Vestibular Function in Patients with Traumatic Brain Injury, presented in partnership with Vanderbilt University

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It's my pleasure to welcome back Dr. Daniel Romero. This course is in partnership with Vanderbilt University. Each year we produce two courses in partnership with Vanderbilt. And we're so delighted to have Dr.

Romero back again presenting on vestibular topic at this time. I'll hand the mic over to you. Thank you, Christy. Well, thank you everyone who's joining in this morning. Um, I'm Daniel Romero.

I am an assistant professor at Vanderbilt University Medical Center. Just to give you a quick little background about my, about what I do from day to day. 50% of my time is patient care. So I do see patients in the clinic, 100% vestibular patients, but I do see patients two and a half days a week. And then I also do some research, vestibular research, as well as teaching courses in graduates.

So a little bit of everything. And, and so I'm very excited to be a part of this and talk to everyone about vestibular function in the context of traumatic brain injury. Just to talk about, you know, a little bit about many of us here. I mean, traumatic brain injury is a, is a big topic in and of itself. But just to talk about a little bit about what the current state of the literature suggests with regard to vestibular function, what are some challenges on the clinical end, but also on the research end that we face with this population as well as some future directions.

All right, so here are my presenter disclosures. I have a salary and then some non financial disclosures as well.

So with regards to learning outcomes, just three main high level points that we'll hit today. One, just discussing the impact of traumatic brain injury on not only the patients themselves, but also on vestibular function. And just talk about the heterogeneity of traumatic tbi. One common theme that you'll find throughout the day is that TBI is variable with regard to discrete test findings. Second, we'll talk about some key challenges in diagnosing and treating vestibular function in chronic TBI as well as just

discuss the role of cortical vestibular processing with respect to tbi.

And then just a quick overview again of the agenda. We're going to talk a little bit about the definitions, pathophysiology, some common myths, again, diagnosis, what are some clinical recommendations at this point, what are some other practices doing with respect to tbi? And then just future directions. And because we're talking about the brain here, it's important to note that we are going to bring in some cognitive aspects of self motion, just cognitive function in general, self motion perception More particularly so to kind of set up the stage for traumatic brain injury. It is a big topic and it can be diagnosed or undiagnosed.

And when it is diagnosed, it can sort of be classified in a couple of different ways. One, probably what you're most familiar with is concussion. When we talk about concussion, we're talking about more mild traumatic brain injury. Now mild is, doesn't necessarily mean it's mild symptoms. These patients certainly go through a variety of different impacts on their quality of life.

But you'll, you'll sometimes hear mild traumatic brain injury switched around with, with concussions specifically. And these are the most common that happen every year. And it's, it's generally defined by the CDC as a bump or blow, blow or jolt to the head that can happen to, from the brain, from the head and brain kind of moving quickly back and forth. And this sudden movement causes stretching and damaged, damaged nerves within the brain. Not only causes chemical changes, but also structural changes to the neuronal pathways.

Secondly, we'll talk about moderate to severe tbi. This is a TBI again caused by a bump, blow or jolt to the head by a penetrating injury. In the United States, severe TBIs actually are linked to thousands of deaths each year. Whether it's results result of falls, motor vehicle accidents, blast injuries, those types of things. And these can really lead to serious health problems, long term health problems and symptoms.

Now mild TBIs can certainly lead to those as well. And you're more likely to see that with, when there's repeated concussions back to back. So the more concussions that somebody sustains, the more likely there are to develop long term health problems. And these changes in the brain lead to symptoms that affect how a person thinks, learns, feels, acts and sleeps. And so there's certainly a lot of impacts on the patient.

Now the classification of TBI again can be mild, moderate and severe. There's several different ways that this is done. Most commonly is the Glasgow Coma scale. It's a 15 point scale that allows ER docs to diagnose a concussion at the degree of the concussion. But also we have to think about TBI in terms of how long this, in terms of the time course of the symptoms.

Certainly there are challenges and things to identify. The priorities do change with respect to whether or not we're managing and treating the patient immediately after the TBI after the brain injury or are these symptoms persisting. And so there's several different definitions out there. But you know, more likely than not you'll see things like acute TBI that's referring to these symptoms immediately after the brain injury or chronic TBI which are, which is associated with symptoms beyond three to six months post the brain injury.

And with respect to outcomes, moderate to severe tbi, more specifically five year outcomes in persons with TBI varied and you can see that there's a variety of recovery in these, in this patient population, patients, of course, like I mentioned earlier, unfortunately there are many patients who suffer moderate to severe TBIs that actually pass away from the injury. Beyond that many patients, 30% do become worse. We do see some improvement in some of this, some of this, some of these patients, but we also see patients that kind of plateau. And so there are a lot of patients out there within what we would call the chronic phase of the injury that are dealing with these symptoms. And so especially with respect to chronic traumatic brain injury, there aren't really a lot of things that help us predict how if somebody is

going to chronically deal with these symptoms in the long run.

And so certainly TBI as a whole is obviously a clinical population that has to be assessed and managed. So traumatic brain injuries are super common. Again, I touched on this a little bit earlier, but again they can have short and long term impacts. We patients experience about 42 million are diagnosed with a concussion worldwide every year to over 223,000 hospitalizations. And TBI does not necessarily affect one population.

You have sports concussions, you have individuals in the military, you also have older individuals. And so, for example, people over the age of 75 have the highest rates of TBI related hospitalizations and deaths.

There's also an economic impact, right? Especially for moderate to severe tbi. These are costly. These patients are getting long term care within the health care system. And so there are economic consequences, costing anywhere from about 81 million in direct health care costs and up to 2.3 billion in indirect health care costs.

Economic and applications for proper treatment are also estimated to be anywhere from about 11,000 per patient and a total societal cost of more than 3 billion. So certainly this is not only affecting the patient at a deep level, but this is also affecting the healthcare system.

And obviously a lot of reasons why somebody can sustain a brain injury. I mentioned a few of these, but assault. And so there isn't necessarily one population. Obviously there's, there's a lot of discussion with it with regard to sports related concussions and some of the brain injuries that the players sustain as well. So, you know, doesn't necessarily stick with that population.

It does go beyond and depending on the type of injury, there can be different Impacts or forces on the brain and that can manifest in different clinical ways. So on the left we do have an example of a deceleration injury where the brain strikes the inside of the skull and rebounds. And there can also be an injury at first or second impact site. And so the brain is obviously being moved within the skull and directly impacting opposite sides of the skull. The right shows a more of a rotational injury.

So you don't necessarily need a direct impact. And this is actually where a lot of patients who sustain concussions actually face. And so what happens here is that the brain does rotate on an axis, causing a stretching or shearing of these neuronal, neuronal axons, which again creates a chemical changes that are happening throughout the brain. And so overall, these forces do lead to a wave of energy that passes through the brain, triggering these neuronal failures and tearings.

We're going to just quickly brief on just a couple of high levels myths with regard to tbi. And so I did just kind of give this away. But a direct impact is necessary for the diagnosis of a mild TBI or concussion. And this is going to be false. Right, so we know that.

I just talked about the rotation of the brain, which can cause a concussion as well. So this movement can happen secondary to, to whatever that bump old jor jolt is.

Secondly, a concussion is technically classified as a mild brain and traumatic brain injury. Of course that's going to be true just due to the nature, due to symptom progression and the recovery prognosis.

And again, most common. And then the third, a loss of consciousness is required for a true diagnosis of TBI. And this is actually false. Okay, so more than 90% of concussions do not involve loss of consciousness.

So let's talk about some of the symptoms. So TBI can obviously result in numerous cognitive and physical symptoms. And dizziness is the second most reported symptom and most linked to protracted recovery, as noted by Gianna Lee and colleagues in 2022. And so you can see just right off the bat, there are a variety of different symptoms. Number one, first and foremost, the thing to remember is that TBI is a cognitive impairment.

Okay. You know, we look at things from a vestibular lens, obviously, but it's, it's, it's important to remember that this is, this is first and foremost a cognitive impairment with secondary effects. So patients have issues with memory, you know, cognitive functions are altered. And so right off the bat, what you can also notice is that dizziness and balance are right among the common symptoms that Patients will experience and dizziness. Imbalance in and of itself is obviously something that's pretty vague and can come from a lot of different places, especially just dizziness in general.

Right. Um, but right off the bat, you know that many of patients dealing with vestibular issues are going to report dizziness and imbalance. And so it's important to know even disorientation. So we know that, you know, vestibular problems related to the inner ear are going to result in some of these. And so certainly many of these symptoms could have a vestibular origin.

And as far as the assessment and management of traumatic brain injury, it is not just like with vestibular assessment. It isn't necessarily isolated to one singular field of study. You know, with respect to a vestibular patient or a dizzy patient, we know that multiple providers are going to be working with that patient. We provide our important objective testing. But patients are also going to see physical therapists, they're also going to see neurologists, ENTs, of course.

So there's, there's, there's going to be, it's a very multidisciplinary approach. And the same thing goes for, for tbi. There it is a team based evaluation consisting of neuropsychologists, neurologists, you know, there's imaging involved and there's also a pretty heavy weight on symptom evaluation, written,

computerized or even just verbal just by talking to the patient. And so there is not one test that really serves as a neurobiomarker for tbi. It's really done as a team to try to understand not only where that patient is immediately after the brain injury to service more or less like a baseline, but also how can we use these tests to kind of track recovery.

And so the general goals for vestibular assessment post TBI are going to be one evaluating the vestibular and ocular reflex pathways. Those are the unique things that we as audiologists can provide. And it shouldn't be surprising that sometimes patients can, or sometimes these reflex pathways can be disrupted. Obviously not in every patient. But you know, these RePet Flex pathways are extremely complex and they travel not only throughout the subcortical system or the brainstem, but they also go up to the cortex.

And there's also a lot of processing that's involved there. And so it's a very intricate reflex pathway that we get to evaluate every day. And not only just the vestibular pathways or the vor, but also ocular motor pathways. And so it's not surprising that in some Patients, these pathways can be disrupted. And I'm highlighting functional VOR balance measures because a lot of the current literature and even just clinical experience from a lot of clinicians that are out there working with TBI patients, patients really tend to, if they're going to break down, if we're going to identify something throughout our measures, more or less, it's going to be with these functional measures, whether it's functional VOR measures or balance related measures, rather than structural damage to these we flex pathways.

Again, we do see some of that and I'll show you all some of that, but just really want to kind of emphasize the functional VOR imbalance aspect of it.

And so overall, again, just identifying abnormalities to really try to help guide recommendations for therapy. Obviously if you do find disruptions or structural damage to these reflex pathways, doing that and again, you know, establishing baseline to measure and track recovery. You know, obviously if you

find somebody with an uncompensated impairment, certainly that can be used to try to than track recovery status with, in terms of vestibular compensation. And again, just like with anything else, you're always trying to rule out in or out otologic involvement. But clinical test recommendations, to be honest, do vary and this is likely due to the inherent variability of tbi.

It's important to remember, I think there is no one single protocol for a TBI patient. And we'll kind of get into why that is. But that's, that's one thing that I do want to emphasize is, you know, these, these injuries are happening in different locations, they're happening in different severity levels and there's different associated factors. And so certainly there isn't necessarily. And so the clinical recommendations and the clinical goals are going to change patient and it's going to also depend on what type of patient you're seeing.

Are you seeing an athlete? Are you seeing someone else? And so there's going to be variability there, but these are just some general things. And obviously we're, we're using this kind of the framework for other dizzy patients as well.

So there are some TB challenges obviously in the TBA and the diagnosis of tbi. I just mentioned this, but there is no one objective test to determine whether a TBI has, has occurred. Again, it's a multidisciplinary approach and there's multiple types and tools and evaluations that clinicians will use or have in their tool belt. And then again, no two TBIs are the same. There's different mechanisms of injury, different symptom profiles, clinical presentations, and then there's obviously kind of associated risk factors such as history of migraines, previous concussions.

And so there's these kind of pose challenges when we're trying to measure, measure a system and trying to identify specific breakdowns.

So we'll, let's dive into a little bit about what we do know about vestibular function after a brain injury. Now I mentioned this previously, but again, the complexity of the vestibular system and ocular motor pathways, highly complex. And the fact that the brain is being pushed around or jolted in this way can in some cases tear these pathways as well. And so, however, there's not a consensus about which part of the vestibular system is most affected. We know that it's, it's, it's a very complex system not only with, with the nerves, but also the end organs.

And so as far as there's not, there's not a whole lot of consensus as far as which part of the vestibular system is most affected. And these questions really are unclear in the literature. Again, which is most vulnerable, which tests are best to best evaluate this population, and what are some common vestibular test results. And so we'll get a little bit into the literature. There's been a ton of TBI related literature.

And so we'll kind of dive in and just talk about what we do know.

And so the traditional view is that TBI can affect multiple levels of the vestibular pathway. And starting with trauma, direct trauma to the inner ear and brainstem. Several studies in the past have shown that TBI is associated with damage to the otoliths themselves, resulting in changes there or just degenerative changes to the otoliths, as well as some speculating that the otoliths are perhaps more susceptible than the semicircular canals.

And like I mentioned earlier, there's a lot of different studies that have attempted to try to answer this question as far as what are the patterns that we may find on our vestibular function test results. There's been a ton of literature out there and a few of my colleagues and I, we started kind of doing, we wanted to do a systematic review to try to get this down. So this is still preliminary, but we wanted to see, given the vast number of cases out there and case reports, retrospective studies, sports related concussion studies, we wanted to see what does the literature show about, are there any patterns that we can pull away from this?

And so there are some patterns based on some of our early review of the literature, we've, we've shown that or we, we Were able to identify that many of these studies do identify some level of peripheral dysfunction pattern about 30% of the time. So clearly not something that's going to happen all day every day. But in, in those cases some general themes whether it's regard to skull based fractures leading to third windows blast injuries, again, otolith dysfunction, more comm. Abnormal that was, that's definitely a theme that we've, we've come across with regard to peripheral dysfunction, horizontal semicircular canal testing, while it tends to be the least impacted and with regard to sports related concussions with regard to mild tbi and I'll show some data a little later on, but we also are seeing that essentially in the more severe cases of moderate to severe tbi, central dysfunction pattern again shouldn't be surprising, but that's, that's a little bit less common actually with regard to central brainstem pathways about 13% of the time. And then these abnormalities tended to be more ocular motor abnormalities and sports related concussions.

So that's why you'll, you'll, you may here ocular motor testing being heavily involved in, because it's easy to do and there are some times where some of our ocular motor tests can be abnormal. V suppression has also been heavily reported within a central dysfunction pattern throughout the literature, but again not every patient. So again it's one thing to be recommend to be mindful of. But a lot of the time too, beyond just structural damage to these pathways, the occurrence of BPPV is quite high in this population as well. You know, especially with patients dealing with more acute symptoms.

I would say it's probably less common in patients with chronic long term issues. But with regard to which again should make sense. Right. So immediately after this, the brain injury, you know, that is, that is something that may be, that we may want to keep mindful, be mindful of with respect to testing for and mixed having both peripheral and central dysfunction patterns tends to be the fewest, the lowest rate of occurrence. And so again these are preliminary findings but you know, these are just some

things that we can pull from the literature right now.

Other studies again have shown more otolith abnormalities than semicircular canal abnormalities.

There's a couple of studies here that have looked at mild TBI cases and are consistently I think showing the same thing.

And the one thing I do want to point out here is by far with respect to the literature, the most common abnormality that research suggests, which is consistently impaired across patients with tbi, regardless of severity or mechanisms of injury, are functional Deficits, whether it's functional vor, but more likely actually functional balance measures.

SOT scores are most commonly abnormal and either composite based scores or condition based scores. Whether you're using for example condition 5 of the SOT or what have you. But regardless of whether you're looking at condition based or composite, most reports out there in the literature do suggest that functional balance measures tend to be abnormal. And you'll actually, most physical therapists actually do use functional balance measures with respect to their assessment and recovery process. And because it's, it tends to be the most affected in this population.

It's, it's a quite, it's, it's pretty valuable to use to not only establish a baseline but to try again, track recovery.

So kind of pulling it all together here, how is, how does the vestibular, how does TBI affect the vestibular system? Much of the literature, much of what we do now, you know, clinical evidence outside of experimental studies do vary widely. And as again, it's largely associated with the, just the heterogeneity of tbi. It's, it's a type of thing that doesn't necessarily result in the same pathophysiology every single time. You know, for example, I mean if we have somebody with neuritis, we know where

it's happening.

We know the general mechanism of injury, yes, we do know what generally is happening in the brain. But these injuries can vary person to person. But again, the most consistent finding is that patients do have difficulty maintaining balance, specifically during tasks that require a high use of vestibular input. And so despite a large proportion of these patients have having clinical enormous exams.

And so that's why I wanted to highlight those functional measures earlier in the talk.

And so again, challenges with respect to TBI related research.

The mechanism of injury severity and phase of the injury are not routinely controlled for in studies. In fact, the vast majority of studies that are out there are retrospective which are again are faced with their own challenges of validity, of internal validity. When you have different methodologies and not necessarily controlling for any of those, you can get variability in your, in your reports or in your findings. And so there's a lot of things that together I think contribute, introduce variability to something that is already inherently variable. And so there's, there's a need, I think for prospective studies because we know that TBI is variable.

So if we can do whatever we can to control the things that we can control, you know, that may help clear the field a little bit. And then lastly the, there's, you know, not a general consensus about which vestibular specific measures are being included in every study.

And so we've here at Vanderbilt, we've been trying to kind of dive into this work a little bit and we've been trying to kind of do more perspective stuff with traumatic brain injury, more specifically moderate to severe tbi. And so I've worked with some colleagues here who have done some amazing work when the TBI in the TBI world and we've tried to kind of plug in a vestibular arm into it. And so we wanted to

first just answer like what is, what are the self reported symptoms of vertigo imbalance in patients with chronic moderate to severe TBI? So we looked at 24 adults with chronic moderate to severe TBI. We defined chronic as being experiencing these symptoms at least there at every single patient that was included in this study was at least six months out from their injury.

And so we wanted to kind of look at these patients when, you know, when, after they were done, you know, whatever symptoms they were experiencing during the acute phase wanted those to resolve and what are the symptoms that they are experiencing more long term. And so we looked at 24 adults and all of these, most of these patients were also matched age, sex and education level to non injured comparison participants as well. And so we're trying to do one to one matching because we want to kind of take some other confounding variables out of it. And we just asked them a simple case history as far as symptoms that they were experiencing on a day to day basis. And there in the gray area you can see our TBI group mirrored to the, our, our NC group, our neurotypical comparisons, and by far you can see how much more symptoms these patients are experiencing.

And when I show you down the road how some of these patients were probably 15 to 20 years out from their injury. So you can see that many of these patients experience a variety of different things, things that obviously come to mind, right there are symptoms of vertigo or imbalance, falls, you know, difficulty with equilibrium, but also a pretty high prevalence of headaches and head pressure. And so there's a variety of different things that could be vestibular in origin, but again we don't really know until we test the system. We then followed up this study with another study where we looked at kind of evidence of peripheral vestibular impairment among adults with chronic moderate to severe TBI. We looked at, we recruited 30 patients with chronic moderate to severe TBI and we matched 1 to 1 to 30 neurotypical controls.

We conducted cervical and ocular vemp testing. We also looked at video head impulse testing to assess the function of the otolith organs and the horizontal semicircular canals, particularly at high frequencies. We didn't necessarily use caloric testing during this study. VHIT is typically much more tolerable in this population, but certainly that is something that we want to try to get a comprehensive look at down the road. And we want to again, just determine the prevalence of how these symptoms affect their quality of life, because it's one thing to report, but are these things actually affecting their quality of life?

And by far, we saw otolith issues in the TBI group. We didn't have a single case, I don't believe, of bilateral otolith impairment. Most, if not all, of the unilateral and many of these TBI patients also had significant amplitude asymmetry. So we're seeing some issues with the saccule there, which both was. These findings were definitely significant compared to the NC group.

But one thing that you can also see is that half of these patients had completely normal CVEPs.

And so, yeah, completely normal findings. And so looking at ovemps, we saw a similar trend, which was also significant. But again, most of these cases, unilateral cases, some were just completely, at most were absent. But, you know, we did have some that were asymmetric based on the cutoffs of our NC group.

But again, about half of the patients with chronic monitor severe TBI had completely normal ovamps.

If we take it, if we take a look at horizontal canal function, for the most part, it looks pretty good with respect to our clinical cutoffs there on the left, we have our NC group. The gain for our NC group compared to the gain for our TBI group. And you could see that really only one or two were below that line. Most of our TBI patients had normal horizontal canal function. I do want to point out an example from one of our participants on the right who had some low gain on the left lateral and borderline gain

on the right lateral.

But the saccade's organized, so that that tells you right there that there's some degree of compensation there that has occurred. And so finding uncompensated peripheral or peripheral impairments affecting the VOR is probably going to be unlikely in this population.

And so overall, we saw that probably 19 of our 30 participants had at least one peripheral impairment, most being otolith, which is consistent with the previous literature. Most, if not everyone, within our TBI group had normal left and right beheads. And so that that Kind of does suggest that the semicircular canals are maybe the most resilient following a brain injury with regard to structural integrity.

And many of these patients were dealing with issues that affecting their quality of life. So obviously, you know, more than 37% of our group TBI group reported dizziness handicaps and those range from mild, moderate to severe and a low to medium level balance confidence, meaning they didn't necessarily feel comfortable walking day to day, a lot did. But there was about 30% of them that reported low to medium balance confidence.

And many of these patients even dealing with some peripheral issues. If you take a look at this is, each row represents one of our participants. But this is just to give you a snapshot of something. Here we have our CVEMPs, OVEMPs and VHIT. And on the very right you can see how many months out they were from their brain injury.

And just to kind of let you all know, every single TBI patient here included in this study sustained a single injury. Okay. They were all diagnosed with moderate to severe TBI and they've all experienced a single injury. And that's how many months they were out of, out of their injury. And so you can see some of them were 20 years post injury while others may be, you know, more recent, more five years.

And so regardless, we should see if there are peripheral issues. We should see some level of compensation occur by that time.

So what else could be contributing here to these episodes? Obviously I pointed out earlier that a lot of these patients do also report headache and head pressure. So could there be a migraine type contribution here? Certainly that could be supported by some of the previous findings in the literature. And so absolutely we can't say for sure with this particular subgroup, but certainly that is something that could be in the differential.

One thing not discussed as often is what TBI does to the level or to the cortex. I talked earlier about the traditional view again is that TBI can affect multiple levels of the vestibular pathway from the inner air brainstem. And with respect to us, that's where we're, you know, designed to assess. But evidence also suggests that the that cortical regions and involved in the processing and integration of vestibular signals can also be affected.

And one of the reasons why that's important is because the higher level vestibular processing and integration is absolutely crucial for higher cognitive tasks such as self motion perception. The literature is pretty clear on that. It's also involved in our overall postural stability. The brain has to process vestibular signals coming from the periphery at a very high level and integrate that with somatosensory input, has to integrate it with visual input. And so there's a lot of complex processing that happens in the brain.

And one of the reasons why I bring this up is because here are these are a couple of studies that have looked at functional balance measures in patients with chronic tbi. And one of the things that they've shown is that 64% of patients with chronic TBI demonstrate an inability to use vestibular cues for balance. I mentioned earlier that it is a functional. These functional deficits are much more common in this population. But the not only looking at the overall composite score like you see on the left from

Ankit and colleagues in 2022, but also on the right looking at condition specific SOT scores.

And many of these patients are not only are not only performing more poorly on this testing, but also falling.

And one interesting thing to note here is that on the left we have ocular motor function, on the right we have vestibular function and we have SOT scores from the composite score all the way to the left to somatosensory scores all the way on the right. The yellow is abnormal ocular motor function and the blue is normal ocular motor function. And this is in a group of patients with chronic, chronic mild TBI. And so what Taylor and colleagues found in 2021 was that whether or not patients were had abnormal ocular motor function or normal ocular motor function, and on the flip side, whether or not they had normal vestibular function or abnormal vestibular function, they're still performing poorly on the vestibular condition of SOT, which would be SOT5. And so they're below the dotted line is going to be the clinical is the cutoff between normal and abnormal.

And you can see that I want to try to focus on the vestibular part of this. Whether or not they had normal vestibular function or abnormal, they were still kind of below that cutoff. And I think this goes to show that obviously balance in and of itself goes beyond just the brainstem or the integrity, the structural integrity of inner ear brainstem reflexes. And so what is happening at the cortical level that could be contributing to these findings? And in order to really understand that, we have to talk about vestibular cognition and its role on postural stability.

So there are several cognitive functions that rely on the use of vestibular input arriving from the peripheral system. These not only include, these include not only memory functions, so, but also Functions that deal with self motion perception and postural stability. So the brain is obviously very complex, but what it does is it takes this information coming from the vestibular system, goes beyond the brainstem, uses it for subcortical reflexes, but also that information continues to go up and it gets

integrated in the brain. It integrates with visual and somatosensory systems. And I think over the years it's been increasingly clear that it's not the vestibular system is not necessarily just this rudimentary reflex that the brain doesn't use.

It influences a range of higher level cord cortical functions.

And I'm going to focus a little bit on self motion perception in general. But this is kind of to show you the complexity of things going on here. In fact, there are several known areas of throughout the brain that utilize vestibular signals. And this is not a direct pathway either. You know, the vestibular end organs send information up the brainstem, through the cerebellum, up all the way up through the thalamus and it gets relayed to different areas there.

It's important to note that there is not a single, I mean there's areas that may respond more heavily to vestibular information but in general there's not a single vestibular cortex in the brain. This information is getting widely distributed and widely integrated throughout the brain.

So these connections to the cortex and are not only relayed to directly but also indirectly.

And mentioned earlier, we're going to talk a little bit about self motion perception, its importance to balance the absence of self motion perception which is described as vestibular agnosia. It's gone by a few different names, vestibular neglect, but I think vestibular agnosia is here to stay. It has been observed in older adults, patients with acute tbi, patients with white matters disease, fall risk patients, especially patients in some patients that don't report vertigo and have bppv. And so self motion perception in and of itself is thought to be mediated by large functional brain networks rather than a specific brain region. And altered connectivity between these networks and these regions can result in the inability to perceive vertigo or the inability to perceive signals arriving from the peripheral vestibular system.

And this has a functional impact, it has an impact on postural stability. In fact, a few years ago my former PhD advisor and I and we've, we looked at this and we wanted to look at the, the clinical significance of failing to perceive vertigo during the caloric test. We had two essentially groups of patients and every single Patient, just to let you know, had normal peripheral vestibular function. They had normal vestibular function tests. We had 25 older adults with normal tests.

Groups were then divided based on the presence or absence of self motion perception during the caloric test. That's the only thing we asked them after the caloric test, other than the sensation of water in your ear, did you perceive motion? It was a binary response, either yes or no. And what we ended up seeing was, despite no significance, significant differences between groups on any of the measures of vestibular function. The absent perception group showed a greater postural instability during condition 5 on the SOT.

They were about 18 times more likely to fall on condition 5 of the SOT even though they had normal VFDs. And nothing else was different compared other than the fact that they didn't perceive caloric perception.

So obviously alterations in self motion perception could lead to chronic balance problems.

And it's important to remember we have a lot of different tests and these tests do an amazing job at measuring all 10 vestibular end organs. But we're measuring subcortical brainstem reflexes. And so we often forget, I think as a field that there's an entire brain up there and there's a lot of things that happen. And the results of this complex processing in the brain is what patients report and what we measure are the structural integrity of vestibular organs and the vestibular reflex pathways. And so with respect to tbi, I think, you know, there, there's certainly a degree of this, obviously no data currently to support it, but I think just given on some of the research that's been done in the past, some of these issues may

go beyond some of the structural damage that we may see in a day to day basis when a TBI patient does present to the clinic.

And that's important to remember and I think that's important. That's one of the reasons why it's so important to have a team based approach because there's, there's obviously other things that, that could be going on here besides damage to these structures.

And so what could be going on? How can we kind of assess. And now I'm just going to talk a little bit very high level, very briefly about just some of the work that we plan to do in this area and apply it to TBI patients and so bear with me, but it's just going to be very high level. And this is kind of where we think some of the future work, future TBI work could go. So recently we've got into eeg.

And for those that are unfamiliar, EEG is essentially a direct brain measure. And you can measure it over time. So you're placing a variety of different electrodes that allow you to pick up the electrical signals and the neurochemical changes that require that from pyramidal cells in the brain. And so when these shell cells on a normal basis change their potentials, it creates an electrical charge that we can then measure at the scalp. And so it creates these electrochemical changes that we're able to detect.

And by placing a variety of different electrodes on the scalp, we can measure variations in brain activity. It's not specific to certain anatomy or certain regions of the brain, but it's more of a collective. How is the brain processing certain inputs? And so one of the ways that we're trying to get into this work is trying to look at how can we measure vestibular mediated cortical function, and are there quantifiable cortical vestibular biomarkers happening in the brain? And could this help kind of clear the.

Or could this kind of, could this line of research add anything to the TBI literature? And so just again, for those who are unfamiliar, similar to vamps, any or abrs, anything that we're doing with regard to electrophysiology, electroencephalography is essentially the same idea, same concept, except your

doing it over a continuous amount of time. You have voltage potentials measured over time, but you also have voltage potentials measured over space.

And it gives, also gives you an ability to represent the data in a variety of different ways, not only across time, but also across space. And so it allows you to kind of see the variations in the brain activity in response to a certain event. And so it gives, it gives you a way to really try to understand how the brain is processing input and not necessarily structural integrity of certain input. And then you attract features within that brain signal. So the brain obviously has different rhythms that it will produce.

And these patterns of electrical activity are very important for processing, communication, state of mind, coordination, and so much more. It's essential for various forms of cognitive function and really allows us to kind of get some really rich data. And so again, it is a direct measure of brain activity, very high temporal precision, and it can match the speed of cognitive function. You get a lot of rich data and you can link findings across species. So it certainly has a lot of advantages.

Some disadvantages, obviously it's limited to some large scale potentials. So large things happening in the brain are picked up by eeg. Some of the smaller, minute stuff are not. Again, there's also some uncertainties in terms of anatomical localization. You're not necessarily looking for specific regions in the brain.

You're just kind of overall trying to get an idea of how the brain is processing certain bits of information. And so how this relates back to tbi. I think some of our future work wants to try to, or we want to try to kind of get into how are there quantifiable biomarkers that the brain can produce in response to a direct vestibular event arriving from the peripheral system? And could that help us kind of get into more higher level cortical processing, especially in a very unique clinical population such as tbi? And can we correlate that to the patient's symptoms, self motion perception as well as functional performance?

So that's just some of the future work that we'll, we want to get into. But, you know, I, I think a lot of this really comes down to trying to do whatever we can to provide some level of information, not only for baseline of patients who have experienced a brain injury, but also ways that we can do to track the recovery.

So I want to thank everyone for your time. Happy to take any questions.

Thank you so much, Dr. Romero. At this time, we'll go ahead and open up the floor. We have just a couple minutes here left until the conclusion of the webinar. Feel free to type any comments or questions for Dr.

Romero. We'd like to thank Vanderbilt University for continuing this partnership with Audiology Online annually. Thank you again to Dr. Romero for coming on each year to share the newest, you know, research and data on the vestibular forefront.

And Dr. Lamira, I don't see any questions coming through, so we'll go ahead and close out the classroom. We'd like to thank you for your time and expertise. We appreciate all of the Audiology Online members who've attended this presentation. Thank you again to Vanderbilt University.

And please don't forget to complete the multiple choice exam should you wish to earn the CE credit if you're an AOC member. Thanks again, everyone.