, and again, observing the patient's eyes for any of those gross disconjugate movements or saccadic errors overshooting.

We can then move on to the next test, the near-point convergence, or also you might remember it as accommodation. But what we are looking at here is the ability for both eyes to converge. We are going to have the patient have a small target. We could use, say, a bit of a stick, and we could put a dot on the end of the stick, or again a pen, or a stick with a little ball on the end of it. We can then ask the patient to bring that stick in towards the tip of their nose nice and slow.

You ask the patient to stop moving that stick, that target, when they see two distinct images, so when they get double vision or when you as a practitioner observe the fact that both of their eyes are no longer converging. We see both eyes slowly coming in together. They are coming in together, and then all of a sudden, one eye deviates out. When you observe that, you get them to stop the stick. That should be at the time when the patient also would start to see double. The patient may see double before that, whichever occurs first, they stop the movement. And then you measure the distance from the tip of the nose to that target. If you look at the picture on the right, we can see the far-right picture showing the measurement from the tip of the nose to that target. Repeat that test three times. Again, at the end of those three performances of those tests ask for the symptoms of headache, dizziness, nausea, and fogginess out of 10. Record those symptoms. But you as a practitioner with your measurements are looking to see can the eyes, of course, converge, and then another thing that you are looking for is on your measurements, are the eyes able to get to 6 centimeters or closer to the tip of the nose? An inability to get closer than 6 centimeters is considered an error with this test.

So again, we are looking for convergence. Seeing double vision or seeing one eye diverge. Record that distance from the tip of the nose to the target, and we are, again, looking for a greater than 6-centimeter distance being considered an error. Recording as symptoms as per all of our VOMS-- Vestibular, Ocular, Motor, Screening-- tests. We record those symptoms out of 10.

The next test in the VOMS is the VOR. With this particular VOR test, what the patient is going to do is they will be looking at a target that is positioned in front of them, again, three feet away or at least arm's distance away, and we are going to ask the patient to move their head right and left. What they are going to do is they are going to have a metronome set up, and the metronome will be set to 180 beats per minute. So that way the patient is going to time the movement of their head in time to the beat. When they hear the beat, they should be to the left. When they hear the next beat, they should be to the right.

At 180 beats per minute, they are going to be moving their head at about a range of 20 degrees. Left, right, left, right, at 180 beats a minute, keeping their eyes on the target in front of them. They are going to do 10 repetitions left and right. Once again, at the end of that test, you are going to record. We are going to ask and then record any symptoms, headache, dizziness, nausea, and fogginess out of 10 again. Record those symptoms.

As the practitioner, while they are doing the test, you are going to be observing their eyes. Can the patient maintain their eyes being fixed on the target throughout the test? If you see that their eyes are losing fixation from the target, what you want to do is see if you can note is it one side that they keep losing fixation. Is it if they turn their head to the right, do they lose fixation? Or if they turn their head to the left, do they lose fixation? Or is it both? See if you can observe for that. After you have done the horizontal VOR testing, you then do it vertical. You are going to get them to nod their head up and down. Same again, 180 beats per minute. 10 repetitions. You are going to observe the eyes to see if they can maintain fixation, and you are going to again record headache, dizziness, nauseousness, fogginess symptoms at the end of each test.

The final test is the visual motion sensitivity test, and what the patient will do here is they will stand with their feet shoulder width apart. You will try to have the patient positioned so that there is movement around them. If you are in a private room, a consultation room, maybe you have it where there is books or a bookshelf or computer screen or things that are in the background to make it a little bit busy in the visual area. You do not want a plain white wall as a background. You want things to be in the patient's background.

The patient will extend their thumb out in front of them. I like to put both hands out in front and overlap the thumbs. The patients are going to stare at their thumbs, and then what they are going to do is they are going to rotate from their ankles. They are going to move their head, their body, their legs together as a whole unit. Imagine the whole body is a log locked together. They are going to rotate at a range of 80 degrees to the right and to the left, and their eyes are staying fixed on their thumb the whole time. This time the metronome is set to 50 beats per minute to maintain the speed. They get to the right, they get to the left, they get to the right, they get to the left in time with the beats, so again, one beat in each direction, and with this one, they perform five repetitions. At the end of this test, you are recording symptoms again of headache, dizziness, nauseousness, and fogginess out of 10. For those that have further training in this area, and they want to go further into this, we can also then look at this test to look at the ability for the eyes to remain fixed on that thumb, and we want to look and see how much movement occurs from the eyes from the thumb, if any. With this test, when we look at the literature, we are just recording symptoms. But if we look at some of the other literature with this test in laboratory settings, we could also look at the ability for the eyes to maintain gaze fixation. But the key thing again at the end of this test is recording the symptoms of headache, dizziness, nauseousness, and fogginess, if there is any, from 0 to 10.

When we look at this VOMS assessment, it is designed for the use in patients age 9 to 40. If we have got someone outside of that age range, the interpretation of these tests can vary. What is important with this

VOM screening is that any abnormal findings or provocation of their symptoms-- so if we do any of these tests and the headache worsens, or the dizziness worsens, or their fogginess or nauseousness worsens, this may indicate dysfunction, and that dysfunction should trigger a referral to the appropriate health care professional for more detailed assessment and management.

Now some of you may have further training in that world of clinical neuroscience and rehabilitation, or vestibular rehabilitation. If not, this is where that relationship's set up with a practitioner who has got further training in this field, whether it is ENT, whether it is audiologist, whether it is a chiropractor with further training in clinical neuroscience and rehabilitation, a physical therapist with further training in rehabilitation. Getting this patient to the appropriate person for further assessment and management.

But on top of the VOMS testing, there is also a couple more clinical assessments that we can do at the bedside. The antisaccade test is one. This can be done computerized, but it can also just be done via fingers. Very similar to the saccade test that you did in the VOMS screening. We set, again, the patient up at least arm's distance away, so about three feet away. We have the target set up about 1 and 1/2 feet to the right of midline, 1 and 1/2 feet to the left of midline. And then you as a practitioner wiggle your finger. With this test, the patient is instructed to look to the finger that does not move. When you wiggle the right finger, the patient is supposed to look to your left finger. What you want to do is make that test random. You might do two snaps of your right finger, then three of your left, then one on your right, one on the left, and you make it completely random. And what you are looking for is any errors that are made. If you wiggle your right finger and they look to the right, you make a note of that error. When we look at that particular test, two sets of 10 random finger snaps, and we get an average of the errors made.

When we look at some of the research that is been done in a computerized laboratory and standardized testing for this, so we have got eye measurements and we have got some very specific numbers. When we look at a concussive group that have suffered a concussion, the antisaccade tests we are seeing groups have between 15 to 18 errors out of the total of 20 snaps. You can see there is a lot of errors that are occurring in a concussion group. So out of your 20 snaps, we are seeing, and expecting to see, maybe up to 15 errors made in the concussion group. This antisaccade test can be another nice test to help in that assessment and diagnosis of ocular motor dysfunction in concussion.

The final test to add in here is the head impulse test, also referred to as the Halmagyi test, or the head thrust test. What we want to do with this particular test is you want to position yourself right in front of the patient. You going to grasp the patient's head on either side, so right hand on the patient's side of their head and your left hand on the patient's side of their head. You want to bring the patient's head into about 30 degrees of flexion. This is to try and make the horizontal canals of the vestibular system line up with the horizon.

Then what you want to do is just very slowly rotate the patient's head from side to side, telling the patient to keep their eyes fixed on your nose. We are going to rotate left and right slowly, just in the way the patients' neck muscles stay relaxed. Their eyes are staying on your nose, and then randomly and suddenly, you want to quickly turn the patient's head very rapidly about 10 degrees from the midline to the left or to the right, and you are observing the patient's eyes. If we look at the picture on the right of the slide again, the top sequence there is showing you what should happen. When you rapidly thrust that patient's head to the right, we should see that their eyes go to the left and maintain fixation on your nose. If we look at the bottom three pictures, we can see with that rapid thrust of the head to the right, the patient's eyes in the middle moved with the head, and then they had a corrective saccade to look back to your nose. That is considered an error. If we thrust someone's head to the right and they lose fixation, that would be considered hypofunctioning of the right vestibular system. Vice versa, if I turn the patient's head rapidly to the left and I saw the patient's eyes lose fixation of my nose and catch up, then that would be hypofunctioning of the left vestibular system.

When we look at the antisaccades and that head impulse test by Balaban et al, that work allowed that group to identify some oculomotor, vestibular, and reaction time characteristics of concussion, and to show that a small subset of the panel, so they did multiple oculomotor tests. They did saccades, and pursuits, and VOR, and a number of other tests, and you can look up the references for this test. But what they showed is that that small subset of tests that they did, which the three tests were saccades, antisaccades, and that Halmagyi, or the head impulse test, those three tests can be utilized to achieve a high specificity and sensitivity for the diagnosis of concussion. That objective, oculomotor, vestibular, reaction time, pattern can then be utilized to help confirm the diagnosis of concussion.

When we look at the research, and we look at a clinical assessment summary, in concussion we should be looking at our mental status and cognition. T**he SCAT5**, that is freely accessible from the **British Journal of Sports Medicine** that was developed through the **Berlin Consensus Statement, that SKAT5** gives you a complete overview of things you should be looking for in your assessment of concussion, the mental status and cognition. They will also be your balance testing in there, as well as symptom testing, as well as other forms of clinical assessment to be performed.

You have also got other mini mental status exams there, as well as depressive types of questionnaires that have all been shown in the literature to be reliable and valid within concussed patients. There is also the world of this autonomic dysregulation and looking and testing for autonomic dysfunction, and then what we have alluded to here today is that vestibular ocular assessment, so looking at the head impulse tests, looking at smooth pursuits, looking at your accommodation, saccades, antisaccades, as well as looking at that visual motion sensitivity. You can also see there is other tests such as gaze holding, dynamic visual acuity in there, as well as other tests such as balance, coordination, testing subpostural stability, tandem gait, as well as all of our neck testing.

So just in summary, what we want to look at here is when we think of assessing a concussion patient, we want to make sure that we are addressing all of these particular topics and assessing all of these particular fields, and if you do not have the skills and the training in this field, we want to make sure that we are part of a team that can allow the appropriate assessment and diagnosis to take place in all of these various fields.

But three very key important areas that have come from the Berlin Consensus Statement are the fields of dysautonomia; or the autonomic dysregulation; vestibular ocular rehabilitation; and cervical spine rehabilitation.

These are three key areas within the world of concussion that we can form part of that multi- disciplinary management team to apply the appropriate patient-centered care and work as part of that team for the patient to get best outcomes.

I hope today has been able to allow you to have a little bit of a different insight into some of the nervous system involvement in the injury, as well as some of those reticular areas, those vestibular, oculomotor areas, that can be involved in a concussive injury, and how we can assess it clinically at the bedside, how to record that, and then from that, that can start formulating our management strategies or the appropriate referral strategies.

Here are some slides of references for you for some further reading on today's presentation, and I hope that has helped you in the clinical assessment of concussion. Any questions, please feel free to make contact.

References:

- Balaban C, Hoffer ME, Szczupak M, Snapp H, Crawford J, Murphy S, et al. Oculomotor, Vestibular, and Reaction Time Tests in Mild Traumatic Brain Injury. Janigro D, editor. PLoS ONE. 2016 Sep 21;11(9):e0162168.
- Blennow K, Hardy J, Zetterberg H. The Neuropathology and Neurobiology of Traumatic Brain Injury. Neuron. Elsevier Inc; 2012 Dec 6;76(5):886–99.
- Brandt T, Strupp M. General vestibular testing. Clin Neurophysiol. 2005;116:406- 426.
- Casa Della E, Affolter Helbling J, Meichtry A, Luomajoki H, Kool J. Head-Eye movement control tests in patients with chronic neck pain; Inter-observer reliability and discriminative validity. BMC Musculoskelet Disord. 2014;15(1):16.
- Ellis MJ, Cordingley D, Vis S, Reimer K, Leiter J, Russell K. Vestibulo-ocular dysfunction in pediatric sports-related concussion. J Neurosurg Pediatr. 2015 Jun 2;:1–8.
- Hellmuth J, Mirsky J, Heuer HW, Matlin A, Jafari A, Garbutt S, et al. Multicenter validation of a bedside antisaccade task as a measure of executive function. Neurology. 2012 Jun 5;78(23):1824–31.
- Hides JA, Franettovich Smith MM, Mendis MD, Treleaven J, Rotstein AH, Sexton CT, et al. Self-reported Concussion History and Sensorimotor Tests Predict Head/Neck Injuries. Med Sci Sports Exerc. 2017 Jul 13;:1.
- Jorns-Haderli M, Straumann D, Palla A. Accuracy of the bedside head impulse test in detecting vestibular hypofunction. J Neurol Neurosurg Psychiatr. 2007 Oct 1;78(10):1113-8.
- Khan R, Conklin H, Jason A, Russell K, Sadighi Z, Merchant T. Associations Among Rapid Bedside Anti-Saccade Assessment and Cognitive Function in Children with Craniopharyngioma. Neurology. 2016; 86(16)SP6:212
- Lee HD, Jang SH. Injury of the corticoreticular pathway in patients with mild traumatic brain injury: A diffusion tensor tractography study. Brain Inj. 2015 Jul 23;:1-4.
- McCrory P, Meeuwisse W, Dvorak J, Aubry M, Bailes J, Broglio S, et al. Consensus statement on concussion in sport-the 5th international conference on concussion in sport held in Berlin, October 2016. Br J Sports Med. 2017 Apr 26;0:1-10.
- Meaney DF, Smith DH. Biomechanics of concussion. Clinics in Sports Medicine. 2011 Jan;30(1):19- 31-vii.
- Mucha A, Collins MW, Elbin RJ, Furman JM, Troutman-Enseki C, DeWolf RM, et al. A Brief Vestibular/Ocular Motor Screening (VOMS) assessment to evaluate concussions: preliminary findings. The American Journal of Sports Medicine. 2014 Oct;42(10):2479-86.
- Sealy A. Vestibular assessment: a practical approach. Occupational Medicine. 2014 Feb. 20;64(2):78-86.