Dynamic Visual Acuity and Cervical Proprioception Following Adolescent Concussion

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Abstract

Prolonged dizziness is common among adolescents after a concussion. The source of dizziness can be multi-factorial involving the vestibular, ocular, or cervical sensorimotor pathways which make treatment challenging. Research has shown a high prevalence of abnormal Dynamic Visual Acuity (DVA) in adolescents following a concussion despite a lack of objective Vestibular Ocular Reflex impairments. The purpose of this study was to examine factors correlated with DVA and cervical proprioception in adolescents with dizziness after a concussion. This quantitative, non-experimental study used a correlational design and gathered data on 14 adolescents between 12 and 18 years of age referred to vestibular physical therapy after a concussion. Data were collected on participants' characteristics and objective measures including DVA, Cervical Joint Position Error Test (JPET), Vestibular/ocular motor screening (VOMS), neck pain, and contact versus non-contact sports involvement. Using Pearson and Spearman rho, correlations among variables were examined. No associations were identified between DVA and Cervical JPET and most participants scored below clinical cut-offs. Negative moderate statistically significant correlations were found between DVA scores and the number of PT visits and between the average Cervical JPE measures and participant's age. Mann-Whitney *U* and independent *t* tests were used to identify differences between participants' type of sport and with or without neck pain. Contact sport participation yielded a statistical difference for Cervical JPET but not DVA. No statistical differences were found between neck pain groups for primary variables. The results highlight the importance of a comprehensive evaluation following a concussion. Future research to better understand prolonged dizziness among adolescents after a concussion is necessary.

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An estimated 1.6 to 3.8 million people experience a concussion from a sport or recreational activities in the United States annually (Centers for Disease Control [CDC], 2017; Harmon et al., 2013). Children and adolescents make up a sizable portion of these injuries (CDC, 2011). Children and adolescents who have a concussion experience prolonged recovery and are at risk for repeat concussions with catastrophic injury (Harmon et al., 2013). Concussions can result in vestibular, oculomotor, and cervical dysfunctions which present as sensorimotor and functional impairments that have potential long-term ramifications (Harmon et al., 2013; Reneker et al., 2018; Zemek et al., 2013).

Complaints of headache, dizziness, imbalance, and impaired vision are common among adolescents post-concussion and are associated with delayed recovery, (Alsalaheen et al., 2010; Kontos et al., 2017; Lau et al., 2011), reduced visual reaction times (Cochrane et al., 2017), and may negatively impact neurocognitive performance (Sinnott et al., 2019). A high prevalence of children with post-concussion dizziness present with abnormal dynamic visual acuity (DVA) (Zhou & Brodsky, 2015), which is defined as the ability to stabilize one's gaze while one's head is moving (Schubert et al., 2008). Dynamic visual acuity impairments result from changes in the vestibular ocular reflex (VOR) causing impaired gaze stability (Dannenbaum et al., 2005). However, VOR abnormalities and peripheral vestibular dysfunction among children, adolescents, and adults are limited after a concussion as determined with specialized objective tests (Alshehri et al., 2016; Christy et al., 2019; Cochrane et al, 2021; Zhou & Brodsky, 2015). Therefore, the pathology involved in impaired DVA requires further investigation to improve post-concussion treatment, facilitate a faster return to function, and reduce the risk for subsequent concussions.

The clinical test for DVA measures gaze stability and involves movements of the head and neck; however, the underlying mechanism of DVA is unclear and not fully understood (Schubert et al, 2008). Aside from DVA impairments, researchers have found prolonged post-concussion headaches and dizziness to be associated with cervical spine impairments including cervical proprioception (Kennedy et al., 2019; Kennedy et al., 2017; Reneker et al., 2018; Schneider et al., 2018; Schneider et al., 2014). Furthermore, cervical proprioception impairments are present in a high percentage of children and adolescents following a concussion but are less frequently assessed (Tiwari et al., 2019). Cervical proprioception provides sensory input from the neck to assist in postural control and gaze stabilization (Leigh & Zee, 2006). Despite the overlap in cervical proprioception and gaze stabilization testing procedures, a direct association between abnormal DVA results and cervical proprioception has not been examined (Leigh & Zee, 2006). Understanding the associations between the vestibular, oculomotor, and cervical systems and their contribution to dizziness in adolescents following a concussion is important for optimizing the quality of their care.

The purpose of the study was to examine factors correlated with impaired dynamic visual acuity and cervical proprioception in adolescents experiencing dizziness following a concussion.

The main research questions are:

1. Is there a relationship between DVA and cervical proprioception impairment following a sports-related concussion for adolescents and youth (ages 12-18 years) presenting with dizziness to outpatient vestibular therapy?
2. What patient impairments are most closely related to DVA and cervical proprioception in adolescents with dizziness following a concussion?

With concussions on the rise within the adolescent population (Zhang et al., 2016), greater use of vestibular physical therapy is necessary for facilitating their return to function because of prolonged dizziness and imbalance. Impaired DVA is a common abnormal finding during a functional assessment of the vestibular system. Recovery of visual acuity during functional dynamic activities is imperative for adolescents to return to learning and sport. Beyond the vestibular system, symptoms of dizziness may be due to disruption in the other two afferent sensory systems which include the cervical proprioception and oculomotor systems. Efficiently and effectively diagnosing the source of dizziness by the vestibular physical therapist is essential for optimal quality of care.

Literature Review

Concussions can result in significant and enduring impairments for children and adolescents (Bey & Ostick, 2009; Kapadia et al., 2019) and cross-sectional cohort studies show the incidence of concussions among adolescents to be increasing (Zhang et al., 2016). When examined prospectively, symptom resolution following adolescent sports-related concussions required an average of 21-28 days rather than the previously estimated 7-10 days with the greatest improvement occurring within the first 14 days (Henry et al., 2016). Furthermore, post-concussion symptoms were present in 11% of children (ages 6 to 18 years) after three months (Barlow et al., 2010). Headache, dizziness, imbalance, double vision, and a variety of cognitive impairment symptoms are common among adolescents post-concussion and are associated with impaired visual reaction times (Cochrane et al., 2017) and delayed recovery (Alsalaheen et al., 2010; Kontos et al., 2017; Lau et al., 2011; Master et al., 2016). However, the differentiation of underlying impairments causing post-concussive dizziness can be challenging especially among adolescent athletes because it depends primarily on subjective self-reporting of symptoms (Duhaime et al., 2012).

Post-Concussion Dizziness

Subjective dizziness has been identified through prospective studies to be one of the only early predictors of prolonged recovery following a sports-related concussion (Lau et al., 2011). Yet, adolescents often have difficulty describing their symptoms (Reneker et al., 2015) and sometimes delay in reporting their symptoms (Asken et al., 2016). The underlying impairments contributing to dizziness and imbalance are difficult to diagnose because they result from a complex sensory integration process involving the vestibular, vision, and somatosensory systems and involve complex motor execution required for eye and head coordination, postural stability, and mobility (Akin et al., 2017).

Post-concussive dizziness can result from one or multiple factors influencing these three afferent systems which contribute to body awareness, position sense, and balance (Schneider et al., 2018). The vestibular system is composed of central and peripheral components and functions as a sensory and motor system. The semi-circular canals and otoliths of the vestibular system provide sensory information while the vestibular-ocular reflex (VOR) and vestibulospinal reflex (VSR) offer gaze stability and postural control during head movements (Vidal et al., 2012). Disruption of the afferent information from the cervical region can also contribute to symptoms of dizziness and imbalance (Kristjansson & Treleaven, 2009). Cervical proprioception is essential to balance and postural control because it sends sensory information to the brain about the orientation of the head on the body and directly connects via projections to the vestibular nuclei with the visual and vestibular systems for efficient and coordinated movements (Kristjansson & Treleaven, 2009).

Vestibulo-Ocular, Cervical Impairments

Retrospective and cross-sectional data indicate that a substantial proportion of children and adolescents experience vestibulo-ocular, cervical, or a combination of both impairments following a concussion (Ellis et al., 2015; Kennedy et al., 2017; Renecker et al., 2018; van der Walt et al., 2019). Furthermore, studies of adolescent athletes following a sport-related concussion revealed central dysfunction causing either vestibular or oculomotor impairments (Leung et al., 2018; Reneker et al., 2018). According to Corwin and colleagues (2015), 81% of pediatric and adolescent patients demonstrate an abnormal VOR or abnormal dynamic balance at the evaluation following a concussion, and as many as 90% of children who experience prolonged symptoms of dizziness or unsteadiness and have been found to present with one or more abnormal balance and vestibular finding (Zhou & Brodsky, 2015).

The prevalence of vestibular, oculomotor, and cervical dysfunction following sports-related concussion highlights the importance of screening for risk factors and impairments before and immediately following a concussion to provide optimal, individualized care (Zuckerman et al., 2016). Research suggests that a comprehensive assessment, followed by physical rehabilitation including vestibular and oculomotor training can reduce vertigo and improve balance and gait, resulting in an earlier return to sport (Alsalaheen et al., 2010; Gottshall & Hoffer, 2010; Kontos et al., 2018; Schneider et al., 2014). Additionally, the Consensus Statement on Concussion in Sport (McCrory et al., 2017) and expert opinion (Gottshall, 2011; Gurley et al., 2013; Kapadia et al., 2019; Kontos et al., 2017) recommend physical rehabilitation to manage vestibular, oculomotor, and cervical impairments and facilitate earlier recovery and return to prior function (Broglio et al., 2015; Schneider et al., 2014). According to van der Walt et al. (2019), the majority of patients with persisting post-concussive symptoms are referred to physical therapy for treatment of the neck, vestibulo-ocular systems, or both. Therefore, therapists need to recognize the multiple systems involved in patients following a concussion and a variety of interventions to address them.

Vestibular and Oculomotor Dysfunction in Concussion

Researchers have developed and tested clinical assessment tools to measure symptoms (Chen et al., 2007) and identify vestibular and oculomotor impairments associated with vestibular disorders (Whitney et al., 1999), specifically following a concussion (Anzalone et al., 2016; Elbin et al., 2018; Mucha et al., 2014). A brief symptom provocation measure called the Vestibular/Ocular Motor Screen (VOMS) has demonstrated high internal consistency, Cronbach's alpha = .92 (Mucha et al., 2014), and the ability to predict the return to sport following a sports-related concussion with predictive probability area under the curve (AUC) of .89 (Anzalone et al., 2016; Mucha et al., 2014). The Visual motion sensitivity (VMS) (odds ratio [OR] = 3.37; $p < .01$) and VOR (OR = 3.89; $p < .01$) domains were the most predictive components of the VOMS (Mucha et al., 2014). The VOMS also identifies prospective changes for patients with concussions when comparing baseline scores to post-injury scores using the total score and change scoring methods (Elbin et al., 2018). Furthermore, Tomczyk and colleagues (2021) found the change score method may provide more clinical utility in identifying specific impairments for treatment planning among adolescents and young adults after a concussion. Beyond vestibulo-ocular and oculomotor screening, the Functional Gait Assessment (FGA) for assessing balance and gait dysfunction have been found to have acceptable interrater (intraclass correlation coefficient [ICC] = .84), intrarater reliability (ICC = .83), and internal consistency (Cronbach’s alpha = .89) in patients with vestibular disorders (Wrisley et al., 2004). Concurrent validity of the FGA was also established with the Activities-specific Balance

Confidence scale (ABC) (r_s = .53; $p < .001$), Berg Balance Scale (r_s = .84; $p < .001$); and Timed "Up & Go" test (r_s = -.84; $p < .001$) for identifying fall risk (Wrisley & Kum, 2010).

A high prevalence of children with dizziness post-concussion present with gaze stabilization and DVA abnormalities (Corwin et al., 2015; Zhou & Brodsky, 2015). Furthermore, a recent prospective cohort study found a significant positive correlation between concussive impacts and DVA impairments (Miyashita & Ullucci, 2020). However, DVA (i.e. reduced visual acuity with concurrent movements of the head and a functional measure of the VOR) is not impacted by exertion in athletes. Therefore, the DVA may provide a more rapid assessment of the balance system in athletes compared to other balance tools including the Balance Error Scoring System (BESS) which is impacted by the athlete's fatigue level and may lead to inaccurate results (Patterson et al., 2017).

Findings of retrospective and prospective repeated measure studies examining vestibular rehabilitation following concussion show improvements in DVA, target acquisition, and target following (Gottshall & Hoffer, 2010; Story et al., 2018), as well as in outcome measures including Dizziness Handicap Inventory (DHI), Post-Concussion Symptom Scale (PCSS), VOMS, ABC, and FGA (Alsalaheen et al., 2010). Significant improvements in children were found in postural control following vestibular rehabilitation as well (Storey et al., 2018). However, the underlying source of DVA abnormality in concussion is unclear and may rather involve the central sensory integration of vestibular and visual input as the abnormalities appear to exist even in the absence of objective peripheral vestibular impairments (Zhou & Brodsky, 2015). Researchers have found limited impairment of the VOR in adolescent and young adult athletes following a concussion with rotational chair, cervical myogenic potential (c-VEMP) (Christy et al., 2019), and video head impulse tests (vHIT; Alkathiry et al., 2019; Alshehri et al., 2016). Furthermore, a recent study by Cochrane et al. (2021) found no significant difference between concussed and non-concussed children and adolescents in objective clinical testing of the peripheral vestibular function and VOR.

Impaired gaze stability, which is often functionally measured with DVA, has implications for children and adolescent athletes on and off the field. Vestibular ocular reflex dysfunction has been linked to a prolonged recovery of academic activities such as reading, writing, and computer skills (Corwin et al., 2015). Additionally, DVA is essential for maintaining focus during rapid head movements which are necessary for sports activities to allow for quick responses (Broglio et al., 2015). Lastly, a retrospective study has shown impaired VOR function is associated with prolonged recovery and a greater likelihood of developing post-concussion syndrome (Ellis et al., 2015).

Cervical Proprioception Impairment and Concussion

Several researchers have explored the role of the cervical spine and impaired cervical proprioception in dizziness following sports-related concussion (Morin et al., 2016), and have found the cervical spine contributes to prolonged post-concussion symptoms such as headache and dizziness (Cheever et al., 2021; Kennedy et al., 2019; Kennedy et al., 2017; Reneker et al., 2018; Schneider et al., 2018; Schneider et al., 2014). Whiplash and concussion injuries can result in neck pain (Cooper et al., 2003) and impaired cervical proprioception due to the density and complexity of sensory receptors throughout the cervical spine (Ellis et al., 2015). Cheever and colleagues (2021) found an increase in cervical joint reposition error among athletes with a history of contact sports. This finding appears to support the idea that cervical proprioception impairments can be associated with concussions. The altered proprioception contributes to a mismatch of sensory information when integrating with sensory input from the visual and vestibular systems and contribute to the sensation of dizziness (Kristjansson & Treleaven, 2009). Furthermore, children and adolescents may be at greater risk for cervical impairments following a concussion due to reduced neck strength (Ellis et al., 2015; Tiwari et al., 2019), ligamentous laxity and sensorimotor systems which are not yet fully matured (Quatman-Yates et al., 2012).

Findings from retrospective chart reviews and case studies suggested a majority of patients had a cervicogenic component of dizziness after concussion (Kennedy et al., 2017). However, most of these patients respond well to neuromuscular reeducation to improve cervical proprioception and sensorimotor integration (Hammerle et al., 2019; Saviola et al., 2016). Hynes and Dickey (2006) found a strong relationship between concussion and whiplash-associated disorder symptoms following a sports-related injury when prospectively examining 183 hockey players (ages 15-35 years). Researchers of a case-controlled, repeated measure study found no differences in the perception of dizziness and cervical proprioception among participants with whiplash-associated disorder and those with an acoustic neuroma (Treleaven et al., 2008). However, the researchers did find some differences between both groups and controls in postural stability and smooth pursuits with the neck in a rotated position (Treleaven et al., 2008). This would seem to indicate concurrent engagement of neck and vestibular systems suggesting impaired cervical proprioception and sensorimotor control of the neck may involve an afferent mismatch between the two systems. In contrast, cross-sectional and prospective cohort studies of young athletes revealed the history of a concussion combined with altered cervical proprioception was predictive of a future head and neck injury (Hides et al., 2017) while vestibular ocular reflex and balance measures were not significantly different between injured and uninjured athletes (Hides et al., 2017; Leung et al., 2018; Schneider et al., 2018).

Vestibular and Cervical Rehabilitation Post-concussion

The most rigorous experimental study to date investigating combined cervical and vestibular rehabilitation for treatment of concussion is a randomized controlled trial by Schneider and colleagues (2014). Study participants randomized to the intervention group received cervical and vestibular rehabilitation compared to a group that only received patient education. Seventy-three percent of the intervention group returned to sport within eight weeks, compared to 7% of the group receiving only the education (Schneider et al., 2014).

Although many adolescents with persisting post-concussive dizziness are referred for cervical and vestibular therapy (van der Walt et al., 2018); no research has been published to our knowledge that has examined the direct relationship between DVA and cervical proprioception impairments following a concussion. The existing literature provides some preliminary evidence that both the cervical sensorimotor system and the vestibular system play a role in post-concussion symptoms of dizziness. Researchers recognize a significant overlap between these balance subsystems, making diagnosis and optimization of treatment challenging for clinicians, which in turn can prolong symptoms and treatment for patients. Yet, the specific roles of the cervical spine and the vestibulo-ocular systems in prolonged post-concussive dizziness are lacking clarity, as research in this area is primarily preliminary (van der Walt et al., 2018). Due to the ease at which symptoms can be exacerbated during clinical testing, clinicians need to be efficient in their identification of impairments and provide targeted treatment (Christy, 2018). The specific relationship between cervical sensorimotor dysfunction and vestibular deficits, as well as other existing adolescent impairments following a concussion, requires further investigation to determine optimal prevention, screening, and treatment strategies.

Method

Study Design

This was a quantitative non-experimental study using a correlational design. This design allowed the examination of relationships among variables (Cottrell & McKenzie, 2011) associated with adolescents following a sports-related concussion. The correlational design assisted in determining if certain participant characteristics contributed more than others to DVA following sports-related concussions. The data collection portion of the study took place from February 2021 through February 2022. The study was approved by the institutional review boards of Northwestern Medicine (Appendix A) and the University of Indianapolis (Appendix B) before participant recruitment.

Participants

A convenience sample was recruited from all physical therapy orders received by Northwestern Medicine West Region Rehabilitation department for patients with the diagnosis of a concussion. Convenience sampling with the use of homogeneity of sample and adherence to inclusion and exclusion criteria increased control for extraneous factors unable to be controlled by lack of randomization (Polit & Beck, 2014). Adolescents between 12-18 years of age who had sustained a concussion and were referred to outpatient physical therapy were eligible for recruitment. Exclusion criteria were adolescents who had a known neurological injury other than concussion, known neuro-ophthalmological condition, fractures, or musculoskeletal injuries other than of the cervical spine within the previous 6 months, and positive clinical tests indicating cervical instability.

Sample Size

An a priori sample size estimation was conducted to identify an appropriate sample size for statistical significance using G*Power 3 (Faul et al., 2007). The DVA test and cervical JPET measures were the variables used to calculate the sample size for a Pearson's *r* correlation. The estimated sample size was 29 as calculated for a moderate effect size, a significance level of .05, and the power set at .80. A moderate effect size was chosen due to a lack of research suggesting an appropriate effect size (Cottrell & McKenzie, 2011). However, the estimated sample size was not achieved due to numerous externally imposed obstacles including the COVID-19 pandemic, reduced adolescent sports during the period of recruitment, and increased workplace restrictions.

A sample size of 14 participants was achieved. A post hoc calculation for power, G*Power 3 (Faul et al., 2007), based on the sample size and statistical significance of .05 indicated the power ranged from .12 to .09 for the correlations of DVA scores and cervical JPET measures.

Setting

The setting for this study was an outpatient physical therapy clinic associated with a large, suburban hospital system in Illinois. The primary researcher (P. C.) performed informed consent and assent as well as the testing at two locations depending on patient preference and referrals. The setting for recruitment and data collection was standardized to a private, outpatient clinic environment.

Data

Data were collected on the following continuous variables: participants' age (in years), duration of time since concussion injury (in days), length of stay in physical therapy (number of visits and weeks seen in therapy), Cervical JPET results (measured in cm for each of six trials to the right and the left), and score on non-instrumented DVA, DHI score (0-100), VOMS total scores and change scores (0-40) for individual domains including VMS and HVOR, and NPRS score (0-10) when pain was present. Nominal variable collected included the participant's gender and contact versus noncontact sport involvement.

Operationalization and Definition of Variables

The operationalization and definitions for the following variables was used for this study.

- Cervical proprioception – Within this study, cervical proprioception was defined as the sensory afferent input from the neck which integrates with vestibular and visual input to provides neuromuscular control of the cervical spine (Kristjansson & Treleaven, 2009) and was assessed by the cervical JPET (Swait et al., 2007).
- Contact sport – For the purposes of this study, contact sports were identified according to the Family Practice Notebook (Moses, 2021). Contact sports included wrestling, hockey, football, and soccer.
- Dizziness – For this study, dizziness was any subjective complaint of dizziness, vertigo, imbalance, or unsteadiness experienced by the participant since the concussion injury. Dizziness was measured according to the subjective perception of handicap related to the participants' symptoms utilizing the DHI (Jacobson & Newman, 1990; Shirley Ryan AbilityLab, 2013).
- Dynamic visual acuity – For this study, DVA was the ability to stabilize one's gaze while one's head is moving and was assessed by change in function from stable acuity compared to head motion acuity at 2 Hz measured as line differential (Dannenbaum et al., 2005) when reading an Early Treatment Diabetic Retinopathy Study (ETDRS) chart (Shamir et al.2016).

- Horizontal Vestibular Ocular Reflex (HVOR) – For the purposes of this study, HVOR was defined as the participants' tolerance to horizontal head movement while maintaining a focal point on a target. A participant's HVOR was measured according to the HVOR subtest on the VOMS using the total symptom score (TSS) (Mucha et al., 2014) and total symptom change score methods (TSCS) (Elbin et al., 2018; Yorke et al., 2016).
- Neck pain – Participant’s neck pain was defined as a subjective rating of his or her neck pain according to the NPRS and self-selecting a number between 0-10 representing their level of intensity (Herr et al., 2004).
- Oculomotor control –Oculomotor control was defined as the ability to control one's eye movements and visually maintain focus on and change gaze to a target. Oculomotor control impairments included any subjective report of visual or perceptual complaints including double vision or blurred vision. Oculomotor control was screened according to the VOMS including the smooth pursuit, horizontal and vertical saccades, and near point convergence (NPC) (Mucha et al., 2014).
- Visual Motion Sensitivity (VMS) – For the purpose of this study, VMS was defined as a participants' tolerance to visual motion and ability to utilize vision for inhibition of vestibular induced eye movements (Quintana et al., 2021). The participant's VMS was measured according to the VMS subtest on the VOMS using the total score method (Mucha et al., 2014) using the change score method (Elbin et al., 2018; Yorke et al., 2016).

Instruments

Instruments used within this protocol are all recommended performance and self-report outcome measures for the assessment of impairments following a concussion. Based on the subjective information, the patient's history, and the time allotted for a typical evaluation, the combined performance measures are not always performed during the initial evaluation as they were within this protocol. Instead, often some of them are typically performed within a second or third visit with the physical therapist. The DHI is most often used as the primary self-report measure if a patient presents with dizziness and the NPRS is commonly used as a preferred pain rating scale for physical therapy and other healthcare professionals. In practice, the VOMS or similar oculomotor and vestibular ocular testing is performed and often includes the DVA during the first visit. Frequently, therapists do not have the time to administer the cervical JPET during the initial evaluation and defer to subsequent visits.

Dynamic Visual Acuity

Dynamic visual acuity was measured according to the non-instrumented test per the protocol described by Schneider et al. (2018) with the use of the ETDRS eye chart (Shamir et al., 2016) adapted from Dannenbaum et al. (2005). The DVA non-instrumented test was found to have excellent criterion validity as evidenced by a sensitivity (100%) and specificity (100%) with passive yaw plane testing when comparing children with bilateral vestibular hypofunction to normal developing children or adults (Rine & Braswell, 2003). Test-retest reliability and interrater/intrarater reliability were also found to be excellent with intraclass correlation coefficients (ICC) = .94 and .84 respectively (Rine & Braswell, 2003). Christy et al. (2014) found a minimal detectable change (MDC_{90}) of 8 optotypes or approximately 1.6 lines for the DVA performed with children (6-12 years old). The DVA sensitivity is 88% and specificity is

69% among children for predicting vestibular hypofunction with a cutoff score of 10 optotypes or 2 lines (Christy et al., 2014)

Cervical Joint Position Error Test

The cervical JPET test also described by some as the cervical relocation test was used to measure cervical proprioception and sensorimotor function by measuring the degree of joint position error (Reiley et al., 2017). The test was performed within this study as described by L'Heureux-Lebeau et al. (2014) utilizing the target developed by Landel (2019) and adapted from Revel et al. (1991) and Treleaven et al. (2003). Normal cervical proprioception has been established as joint position error < 4.5 degrees with a sensitivity of 86% and a specificity of 93% in patients with chronic cervical pain (Revel, et al., 1991). The Cervical Relocation test was found to have a sensitivity of 72% and a specificity of 75% when differentiating between cervicogenic vertigo and benign paroxysmal positional vertigo (L'Heureux-Leabeau et al., 2014). Test-retest reliability for relocation to neutral head position was found to be adequate to excellent with ICC = .45 – .80 (Lee et al., 2006). Interrater and intrarater reliability among physical therapists has been found to range from ICC = .97 – .99 in patients following whiplash injury (Loudon et al., 1997). Additionally, the cervical relocation test demonstrates predictive validity with 60% sensitivity and 54% specificity for whiplash-associated disorders and healthy controls (Treleaven et al., 2006) and discriminant validity (Treleaven et al., 2003). Loudon et al. (1997) also found a significant difference between an average error score with patients with whiplash compared to normal controls.

Dizziness Handicap Inventory

Two self-report measures were also completed to assess participants' subjective perception of their symptoms of dizziness and pain as well as the associated handicap. The DHI has been found to have strong psychometric properties for vestibular dysfunctions (Shirley Ryan AbilityLab, 2013) and has been utilized to quantify levels of impairment and subjective dizziness in patients following a concussion (Alsalaheen et al., 2010; Quatman-Yates et al., 2020). Jacobson and Newman (1990) demonstrated excellent test-retest reliability (r = .97) and excellent internal consistency (Cronbach's alpha = .89) for total score with central and peripheral vestibular pathology. Criterion validity has also been established. An excellent correlation was found between the DHI and the Activities-specific Balance Confidence scale (r = -.64) (Whitney et al., 1999) and a good correlation was found between DHI and the Short Form Health Survey (SF-36) in persons with vestibular disorders (r = .53 to .72) (Fielder 1996). Furthermore, Gottshall et al. (2003) found a significant correlation between DHI and DVA test one week following a mild traumatic brain injury.

Vestibular/Ocular Motor Screen

The VOMS was used to screen for vestibular and ocular impairments. The VOMS is a brief symptom provocation measure that assesses four domains including headache, dizziness, nausea, and fogginess within the oculomotor and vestibular ocular subtests of smooth pursuits, horizontal and vertical saccades, convergence, horizontal and vertical vestibular ocular reflex (HVOR and VVOR), and VMS (Kontos et al., 2017). Participants rated their symptoms of headache, dizziness, nausea, and fogginess before and after performing the test components on a Likert-type scale where 0 indicated no symptoms and 10 indicates severe symptoms (Alkathiry et al., 2019; Kontos et al., 2017). A total symptom score (TSS) and total symptom change score (TSCS) for each subtest can then be calculated (Yorke et al., 2016).

The VOMS has demonstrated high internal consistency Cronbach's α = .92 - .97 and sensitivity using the total symptom score (Moran et al., 2018; Mucha et al., 2014), and a medium to high internal consistency for the individual subtests (Iverson et al., 2021). However, Tomczyk and colleagues (2021) suggested change scores can be even more clinically useful in assessing an individual's vestibular and oculomotor impairments following concussion among high school and collegiate athletes. Additionally, researchers have reported the use of overall change scores and identified an associated optimal clinical cut-off of $\geq$ 3 points with an AUC of .73 (Elbin et al., 2021).

The VOMS has growing research supporting its use in acute sports-related concussion assessment. The tool can identify concussed from non-concussed athletes (Mucha et al., 2014) and yields very low rates of false positives among children and adolescents (Iverson et al., 2021; Moran et al., 2018). The VOMS can also predict the return to sport following sports-related concussion (Anzalone et al., 2016) and document prospective changes (Elbin et al., 2018) including those associated with athletes who are receiving vestibular physical therapy (Alsalaheen et al., 2020). Combining the scores for VOR, VMS, and near-point convergence (NPC) resulted in a predictive probability AUC of .89 for recognizing a concussion injury (Mucha et al., 2014). Furthermore, researchers have found testing order not influential in the severity of scores among healthy high school athletes (D'Amico et al., 2021), and the tool shows greater stability under athletic exertion compared to other frequently utilized assessment tools for this population (Worts et al., 2018). Lastly, the VOMS items demonstrate moderate concurrent validity with the Post Concussion Symptom Scale (PCSS) (Mucha et al., 2014) and a moderate to strong concurrent validity with the DHI sub-scales (Eagle et al., 2022).

Numeric Pain Rating Scale

Lastly, neck pain was also assessed as part of the evaluation using the NPRS. Herr and colleagues (2004) found excellent interrater reliability with 100% agreement between two testers and excellent internal consistency (Cronbach's alpha = .87 - .88). Additionally, excellent convergent validity has been established with the Visual Analog Scale (r = .94, 95% CI [.93-.95]) (Bijur et al., 2003).

Procedures

Screening

When a new patient was referred to outpatient vestibular physical therapy with a diagnosis of concussion, the primary researcher who was also the evaluating therapist, performed a thorough chart review of the patient's EMR before the evaluation visit to determine if the patient met the study eligibility. A total of 23 adolescents with a concussion were referred to vestibular physical therapy during the recruitment period and screened for eligibility for enrollment into the study.

Recruitment

For patients who met the criteria for enrollment, the evaluating therapist contacted the potential participant's guardian via phone prior to the day of the evaluation. During the phone conversation, the evaluating therapist (P. C.) introduced the study, informed the guardian of the patient's eligibility, and specified they would receive further information on the study when they present for the physical therapy evaluation. For patients who expressed interest in participating in the study, a 15-minute extra time block was allotted just prior to the evaluation for further discussion of the study. Recruitment started in February 2021 following obtaining approval from both the Northwestern and University of Indianapolis IRBs and continued until February 2022. Fourteen participants were enrolled in the study. A flowchart is provided in Figure 1 indicating the reasons for exclusion or inability to recruit participants.

Informed Consent and Assent

If the study participant's parent or guardian agreed to study participation, the informed consent and assent process was conducted prior to the onset of the physical therapy evaluation. Study participants and their guardian were informed of any risks or benefits in participating in the study as well as Health Insurance Portability and Accountability Act (HIPAA) requirements by the evaluating therapist. Information regarding how the data would be utilized and secured by the research team was discussed. If in agreement, participants and guardians were asked by the evaluating therapist/primary researcher to complete an assent and consent form, respectively. All participants and their guardians were given opportunities to have any questions or concerns regarding the study addressed before the physical therapy evaluation began within the outpatient physical therapy clinic. The consent and assent documents were stored in the media manager of the EMR.

Testing

During the physical therapy evaluation, instruments used were tests and measures standard and recommended for the practice of vestibular therapists specialized in treatment in patients with concussions, are free for clinician use, and have documented reliability and validity. Those instruments include the following: the DVA, Cervical JPET, NPRS, VOMS, and DHI. The physical performance tests and measures of oculomotor, vestibular, and cervical proprioception systems which were included in the study were collected in a standardized manner including identical instructions given to participants when conducting the tests in an outpatient clinical examination room. Tests and measures were performed in the same sequence and as described in Shirley Ryan AbilityLab rehabilitation measures database for the DVA (2014), JPET (2013), and NPRS (2013). The VOMS was performed according to procedures described by Mucha et al. (2014). The DVA was performed in standing and the remaining tests were performed in sitting. The DHI, a self-report measure, was issued and completed by the participant before the evaluation.

Data Collection

During each participant's evaluation, P. C. recorded the measures in the EMR as is standard practice for a physical therapy evaluation. Then, immediately following the evaluation, the therapist calculated and scored the outcome measures and recorded the raw and total scores within the EMR. Each calculation was performed at least twice to ensure accurate calculations. Calculations computed included the mean score of the cervical JPET test, the total sum score on the DHI, the total and change scores on the VOMS for VMS and HVOR subtests (0-40), the change score of the dizziness domain for the VMS and HVOR (0-10), and the differential score for the DVA two conditions. Any paper documents including the self-report measure (DHI) and the JPET target with individual trials marked, were uploaded into the media manager of the NWM EMR for future reference. The written evaluation and calculated scores were recorded in the EMR within 24 hours of completion. Data of interest for this study was then extracted from Epic, the NWM EMR, by the primary researcher and transferred to a password protected Excel spreadsheet. At that time, the data was screened for accuracy and missing data. To assess for accuracy, the primary researcher recalculated scores in Excel using the raw scores from the paper documents scanned into Epic and compared to the recorded calculated scores. If data appeared to be missing, the primary researcher returned to the medical record to collect necessary data or followed up with the participant and parent as appropriate. Names and personal identifiers were not used by the primary researcher when extracting from the EPIC EMR database and transferring to the Excel spreadsheet. At that time, participants were assigned a unique, 8-digit identification number representing the clinic, month and date of the evaluation, and sequential order following recruitment into the study.

Data Management

The primary researcher imported data into the IBM SPSS for Windows, Version 28.0 (IBM Corp., Armonk, NY) and prepared the data for analysis once an appropriate sample size had been reached. Data were stored on the primary researcher's password protected NWM assigned laptop computer. Data were cleaned to identify any outliers and rectify any data entry errors (Cottrell & McKenzie, 2011). The owner of this data was NWM and procedures for data utilization were addressed according to the NWM and University of Indianapolis IRB requirements.

Data Analysis

Data analysis was conducted utilizing IBM SPSS for Windows, Version 28.0 (IBM Corp., Armonk, NY). All tests were two-tailed, and an alpha level of .05 was considered statistically significant. Descriptive statistics were calculated to describe the sample and outcome variables. Continuous variables were reported as means, standard deviations, medians, and minimum and maximum values. Non-normally distributed continuous variables were identified according to the Shapiro-Wilk test and noted. Continuous variables included participants' age (years), duration of time since concussion injury (in days), length of stay in physical therapy (number of visits), length of stay in weeks, Cervical JPET (measured in cm and an average score for 6 trials to the right and left), score on non-instrumented DVA test, DHI score (0-100), VOMS VMS and HVOR scores (0-40), and NPRS score (0-10) when neck pain was present. Nominal data including gender (female, male) , sport involvement (contact, non-contact), and presence of neck pain (yes, no) were reported as frequencies and percentages.

Inferential statistics were also conducted to determine the correlation among variables. Bivariate correlation results and scatterplots were assessed for linear relationships, outliers, and homoscedasticity (Keller & Kelvin, 2013). To address the research question of what the relationship is between Cervical JPET scores (right, left, and average) and DVA scores (line differential) post-concussion, Spearman rho correlations were used (Cottrell & McKenzie, 2011; Keller & Kelvin, 2013). To address the second research question, Spearman rho correlations were used to assess the association between DVA scores and other participant impairment variables. Pearson correlation coefficients were used to determine associations between Cervical JPET measures and other participant impairment variables except for VOMS measures, LOS in weeks, and age in years which required nonparametric Spearman rho correlations. Correlation strength was interpreted using the descriptive terms as follows: $.30 < r < .50$ = weak correlation; $.50 < r < .70$ = moderate correlation; and $r > .70$ = strong correlation (Moore et al., 2013).

A Fisher's exact test was conducted to determine whether differences existed between adolescents who had a concussion resulting from a contact sport versus a noncontact sport and neck pain or no neck pain. An independent *t* test was performed to compare Cervical JPET scores to whether or not the concussion was due to contact or non-contact sports and the Mann-Whitney *U* for DVA scores. Appropriate bivariate analysis tests (Fisher's exact, independent *t*, and Mann-Whitney *U*) were also run for secondary outcome variables including the VOMS and participant demographics to determine if differences exist.

Results

Descriptive statistics for the overall demographics of the participants are displayed in Table 1 and 2. Of the 14 adolescents enrolled in the study (*M* = 14.6, SD = 1.34, range = 12-17 years), a total of 50% (*n* = 7) of the sample was female. Fifty percent (*n* = 7) presented with neck pain and 64.3% (*n* = 9) experienced a concussion resulting from a contact sport. Participant's mean age was 14.64 years and the mean days from injury until the first clinical visit was 15.79.

Descriptive statistics for the primary study variables are displayed in Table 3. A minority of participants, 28.6% (*n* = 4), had an abnormal DVA score (i.e., greater than 2-line differential); however, most participants, 64.3% (*n* = 9), reported dizziness with DVA testing. A minority of participants also had an abnormal finding for the right, left, and average Cervical JPET measures. However, 85.7% (*n* = 12) had VOMS change scores above the clinical cutoff for the VMS subtest and 71.4% (*n* = 10) were above clinical cutoff for the HVOR subtest. In addition, 85.7% (*n* = 12) participants had a moderate to severe perception of handicap on the DHI.

Research Question 1

Spearman rho correlations were used to determine the association between DVA scores and Cervical JPET measures. Please see Table 4. Overall, the correlations between the DVA scores and the Cervical JPET scores ranged from .17 to .22. However, they did not meet statistical significance ($p < .05$), and therefore, no association between variables was found.

Research Question 2

Correlations between primary outcome variables and other outcome variables are also displayed in Table 4. The associations between DVA scores and other outcome variables were mostly negligible to weak and exceeded the significance level of .05. The association between the DVA score and the HVOR dizziness domain change score using the Spearman rho approached a moderate level of association, $r_s = .46$; $p = .098$. Most correlations between Cervical JPET measures and other outcome variables range from -.46 to .40 but did not meet statistical significance ($p < .05$). However, right Cervical JPET and VOMS baseline scores showed a moderate statistically significant positive correlation ($r_s = .56$, $p = .036$). Correlations between primary outcome measures and participant demographics can be seen in Table 5. Negative moderate statistically significant correlations were found between DVA score and number of PT visits (r_s = -.59, *p* = .028) and the average Cervical JPE measures and participant's age (r_s = -.57, *p* = .033).

A Mann-Whitney *U* test was used to determine if there was a significant difference between DVA scores for those with contact and non-contact involvement, but no significant statistical differences were found. Please see Table 6. An independent *t* test was used to compare Cervical JPET measures and number of PT visits to determine if differences among participants with a concussion from contact versus non-contact sports were statistically significant. A statistically significant difference was found *t*(12) = 2.87, *p* = .014, 95% CI [-2.93, -.398] for the left Cervical JPET. The effect size was huge (*d* = 1.60). Furthermore, a significant difference in mean Cervical JPET measures was also found between participants who had a contact concussion and those who dd not, *t*(12) = -2.33, *p* = .038, 95% CI [-3.08, -1.01] with a very large effect size (*d* = 1.30). In addition, a difference was found for PT visits *t*(12) = 2.32, *p* = .039, 95% CI [0.37, 11.54] with a very large effect size (*d* = 1.29).

Lastly, a Mann-Whitney *U* test was used to determine if any differences existed between participants with or without neck pain for DVA scores and VOMS subtests. The Mann-Whitney *U* test, *Z* = -2.82, *p* = .005 indicated the groups differed statistically for VOMS baseline score at an alpha level of .05 with a huge effect size (*d* = 2.29). Please see Table 7 for additional results. An independent *t* test was used to determine if any differences existed for Cervical JPET measures and PT visits, but no statistically significant differences were found between participants with or without neck pain.

Discussion

The purpose of this study was to examine whether an association exists between DVA and cervical proprioception among adolescents following a concussion and to identify the characteristics or impairments most closely related to those measures. A negligible association was found between the primary outcome variables of DVA scores and cervical JPET measures. Furthermore, most of the participants scored below the clinical cut-off for both primary outcome measures, indicating most participants fell within the normal limits for DVA and cervical joint repositioning errors despite their moderate level of perceived disability from dizziness. This suggests their experience of dizziness cannot be simplified to a single, direct association with their peripheral vestibular or cervical sensorimotor systems. Although a relationship was not found between the two primary outcome variables, a few clinical gems were identified.

Dynamic Visual Acuity Results

In this study, only 28.5% (*n* = 4) of participants presented with an abnormal clinical DVA while over twice as many experienced provocation or exacerbation of dizziness with the testing. These results expand upon the current conflicting evidence within the literature regarding VOR and DVA testing following a concussion. Many authors have found abnormalities above the normal clinical threshold for DVA post-concussion (Gottshall et al., 2003; Schneider et al., 2014; Wright et al., 2017; Zhou & Brodsky, 2015) or a positive correlation between DVA loss and head impacts (Miyashita & Ullucci, 2020). However, other researchers have not found a DVA change or loss following a concussion (Alshehri et al., 2016; McDevitt et al., 2015; Schneider et al., 2018). Moreover, Cochrane and colleagues (2021) reported no differences between children with and without a concussion for objective clinical tests of vestibular, balance, or oculomotor function.

Within the study performed by Zhou and Brodsky (2015), a much higher percentage, 55%, of children (*n* = 23) were found to have abnormal DVA testing compared to the current study. This difference could be due to multiple factors. First, their sample differed in multiple ways. The mean age of their sample was younger (*M* = 13.9 years, SD = 2.8) with a broader age range (8 – 18 years) as well as unequal in gender with 25 females and 17 males. Also, in general, participants were tested less acutely (*M* = 26 weeks, SD = 20; range = 1 - 96) than in the current study (Zhou & Brodsky, 2015). Finally, computerized DVA test was utilized in their study. Resultantly, the researchers were able to determine the laterality of the DVA function and identified some participants with unilateral abnormalities. The clinical non-instrumented DVA test utilized in the current study does not have the same capability.

In contrast to Zhou and Brodsky's study (2015), Schneider and colleagues (2018) worked with a sample of similar age to the current study (13 – 17 years). However, their participants were predominantly male (83.6%). They found no difference in either non-instrumented or computerized DVA testing pre- and post-concussion. However, in comparison to the current study, a similar median of 2 and range of 1 to 3 was reported for their clinical DVA repeat measures post-concussion.

Although DVA loss has not been consistently identified with testing throughout the literature, symptoms experienced during the DVA or other VOR testing post-concussion do seem to be a consistent finding (Alshehri et al., 2016; Christy et al., 2019; Corwin et al., 2015; Ellis et al., 2015; Wright et al., 2017). Alshehri et al. (2016) did not find statistically abnormal degradation of visual acuity or an abnormal gain during a dynamic task compared to the stable condition, but did find an increase in headache, dizziness, and nausea during the testing. Similarly, Christy et al. (2019) found no difference between concussed and non-concussed athletes for VOR function according to rotational chair testing or Cervical Evoked Myogenic Potential (cVEMP) test; yet the majority of concussed athletes had symptom provocation, especially at higher frequencies. Furthermore, in this current study, most participants were above the abnormal cut-off for the VOMS change score and more specifically the HVOR change score which reflects an increased symptom provocation with a dynamic visual acuity task.

Whether or not the score is above the clinically abnormal threshold, symptom provocation with DVA testing is clinically relevant. This is especially the case when assessing adolescents who are struggling to return to school or want to return to their sport. Provocation of symptoms with dynamic gaze stability (VOR) can negatively impact the attention and concentration necessary for reading and computer use and lead to less desirable outcomes. Similarly, the ability to focus on a target with clear vision while one's head and body are moving without symptoms interfering with the task is essential for an athlete to safely perform complex balance and agility skills. Wallace and Lifshitz (2016) have argued that "provocation of symptoms during the DVA indicates injury-induced damage" (p. 160). Some other authors have suggested that abnormal DVA testing may not reflect a specific peripheral vestibular system injury or impairment but rather may reflect dysfunction of the central processing of visual and vestibular sensory input (Christy et al., 2019; Zhou & Brodsky, 2015). Furthermore, the history of motion sickness or sensitivity susceptibility also appears to be predictive of prolonged vestibular ocular impairments and associated with a greater number of adolescents' affective complaints post-concussion (Sufrinko et al., 2019). The current study found the DVA score was approaching a weak positive correlation with the VOMS VMS change score for the dizziness domain within this current study as well. Recent research has implicated motion sickness susceptibility as a possible preexisting risk factor for prolonged vestibular ocular dysfunction post-concussion (Elbin et al., 2019) and may be linked to the symptom provocation observed with DVA testing in the current study and other similar findings.

A statistically significant moderate negative correlation between DVA and PT visits was identified in this study. According to this statistical finding, participants who were above the abnormal cut-off for the DVA required fewer physical therapy visits to return to their normal level of function. However, one of the four participants stopped therapy without a formal discharge due to work commitments, and therefore, her exact status and function are unknown. Although everyone experiences different symptoms and recovery trajectories with a concussion, patients who have greater severity or number of symptoms initially seem to experience prolonged recovery (Iverson et al., 2017). Therefore, this finding conflicts with much of the prior evidence. With such a small sample size, an abrupt discharge from therapy may have contributed to the unexpected findings.

Cervical Proprioception Results

The cervical JPET correlations and comparisons yielded multiple clinically relevant results. First, a statistically significant difference was found for the left and average cervical JPET between those participants engaged in contact versus non-contact sports. Those participants engaged in contact sports had greater cervical repositioning errors, especially with left repositioning to center from a right rotated position. This finding supports prior literature results in which athletes who have engaged in contact sports have had greater cervical spine JPET (Cheever et al., 2021b; Hides et al., 2017; Lark & McCarthy, 2007; Leung et al., 2022; Pinsault et al., 2010). Additionally, Hides and colleagues (2017) found left repositioning to neutral from a right cervical rotation position to have significantly greater odds of sustaining a head and neck injury during contact sports. This asymmetrical finding seems to correspond with the current study and deserves further examination to determine whether this might relate to dominant handedness or another internal or external characteristic of the athlete.

Within the current study, only two participants in the contact group were female, and therefore, most of the contact group was male while the entire noncontact group was female. This may indicate gender as a differentiating factor in cervical proprioception among contact and noncontact groups. Much of the prior literature involving the assessment of contact groups and cervical proprioception has largely investigated males and male-dominated sports (Farley et al., 2021; Hides et al., 2017; Lark & McCarthy, 2007; Leung et al., 2018; Leung et al., 2022). A few have more recently begun to look at female participation (Cheever et al., 2021a) or mixed groups (Cheever et al., 2021b; Schneider et al., 2018). Continued investigation of females engaged in contact sports compared to males may be warranted. The number of required PT visits was significantly more for the current study's noncontact versus the contact group. According to Iverson and colleagues (2017), gender does appear to be a risk factor for prolonged recovery. In general, females take longer to recover from a concussion and tend to report more symptoms before and after the injury (Iverson et al., 2017).

Another association identified in this study was a moderate negative correlation between the average cervical JPET measure and the participant’s age. This indicates the younger participants in this study were more likely to have cervical repositioning errors. This finding may reflect their sensorimotor development. A systematic review on sensorimotor function during adolescence by Quatman-Yates and colleagues (2012) reported that sensorimotor regressions are common in adolescence and a greater risk for injury may exist for those adolescents who are experiencing a growth spurt or adolescent awkwardness. Their findings would appear to substantiate why younger participants in this study had greater impaired cervical proprioception in general.

Interestingly, no difference was found in cervical JPET measures among participants with or without neck pain. Although most participants did not have cervical JPET measures above the clinical cut-off for abnormality, a significant difference was not found between the groups for right, left, or average repositioning errors. Typically, the presence or absence of neck pain and a known neck injury are factors that direct an evaluating therapist to assess cervical sensorimotor function with the cervical JPET or another such measure to determine if a portion of a patient's dizziness is cervicogenic, resulting from the cervical spine (Aligene & Lin, 2013; Reiley et al., 2017; Treleaven, 2017). A key feature in differentiating cervicogenic dizziness from vestibular dysfunction is the associated neck pain (Ernst et al., 2005). However, in the case of a concussion, differentiating between the symptoms resulting from the concussion or a possible subsequent neck injury can be challenging due to their shared causes and symptoms (Cheever et al., 2016). Previous authors have emphasized the importance of screening the neck because neck pain is a common symptom occurring following a concussion (Benson et al., 2011; Schneider et al., 2018), and comorbidity of cervical dysfunctions can contribute to prolonged recovery following a concussion, especially among pediatric athletes (Cheever et al., 2021c; Ellis et al., 2018). Kennedy and colleagues (2019) reported that 90% of patients with persistent symptoms after a concussion had neck problems, particularly in the upper cervical spine. The current study would support the importance of screening the cervical spine and cervical proprioception following a concussion regardless of neck pain.

Neuromuscular reeducation and sensorimotor retraining are beneficial in reducing dizziness after a concussion. However, a retrospective study involving 73 children and adolescents revealed that cervical joint proprioception is not examined in a large percentage of children and adolescents post-concussion when examining the cervical spine involvement (Tiwari et al., 2019). Furthermore, Bailey et al. (2021) suggested cervical muscle strength, endurance, and proprioception may contribute to a lower frequency of concussions and found a reduced number of concussions associated with participation in a neck training program among rugby players. In a prospective cohort study (N = 165), Farley et al. (2021) found those rugby players with a right rotation reposition error were associated with a 5% concussion risk for every 10% increase in right rotation reposition error. Furthermore, Hammerle and colleagues (2019) found a decrease in dizziness among military concussion patients with cervical proprioception training compared to those who received the typical vestibular rehabilitation therapy regardless of whether they had neck pain or no neck pain post-injury.

The current study's results indicate cervical sensorimotor dysfunction may exist in the absence of neck pain among this patient population. This is significant for clinicians to know as it highlights the importance of performing a thorough examination of the cervical spine even when a patient may deny neck pain or injury. A concussion examination should include cervical sensorimotor measures such as the cervical JPET in multiple directions. Future studies should further determine whether the presence or absence of neck pain is a significant subjective factor in cervical sensorimotor impairment and cervicogenic dizziness.

Clinical Application

The findings of this study are clinically meaningful because knowing there are negligible associations between DVA and cervical JPET may help inform practicing physical therapists to appreciate the complexity of the visual, vestibular, and somatosensory systems function. These results highlight the heterogeneous nature of concussion injuries and the dizziness associated with a concussion is not isolated to vestibular system deficits. Clinical implications of these findings include the necessity of a multifaceted, thorough assessment and individualized approach to treatment. Evaluating clinicians should include an array of objective measures that not only assess the function of the vestibular, ocular, and sensorimotor systems but also the associated symptom provocation brought about by the testing and functional tasks. Consideration regarding preexisting factors including history of motion sensitivity, gender, developmental stage, and underlying neck pathology also need to be considered. Identifying impairments within concussion subtypes but recognizing cross over between the subtypes is essential (Ellis et al., 2015; Lumba-Brown et al., 2020). Furthermore, a comprehensive assessment of the cervical spine and cervical proprioception to identify underlying cervicogenic dizziness should be evaluated whether or not an adolescent presents with neck pain.

Study Limitations and Implications for Future Research

A few limitations to this study are notable. First, the inability to meet the targeted number of participants for the study is the largest limitation. The study primarily relied on internal direct referrals from a subspecialty Sports Medicine physician with concussion expertise. Some potential participants were not recruited due to the centralized scheduling system within Northwestern Medicine scheduling the patient with another therapist before the primary investigator could recruit the patient for participation. The small sample size contributed to inadequate power within the study and therefore, resulted in a reduced chance of detecting a true correlation or effect. Therefore, future studies should attempt to examine the relationship between these two variables with a larger sample size to ensure more optimal power to more conclusively determine if any relationship exists between DVA and cervical proprioception following a concussion among the adolescent population.

Second, this study used the non-instrumented, clinical DVA to assess the participants' dynamic visual acuity. Although this tool was used due to the lack of access to a computerized version, the clinical version of the test does come with some potential pitfalls. The velocity of head movement and frequency of turns were attempted to be controlled via the use of a metronome, but room for human error always exists. Furthermore, the computerized DVA can laterality of dysfunction (Zhou & Brodsky, 2015). Future studies may want to consider instrumented versions of the primary outcome variables with a larger sample size to confirm whether a lack of association between the variables exists.

Another limitation is the study did not include neuropsychological screening or any concussion-specific self-report measure which could identify cognitive or psychological impairments. Trauma can trigger mental health issues, especially among adolescents (Schneider et al., 2016). Literature also suggests that adolescents may be more at risk for the social and psychological impacts of a concussion or possess varying motivational considerations which impact their lived experiences (Valovich McLeod et al., 2017) and may influence their return to normal functioning (Iverson et al., 2017). Future studies may include additional self-report measures specific to concussion to help capture possible cognitive or other impairments which may impact participants' performance with clinical assessments.

Lastly, the study is a prospective, cross-sectional quasi-experimental design and the correlational nature limits the ability of the study to explore any cause-and-effect relationships. The study involved adolescents between the ages of 12 to 18 years, and therefore, it is unknown if similar results would be found among children or collegiate athletes. The results cannot be generalized or applied to other age groups. Future studies may consider including other age groups and matched controls for comparison of results to determine if demonstrated differences are a result of the concussion or other extraneous factors.

Conclusion

In summary, this study found no significant correlation between DVA and cervical JPET among an adolescent population. Neither DVA score nor cervical JPET measures were clinically above abnormal cut-offs for this small sample. However, DVA provoked symptoms in most participants. Participants with higher initial DVA scores required fewer PT visits, and younger participants had more cervical joint repositioning errors with cervical JPET. Lastly, cervical proprioception was more impaired with those adolescents involved in contact versus non-contact, but surprisingly, a difference did not appear to exist between those participants with neck pain and no neck pain. These results highlight the need for a comprehensive approach to evaluation to identify sources of dizziness among the adolescent population following a concussion to provide an individualized plan of care for optimal recovery. Future research to better understand prolonged dizziness among adolescents following a concussion is necessary.

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Table 1

Descriptive Statistics for Participant Demographics and Injury Characteristics (N = 14)

	n (%)
Gender	
Female	7 (50)
Male	7 (50)
Sport Contact	
No	5 (35.7)
Yes	9 (64.3)
Sport Contact Type	
Non-Contact	
Cheerleading	2 (14.3)
Volleyball	2 (14.3)
Weight-lifting	1 (7.2)
Contact	
Hockey	1 (7.2)
Soccer	4 (28.6)
Wrestling	4 (28.6)
Neck pain	
No	7 (50)
Yes	7 (50)

Table 2

Descriptive Statistics Age and Injury Characteristics (N = 14)

	M (SD)	*Mdn*	Min	Max
Age (years)	14.64 (1.34)	15.0	12.0	17.0
Time since injury (days)	15.79 (9.55)	13.0	5.0	33.0
Physical therapy visits	7.57 (5.32)	5.5	2.0	18.0
LOS in therapy (weeks) [a]	5.61 (6.12)	4.1	1.6	24.8

Note: SD = standard deviation; Min = minimum; Max = maximum; LOS = length of stay

Table 3

Descriptive Statistics for Outcome Variables (N = 14)

	M (SD)	*Mdn*	Min	Max	*n* (%) Abnormal [a]
DVA Score	2.00 (0.96)	2.00	1.00	4.00	4 (28.6)
Dizziness with DVA	3.29 (2.95)	3.25	0	7.00	9 (64.3)
Cervical JPET					
Right	4.75 (1.95)	4.39	1.75	7.50	4 (28.6)
Left	4.54 (1.30)	4.27	2.47	6.80	0 (0)
Average	4.65 (1.42)	4.33	2.75	7.00	1 (7.1)
VOMS TSS VMS	12.29 (5.92)	12.75	1.00	20.00	13 (92.8)
VOMS TSCS VMS	6.22 (3.97)	6.25	0.50	16.50	12 (85.7)
VOMS TSS HVOR	10.21 (6.02)	11.25	0	20.00	13 (92.8)
VOMS TSCS HVOR	4.14 (2.90)	3.50	0	10.50	10 (71.4)
VOMS VMS Dizziness TSCS	3.21 (2.67)	3.50	0	7.00	9 (64.3)
VOMS HVOR Dizziness TSCS	2.29 (2.14)	2.50	0	6.50	9 (64.3)

DHI Score	38.71 (13.33)	39.00	12.00	62.00	12 (85.7)
Neck Pain NPRS Score	1.46 (1.95)	0.50	0	5.00	7 (50.0)

Note. SD = standard deviation; Min = minimum; Max = maximum; DVA = Dynamic Visual Acuity; JPET = Joint Position Error Test; VOMS = Vestibular/Ocular Motor Screen; TSS = Total symptom score; HVOR = horizontal vestibular ocular reflex; VMS = visual motion sensitivity; TSCS = total symptom change score (0-40); DHI = Dizziness Handicap Inventory (0-100); NPRS = Numeric Pain Rating Scale (0-10).

[a] Clinically abnormal: DVA clinical cut-off ≥ 2-line differential; Dizziness with DVA considered abnormal if > 0 on 0 to 10 scale; Cervical JPET cut-off > 7 cm; VOMS cut-off score ≥ 2; DHI cut-off > 31 indicating moderate or severe perception of impairment; Neck pain NPRS considered abnormal if > 0 on 0 to 10 scale.

Table 4

Spearman Rho Correlations Between Outcome Variable Scores (N = 14)

	DVA score		R Cervical JPET		L Cervical JPET		Avg Cervical JPET	
	r_s	*p*	r_s	*p*	r_s	*p*	r_s	*p*
DVA Score			.19	.510	.17	.564	.22	.460
R Cervical JPET	.19	.510						
L Cervical JPET	.17	.564						
Avg Cervical JPET	.22	.460						
VOMS Base	-.08	.777	.56	.036*	.18	.539	.39	.164
VOMS Dizziness Base	-.40	.157	-.13	.668	-.33	.243	-.33	.257
VMS TSS	-17	.563	.26	.380	-.15	.609	-.02	.940
VMS TSCS	.17	.573	-.26	.369	-.46	.102	-.44	.112
VMS Dizziness CS	.30	.299	-.21	.474	-.28	.338	-.31	.285
HVOR TSS	-.04	.894	.40	.158	-.01	.970	.26	.378
HVOR TSCS	.10	.734	.17	.558	-.21	.476	.06	.851
HVOR Dizziness CS	.46	.098	.08	.783	-.13	.667	-.02	.938
DHI Score [a]	-.10	.740	.08	.789	-.11	.699	-.00[b]	.994
Neck pain NPRS score	-.15	.618	.26	.367	-.13	.665	-.01	.981

Note: DVA = Dynamic Visual Acuity, Cervical JPET = Cervical Joint Position Error Test; R = repositioning to the right from an active left rotation, L = repositioning to the left from an active right rotation, and A = average of scores from right and left relocation. VOMS = Vestibular/Ocular Motor Screen; TSS = Total symptom score (0-40); VMS = Visual motion sensitivity; TSCS = Total symptom change score (0-40); DHI = Dizziness Handicap Inventory (0-100); NPRS = Numeric Pain Rating Scale.

[a] Pearson correlation reported.

[b] $r = -.002$

* significant < .05 level

Table 5

Correlations with Demographics and Participant Impairment Variables (N =14)

	DVA score [a]		R Cervical JPET		L Cervical JPET		Avg Cervical JPET	
	r_s	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Days post injury	-.42	.133	-.26	.380	-.48	.084	-.39	.165
Age (years) [a]	-.11	.701	-45	.109	-.35	.214	-.57	.033 *
PT visits	-.59	.028 *	.11	.717	-.07	.814	.04	.894
LOS (weeks) [a]	-.50	.070	.10	.725	.04	.905	-.00[b]	.994

Note: DVA = Dynamic Visual Acuity; JPET = Joint Position Error test; R = repositioning to the right from an active left rotation, L = repositioning to the left from an active right rotation, and Avg = average of their scores from right and left relocation; PT = physical therapy; LOS = length of stay

[a] Spearman rho correlation reported

[b] $r_s = -.002$

* significant < .05 level

Table 6

Comparison of Outcome Variables Between Non-Contact and Contact Groups (N = 14)

	Non-contact (n = 5)	Contact (n = 9)					
	M (SD)	M (SD)	t	95% CI		p	ES
				LL	UL		
DVA	1, 1-3 [a]	2, 1-4[a]	-1.19 [b]			.233	0.67
R Cervical JPET	3.77 (0.84)	5.28 (2.21)	-1.83[c]	-3.33	0.30	.094	1.01
L Cervical JPET	3.47 (0.88)	5.14 (1.11)	-2.87	-2.93	-0.40	.014	1.60
Avg Cervical JPET	3.63 (0.85)	5.22 (1.38)	-2.33	-3.08	-0.10	.038	1.30
PT visits	11.40 (6.15)	5.44 (3.58)	2.32	0.37	11.54	.039	1.29

Note. Non-contact = cheerleading, volleyball, and weightlifting; Contact = wrestling, soccer, and hockey; EF = Effect size (Cohen's *d*): DVA = Dynamic Visual Acuity, Cervical JPET = Cervical Joint Position Error Test, R = repositioning to the right from an active left rotation, L = repositioning to the left from an active right rotation, and A = average of scores from right and left relocation; PT = physical therapy.

[a] Median and range reported

[b] Mann-Whitney *U* test reported.

[c] Welch test reported.

Table 7

Comparison of Outcome Variables Between Neck Pain and No Neck Pain Groups (N = 14)

	Neck Pain (*n* = 7)	No Neck Pain (*n* = 7)					
	M (SD)	*M* (SD)	*t*	95% CI		*p*	ES
				LL	UL		
DVA	2, 1-4 [a]	2, 1-3 [a]	-0.20[b]			.840	0.11
R Cervical JPET	5.21(1.75)	4.27(2.15)	-0.90	-3.23	1.34	.387	0.48
L Cervical JPET	4.53(1.25)	4.56(1.44)	0.04	-1.54	1.60	.971	0.02
Ave Cervical JPET	4.88(1.45)	4.42(1.47)	-0.58	-2.15	1.24	.572	0.31
VOMS Baseline	2.5, 0-6 [a]	9.5, 3.0-16.5 [a]	-2.82[b]			.005	2.30

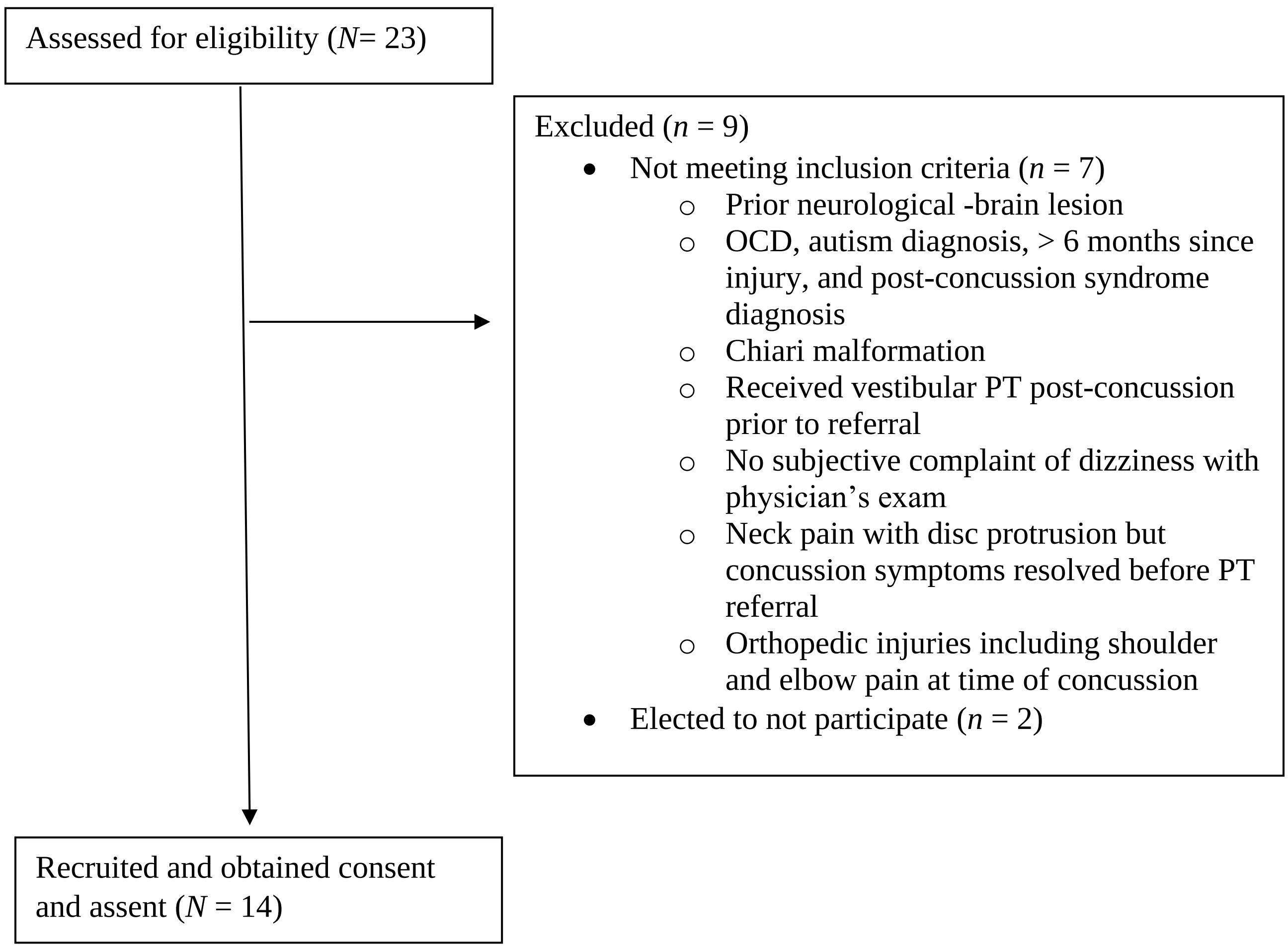
Note. EF = Effect size (Cohen's *d*); DVA = Dynamic Visual Acuity, Cervical JPET = Cervical Joint Position Error Test, R = repositioning to the right from an active left rotation, L = repositioning to the left from an active right rotation, and A = average of scores from right and left relocation; PT = physical therapy; VOMS = Vestibular/Ocular Motor Screening baseline score (0-40).

[a] Median (minimum - maximum) reported.

[b] Mann-Whitney *U* test with Z test statistic reported.

Figure 1

Participant Recruitment Flowchart



Note. OCD = obsessive compulsive disorder; PT = physical the

Appendix A

Northwestern Memorial HealthCare Institutional Review Board Approval Notice

Northwestern Memorial HealthCare Institutional Review Board (NMHC IRB)
25 North Winfield Road
Winfield, IL 60190
Phone: 630-933-6528
Fax: 630-933-2713

Approval Notice
Initial Review (Expedited)
Continuing Review NOT Required

December 15, 2020

Pam Cornwell, PT, MHS, NCS
2635 Church Road
Suite 103
Aurora, IL 60502

RE: Research Protocol 20-074
Dynamic Visual Acuity and Cervical Proprioception Following Adolescent Concussions

Dear Ms. Cornwell:

Initial expedited review of the above-named study was completed by the IRB Chair as authorized by 45 CFR 46.110 category(s) Expedited Category 5 & 46.404/50.51. This project now meets all the criteria for approval. If all other Northwestern Medicine approvals have been obtained, the research may begin.

Approval Date:	December 15, 2020
Protocol Version:	Version 2, August 5, 2020
Consent and Authorization:	v2, 12.15.20
Blood and Tissue Consent:	NA

Date Yearly Check-in Deadline: December 14, 2021

Note: All other documents submitted as part of this application were reviewed and approved by the IRB. Please refer to the initial submission event in IRB Manager for the complete list of materials.

Please note that while this study does not require formal continuing review, yearly checl<-in is required.
Please submit a yearly check-in form in the electronic IRB system by the deadline above. It is your responsibility to ensure modifications, unanticipated problems, deviations, and closure of the study are reported to the IRB timely.
Please keep in mind that you, as Principal Investigator, have responsibilities and obligations related to this study. The NMHC IRB policies can be found on Policy Manager on the Intranet, within the electronic IRB system, or by request from the IRB office.

Communication: Investigators are obligated to maintain communication with the IRB for the duration of the research according to federal regulations and NMHC IRB policies in order to ensure adequate protection of research subjects.

Conduct of study: It is the investigator's responsibility to ensure that he/she and his/her research staff are fully trained and aware of all scientific, protocol, human subjects, privacy, and ethical matters related to the conduct of the research. If you are uncertain of any of these areas, please call the IRB office at 630-933-6528 before undertaking the research.

Informed consent document: Unless other arrangements have been approved by the IRB and noted in this approval letter, it is the PI's responsibility to ensure that a copy of the signed consent document is put into the subject's medical record if the study involves Northwestern Medicine patients. In all cases, the original should be kept in the research files and a signed copy should be given to the subject.

Verification of consent: The PI is responsible for documentation in the case history (research file and/or medical record) that the informed consent/authorization process took place and that an informed consent document, if applicable, was signed by the subject prior to participation in the study. This documentation must be done to demonstrate that the appropriate discussion took place with the prospective subject about the elements of informed consent/authorization and that their questions were answered.

Status changes to studies: An investigator must immediately notify the IRB in writing whenever a protocol is placed on hold or suspended by the sponsor for any reason or if the study is temporarily or permanently closed to subject accrual.

Protocol and Informed Consent Document revision: Any changes to the protocol and/or informed consent/authorization document must be reviewed and approved by the NMHC IRB prior to implementation. The only except is where the change is avoiding an immediate apparent hazard to a subject. External agencies (i.e. pharmaceutical companies, device vendors, etc.) may provide information to assist in the process, but have no authority to grant approval or authorizations or deviations from the original protocol or informed consent/authorization document. The NMHC IRB requires any changes that may affect a subject's willingness to participate or continue participation in a research study to be submitted promptly.

Problems that require prompt reporting to the IRB: You must promptly report significant problems that occur during the conduct of the research to the NMHC IRB. The IRB will then determine if reporting to external agencies is necessary.
Recruitment materials: Recruitment materials to be viewed by potential research subjects (advertisements, letters to potential subjects, internet postings, and any other media for subject recruitment) require IRB review and approval prior to taping, publication, distribution and/or posting.

If you have any questions or need further help, please contact the IRB Office at 630-933-6528.

Sincerely

Gregory Kozeny, MD
NMHC IRB Chair

Appendix B

University of Indianapolis Institutional Review Board Notification of Approval

UNIVERSITY of INDIANAPOLIS

Human Research Protections Program (HRPP)

1400 East Hanna Ave
Sease, Room 201L
Indianapolis, IN 46227

1 (317) 781-5774
http://irb.uindy.edu
hrpp@uindy.edu

NOTIFICATION OF APPROVAL

Study Number: **01358**
Approval Date: **January 29, 2021**
Version: **1**

Title: ***Dynamic Visual Acuity and Cervical Proprioception following adolescent concussions.***

Stephanie Miller, PhD, PT, NCS
Krannert School of Physical Therapy
February 2, 2021

Dear Dr. Miller,
The above-referenced human subjects research project has been approved by the University of Indianapolis Institutional Review Board (UIndy IRB) operating under Federal Wide Assurance – FWA00027197.

Level of Review:

Expedited – research activities pose no greater than minimal risk to research subjects.

Approval Limitations:

This approval is limited to the activities described in the application. It is expected that the research be carried out strictly according to the approved protocol.

Changes / Modifications:

No changes are to be made to the approved protocol or consent form/s without prior review and approval by the UIndy IRB. All changes (e.g., procedure, study locations, recruitment materials, study instruments, informed consent, research personnel, etc.) must be prospectively reviewed and approved by the IRB before they are implemented.

Adverse Events and Unanticipated Problems:

Any adverse events or unanticipated problems relating to the research must be reported to the HRPP office as soon as possible.

Continuing Review:

Continuing review for this protocol is ***not*** required. However, the HRPP office will do an annual check in with you to obtain an update.

HRPP Jan 2019

UNIVERSITY of INDIANAPOLIS

Human Research Protections Program (HRPP)

1400 East Hanna Ave
Sease, Room 201L
Indianapolis, IN 46227

1 (317) 781-5774
http://irb.uindy.edu
hrpp@uindy.edu

Additional Information:

Please contact the UIndy HRPP office hrpp@uindy.edu with any questions or concerns about this letter or other HRPP matters.
Please keep a copy of this letter for your records.

Sincerely,

Erin M. Fekete, Ph.D.

Erin Fekete, Ph.D.
Faculty IRB Chair
Interim Associate Dean and Director of Psychological Sciences
Associate Professor of Psychology
College of Applied Behavioral Sciences
University of Indianapolis

Appendix C

IRB Yearly Check-in Notice

Northwestern Medicine

Northwestern Memorial HealthCare
Institutional Review Board (NMHC IRB)
25 North Winfield Road
Winfield, IL 60190
Phone: 630-933-6528
Fax: 630-933-2713

Yearly Check-In Notice
HSPP Requirements Met

December 13, 2021

Pam Cornwell, PT, MHS, NCS
2635 Church Road
Suite 103
Aurora, IL 60502

RE: Research Protocol #: 20-074
"Dynamic Visual Acuity and Cervical Proprioception Following Adolescent Concussions"

Dear Ms. Cornwell:

The yearly check-in for the above referenced study was received by the HSPP Office. Please note that while this study does not require formal continuing review, yearly check-in is required. Please submit a yearly check-in form in the electronic IRB system by the deadline of **December 14, 2022**. It is your responsibility to ensure modifications, unanticipated problems, deviations, and closure of the study are reported to the IRB timely.

Protocol Version: Version 2, August 5, 2020
Consent and Authorization: v2, 12.15.20
Date Yearly Check-in Deadline: December 14, 2022

If you have any questions or need further help, please contact the IRB office at 630-933-6528.

Sincerely,
NMHC Human Subject Protection Program

Appendix D

Vestibular/Ocular Motor Screening Scoring Sheet

VOMS SCORING SHEET

Symptoms on a 0 - 10 (severe) scale

Modified from Mucha A, Collins MW, Elbin RJ, FurmanJM, Troutman-Enseki C, DeWolf RM, Marchetti G, Kontos AP.

Vestibular/Ocular Motor Test	N/T	Headache	Dizziness	Nausea	Fogginess	Comments
Baseline Symptoms (Pre VOMS)						
Smooth Pursuit						
Saccades (horizontal)						
Saccades (vertical)						
Convergence (NPC) #1 ____ cm #2 ____ cm normal 5 cm or < (2") #3 ____ cm						
VOR Horizontal (180 bpm)						
VOR Vertical (180 bpm)						
Visual Motion Sensitivity (50 bpm)						

Brief Instructions : patient seated unless noted otherwise. 9-40 y/o, 1 day or > after injury

Pursuit - one stick, 3' away and level with patient's nose, move stick slowly 1.5' to the left and 1.5' to the right. Repeat moving stick vertically. Slow : 2 seconds to go L to R & again L to R. 2 repetitions each direction.

Saccade - start 2 sticks, 3 feet away and level with patient's nose . Each stick 1.5' to the left and right of nose. Look over & back 10x. Repeat vertically. Patient is to move eyes as fast as they can.

NPC - 1 stick, 3' away and level with patient's nose. Move stick slowly towards nose. Stop when they report seeing double or you see an eye turn/drift. Measure distance to nose.

VOR - Hold one stick, 3' away and level with patient's nose. Speed of head movement, 180 bpm. Patient is asked to turn head 20 degrees left and right, 10 times maintaining focus on target. Repeat vertically.

Visual Motion Sensitivity - Standing, patient holds stick or thumb; arms reach in front of nose. While maintaining fixation on stick, rotate head arms and trunk left and right 80 degrees 5x at 50 bpm.

Name:______________________________________ DOB:__________ DOI:__________
Date:___________

Appendix E

Dizziness Handicap Inventory

The Dizziness Handicap Inventory (DHI)

P1. Does looking up increase your problem?	○ Yes ○ Sometimes ○ No
E2. Because of your problem, do you feel frustrated?	○ Yes ○ Sometimes ○ No
F3. Because of your problem, do you restrict your travel for business or recreation?	○ Yes ○ Sometimes ○ No
P4. Does walking down the aisle of a supermarket increase your problems?	○ Yes ○ Sometimes ○ No
F5. Because of your problem, do you have difficulty getting into or out of bed?	○ Yes ○ Sometimes ○ No
F6. Does your problem significantly restrict your participation in social activities, such as going out to dinner, going to the movies, dancing, or going to parties?	○ ○ Yes Sometimes ○ No
F7. Because of your problem, do you have difficulty reading?	○ Yes ○ Sometimes ○ No
P8. Does performing more ambitious activities such as sports, dancing, household chores (sweeping or putting dishes away) increase your problems?	○ ○ Yes Sometimes ○ No
E9. Because of your problem, are you afraid to leave your home without having without having someone accompany you?	○ ○ Yes Sometimes ○ No
E10. Because of your problem have you been embarrassed in front of others?	○ Yes ○ Sometimes ○ No
P11. Do quick movements of your head increase your problem?	○ Yes ○ Sometimes

	○ No
F12. Because of your problem, do you avoid heights?	○ Yes ○ Sometimes ○ No
P13. Does turning over in bed increase your problem?	○ Yes ○ Sometimes ○ No
F14. Because of your problem, is it difficult for you to do strenuous homework or yard work?	○ ○ Yes Sometimes ○ No
E15. Because of your problem, are you afraid people may think you are intoxicated?	○ Yes ○ Sometimes ○ No
F16. Because of your problem, is it difficult for you to go for a walk by yourself?	○ Yes ○ Sometimes ○ No
P17. Does walking down a sidewalk increase your problem?	○ Yes ○ Sometimes ○ No
E18.Because of your problem, is it difficult for you to concentrate	○ Yes ○ Sometimes ○ No
F19. Because of your problem, is it difficult for you to walk around your house in the dark?	○ ○ Yes Sometimes ○ No
E20. Because of your problem, are you afraid to stay home alone?	○ Yes ○ Sometimes ○ No
E21. Because of your problem, do you feel handicapped?	○ Yes ○ Sometimes ○ No
E22. Has the problem placed stress on your relationships with members of your family or friends?	○ ○ Yes Sometimes ○ No
E23. Because of your problem, are you depressed?	○ ○ Yes Sometimes

	○ No
F24. Does your problem interfere with your job or household responsibilities?	○ Yes ○ Sometimes ○ No
P25. Does bending over increase your problem?	○ Yes ○ Sometimes ○ No

Used with permission from GP Jacobson.
Jacobson GP, Newman CW: The development of the Dizziness Handicap Inventory. *Arch Otolaryngol Head Neck Surg* 1990;116: 424-427

DHI Scoring Instructions

The patient is asked to answer each question as it pertains to dizziness or unsteadiness problems, specifically considering their condition during the last month. Questions are designed to incorporate functional (F), physical (P), and emotional (E) impacts on disability.

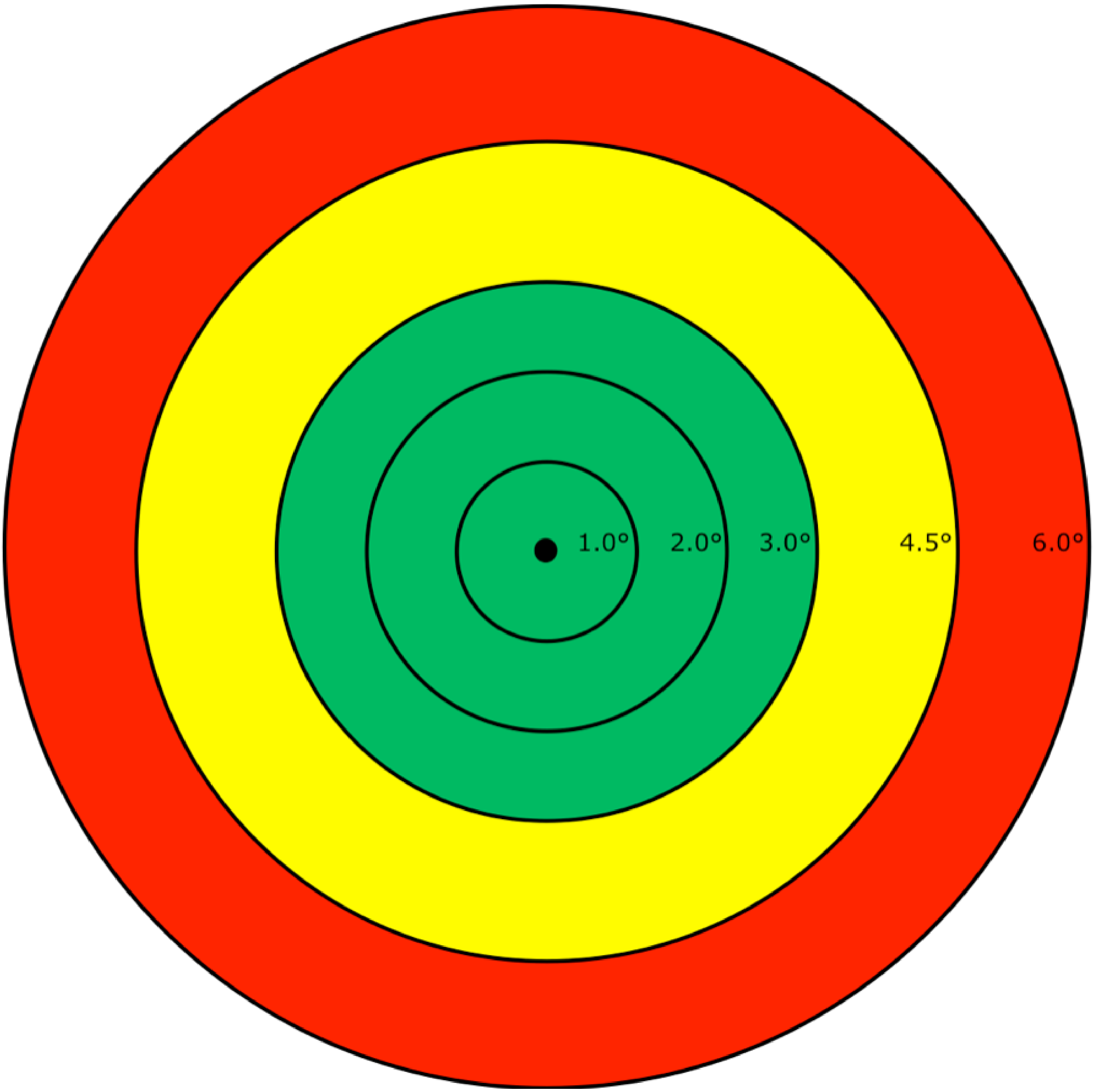
To each item, the following scores can be assigned: No=0 Sometimes=2 Yes=4

Scores:
Scores greater than 10 points should be referred to balance specialists for further evaluation.

16-34 Points (mild handicap)
36-52 Points (moderate handicap)
54+ Points (severe handicap)

Appendix F

Cervical Joint Position Error Target



Target Distance: 90cm

 Rob Landel, PT, DPT, OCS
www.skillworks.biz

Errors of >4.5° (for this target, beyond the yellow circle) are likely to be significant.

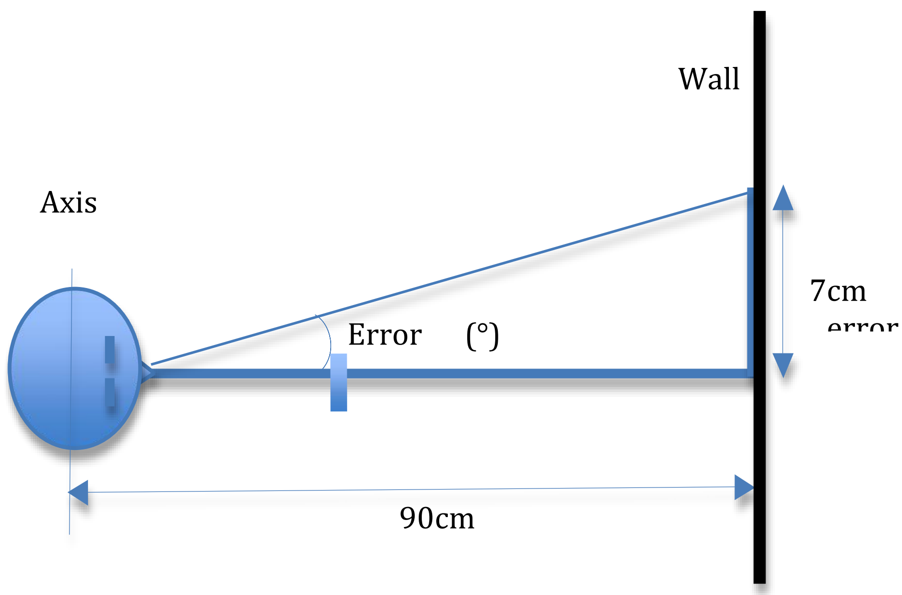
Treleaven J, Jull G, Sterling M. Dizziness and unsteadiness following whiplash injury: characteristic features and relationship with cervical joint position error. J Rehabil Med. 2003; 35(1):36-43.

Distance from center of the target to a 4.5-degree error depends the distance the patient is from the target. This target is calibrated for a patient who is 90 cm away.

If the patient (center of axis of rotation to the target, thus, the crown of the head) is 90 cm from the target, then a 7 cm error from the center of the target translates to a 4.5 degree error:

Arctan of 7cm/90cm = 4.5 degrees

On a calculator, arctan is often shown as tan^{-1}.



So, the error in degrees is the arctan (or tan^{-1}) 7/90, or 4.5°.